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Chief Engineer and General Manager

March 28, 2014
File No: 31-300.25

Mr. Sam Unger, Executive Officer
California Regional Water Quality Control Board
Los Angeles Region
320 W. 4th St., Suite 200
Los Angeles, CA 90013

Attn: Information Technology Unit

Joint Water Pollution Control Plant
CI No. 1758; Resolution R12-003; NPDES No. CA0053813
Special Study Final Report Submission

As required under Resolution R12-003, please find enclosed the final report for the following special study:

1) Nutrient Loading and Receiving Water Impacts (JWSS-12-001).

Unless otherwise instructed by the Regional Board or Regional Board staff, this will be the final submission associated with this Special Study. However, any other reports or peer-reviewed publications resulting from these studies will also be provided to Regional Board staff as they become available.

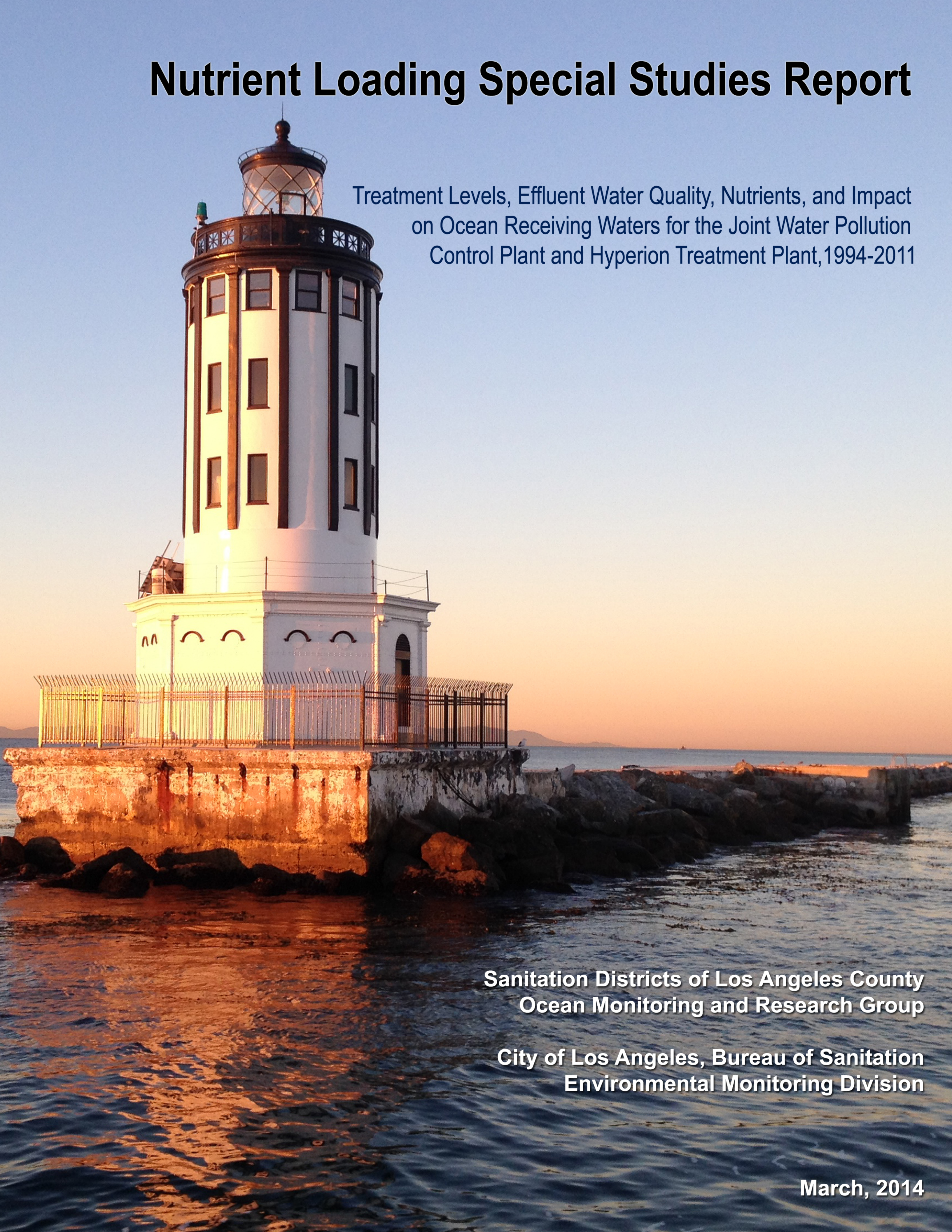
I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Very truly yours,
Grace Robinson Hyde

Joseph R. Gully
Supervising Environmental Scientist
Technical Services Department

JRG:AH:cv
Enclosure

Nutrient Loading Special Studies Report



Treatment Levels, Effluent Water Quality, Nutrients, and Impact on Ocean Receiving Waters for the Joint Water Pollution Control Plant and Hyperion Treatment Plant,1994-2011

Sanitation Districts of Los Angeles County
Ocean Monitoring and Research Group

City of Los Angeles, Bureau of Sanitation
Environmental Monitoring Division

March, 2014

Nutrient Loading and Receiving Water Impacts

(Nutrients, Treatment Levels, and effects on DO, pH and light transmission of Ocean Receiving Waters at the Joint Water Pollution Control Plant and Hyperion Treatment Plant)

EXECUTIVE SUMMARY

In their most recent National Pollutant Discharge Elimination System (NPDES) permits, the Hyperion Treatment Plant (HTP) and the Joint Water Pollution Control Plant (JWPCP) wastewater treatment plants are required to conduct a special study to assess existing effluent and receiving water nutrient data and to quantify any effects from the nutrients on the dissolved oxygen (DO), pH, and percent light transmission (LT) of the receiving waters. The two agencies responsible for these facilities worked cooperatively to draft a proposal to the Los Angeles Regional Water Quality Control Board (LARWQCB) to outline how the study could be completed. On April 5, 2012, the LARWQCB adopted Resolution No. R12-003, approving this special study. The agencies have continued to coordinate efforts and have chosen to combine results into a final integrated study report.

Noting that JWPCP and HTP completed significant upgrades to treat all wastewater to full secondary (FS) levels in 2002 and 1998, respectively, the authors of this study chose to compile annual average effluent nutrient mass emission rates (MER) for all years 1994 to 2011, including a period when both plants produced only partial secondary (PS) treated effluent. Averages were then prepared for time periods representing different treatment levels at each plant. Only small changes in the mass emission rates of total nitrogen to the ocean were seen between the periods of PS and FS treatment, the JWPCP saw a 9% drop, while the HTP saw a 9% increase (the HTP increase is due to alterations in treatment to produce higher quality biosolids). Between PS and FS, total phosphate dropped 78% at JWPCP and 33% at HTP. More significant declines in nutrient discharges occurred decades earlier. The combined nitrogen and phosphate discharges of JWPCP and HTP declined by 65% and 89%, respectively, from 1971 to 2011.

When operating at PS, between 1994-2002, the JWPCP discharged an average of 17,638 metric tons per year (mtons/yr) of total nitrogen to the Palos Verdes receiving waters, consisting of 82% ammonia, 17% organic nitrogen, and less than 1% nitrate and nitrite. After going to FS in late 2002, from 2003 to 2011, the JWPCP discharge has averaged 16,030 mtons/yr of total nitrogen, with 92% ammonia, 8% organic nitrogen, and just trace amounts of nitrate and nitrite. From 1994-2002, the JWPCP discharged 4,515 mtons/yr of total phosphate. Phosphate MERs declined 78% to 1,008 mtons/yr for the 2003-2011 period.

Between 1994-1998, under PS treatment, the HTP discharged an annual average 15,096 metric tons per year (mtons/yr) of total nitrogen to Santa Monica Bay (SMB). Despite going to FS, over the period 1999-2011, the total nitrogen discharge has climbed slowly, averaging 16,435 mtons/yr. Concurrently, the organic nitrogen fraction of total nitrogen declined from 17% in 1994-1998 to 9% in 2003-2011, while the proportion of ammonia increased from 82% to 90%, and the nitrate and nitrite fraction was under 2% in both PS and FS periods. The average total phosphate discharged declined from 5,709 mtons/yr between 1994-1998 to 3,805 mtons/yr for the 1999-2011 period.

Both agencies have requirements to sample the receiving water for ammonia, the dominant nutrient in the treated effluent, at multiple sites and depths during offshore water quality surveys. Annual average and 95th percentile receiving water ammonia concentration values were compiled from 1994 to 2011. No significant changes in the receiving water levels of ammonia were determined as the result of treatment changes at either plant.

Time series trend plots of effluent parameters of interest (DO, pH, turbidity, temperature, and salinity) for 1994 to 2011 showing plume-depth data from all offshore surveys were prepared to document the levels of background variability, and the long-term trends that are apparent in some parameters such as DO. Overlain on these graphs are data representing reference and plume areas. The averages of the reference, plume, and zone of initial dilution (ZID) site, for each parameter at the plume depth were extracted for each treatment period, and summarized in tables and graphs. While differences are evident, relative levels appear to be fairly consistent across treatment periods, suggesting that changes in treatment did not alter the receiving water conditions. The time series data show a high degree of variability in the receiving water due to large-scale natural phenomenon

(i.e. ENSO, PDO, seasonal cycles, upwelling…). The average values for treatment periods suggest that when these natural phenomena are removed, a localized effluent effect is detectable but within compliance. However, it is important to emphasize that this dataset cannot answer questions about indirect effects of wastewater nutrient inputs into the coastal environment.

By 2003, both plants provided FS treatment to 100% of the effluent. To assess ongoing receiving water effects, the 2003-2011 offshore receiving water DO, pH, and LT data were averaged, and absolute and percent anomalies were calculated. The original data distributions, anomalies, and percent anomaly of each parameter were plotted on an along-shelf and two cross-shelf transects that include the ZID sites nearest each outfall. An effluent plume feature is apparent in the anomaly and percent anomaly graphs and coincides with the effluent plume feature from equivalently prepared average plots of distributions of the plume tracers salinity, colored dissolved organic matter (CDOM), and ammonia. The anomaly in the DO and pH feature often appears to be due to entrainment of the rising buoyant effluent of a large volume of ambient receiving water with naturally lower DO and pH values. Reference waters near each outfall were assessed for the average difference in temperature, DO, and pH between the plume depth and the outfall depth. Through the comparison of the differences in average values between the plume and reference, the average entrainment contribution was roughly estimated for each plant. Entrainment accounted for 57%- 78% of reductions in DO and 42%-50% of changes in pH, leaving approximately 22%-43% and 50%-58% respectively, unexplained. It was not possible, given the restrictions of the dataset, to tease apart the direct effects of the effluent, from any possible secondary effects due to effluent nutrients.

The relative contribution of nutrients to the southern California Bight was a key question addressed through the Southern California Bight 2008 Regional Monitoring Program. The final conclusions of that study were that publicly owned treatment works (POTW) contributions were one to two orders of magnitude below natural contributions from upwelling in the SCB, but that in the heavily urbanized regions of the SCB, and at smaller spatial scales within 10-20 kilometers of the coast, the POTW nitrogen input, mostly as ammonia, might be roughly comparable to the natural upwelling of nitrogen, primarily in the form of nitrate (Howard et al.,2014). Other programs that have monitored SCB nutrient levels, away from the outfalls, such as the California Cooperative Oceanic Fisheries Investigations (CalCOFI), have documented that nitrate is nearly always present and detectable, and is defined by a pattern of increasing levels with depth.

Within the limited areal extent of the POTW water quality monitoring programs, ammonia nitrogen is found to have a localized feature near the discharge point, with concentrations dropping quickly within a few kilometers of the outfalls. Ammonia sampling at the perimeter of the water quality survey area reveals that ammonia is close to or below detection levels at most perimeter sites. The highest ammonia concentrations are located deeper than 20 meters below the surface at sites nearest the outfalls. When comparing averaged water column distributions, the depth of the maximum effluent ammonia feature appears to be deeper than the depth to the chlorophyll fluorescence maximum. At the same time, examination of POTW water quality data does not find increased phytoplankton concentrations associated with the effluent plume. However if phytoplankton were utilizing effluent nutrients it would likely be occurring far from the discharge point.

This review did not find major alterations of DO, pH, or LT near the HTP or JWPCP outfalls in either the PS or FS treatment periods. What small differences between reference and plume that were found appear to be largely explained by entrainment. The California Ocean Plan (COP) includes a numeric standard that DO should not be reduced by more than 10%. Assessing the 2003 to 2011 time period of FS treatment, the residual unexplained DO reductions after entrainment are 0.18 mg/L at JWPCP and 0.11 mg/L at HTP, and equate to 3% and 2% reductions, respectively relative to the reference DO. The COP standard for pH states that pH should not be altered more than 0.2 units. The residual unexplained change in pH at JWPCP and HTP is only 0.035 pH units. These results are supported by the ongoing, continuous effluent monitoring for BOD, pH, TSS, and turbidity, which confirms that FS-treated effluent should have a limited direct effect on receiving water distribution patterns after completion of initial dilution. While some nutrient MERs decreased with the implementation of FS, nitrogen in the form of ammonia did not. The limitations of this dataset to address the impact of effluent on receiving water DO, pH, and LT include the following, DO measurements were not made below 100 m depth in upwelling source waters, current generation pH sensors have limited accuracy, high local natural scale variability in LT complicates assessment of effluent effects, and nitrification (the biological transformation of ammonia, the dominant form of nitrogen in effluent, to nitrate) rates are unknown. To address these limitations, the Water Quality Compliance Committee has been developing new compliance testing methods, and the Southern California Bight 2013 Regional Monitoring Program will be assessing the reliability of the existing pH time series and collecting accurate discrete pH and carbonate chemistry samples, as well as working with coastal modelers to estimate secondary effects of anthropogenic nutrient sources. However, the fact that nutrient MERs were documented to be significantly higher in 1971 when effluent flows were higher and treatment was only primary, suggests that any recent declines in regional DO, pH, and LT are not being driven by the discharges.

INTRODUCTION

This report was prepared by the Sanitation Districts of Los Angeles County (Sanitation Districts) and the City of Los Angeles (CLA) to comply with the special study reporting requirements in the JWPCP and HTP National Pollutant Elimination Discharge Elimination System (NPDES) permits issued by the LARWQCB in September 2011 (LARWQCB Order No. R4-2011-0151) for JWPCP and for HTP in November 2010 (LARWQCB Order No. R4-2010-0200).

The NPDES permits for the JWPCP and the HTP both contain the following identical requirements for a special study:

> "***Special Study – Nutrient Loading and Receiving Water Impacts***
>
> *By July 14, 2012, consistent with the logistics described in section I.D.3 of the MRP, the Discharger shall propose, as a special study, a summary assessment of existing nutrient data (both effluent and receiving water) collected under the Order/Permit during the period of secondary treatment and quantify the resulting effects, if any, of the discharge on receiving water quality for dissolved oxygen, pH, and percent transmission.*"
>
> Staff from the Sanitation Districts and the CLA met with LARWQCB staff on December 20, 2011, and presented a proposal for the completion of the study. The four key objectives were identified as:

- Summarize existing nutrient data – prior to and following initiation of Full Secondary treatment (FS);
- Document changes in mass loadings due to initiation of FS treatment;
- Quantify any identified impacts on receiving water quality for DO, pH, and LT; and
- Identify the geographical distribution of any identified impacts on receiving water quality for DO, pH, and LT.

Nutrients and Wastewater- Background

The CLA and Joint Outfall System (JOS) collection systems gather wastewater from a combined population of over 9 million. The majority of this wastewater is from indoor residential use with additional contributions from industrial and commercial users. The wastewater has high levels of nutrients, particularly nitrogen and phosphorous. The two independent collection systems both capture and treat some wastewater at inland water reclamation plants (WRPs). Since about 2000, these WRPs have utilized nitrogen nutrient removal to further improve the tertiary-treated effluent, allowing it to be reused for a variety of beneficial purposes, and be released into environmentally sensitive waterbodies. The solids from the WRPs, and the majority of the wastewater are treated at the JWPCP and HTP plants. Neither the JWPCP nor HTP provide focused nutrient removal treatment, which is expensive, and would reduce the overall plant treatment capacity. However, as a result of the very high percentage of solids removal during secondary treatment, a significant amount of nitrogen and phosphorous is removed at the JWPCP and HTP, and then disposed of in a variety of ways at inland sites, further reducing the ultimate nutrient load sent to the ocean.

The final effluent from the JWPCP and HTP is discharged through ocean outfalls located on the seafloor. The outfalls have extended diffusers to increase initial dilution of effluent with ambient seawater. For example, the diffusers on the JWPCP 90 and 120 inch outfalls consist of several hundred small ports spaced at intervals along the last approximately 1,000 m of the outfalls in depths ranging from 50-60 m. By 1960, the Sanitation Districts had already accumulated 20 years of experience with installation and operation of multiport diffusers, and had concluded that their use led to reductions in odor, discoloration, turbidity and bacterial levels in receiving waters (Rawn et al. 1959).

Modeling studies predict that the buoyant plumes from each port should merge and stabilize within density-stratified layers of overlying water (Fischer et al. 1979). Models incorporating empirical data about the diffuser design, effluent properties and ambient ocean conditions are able to accurately estimate initial dilutions of effluent (Muellenhoff et al. 1985). Roberts et al. (1989a, 1989b, 1989c) confirmed these theoretical results using scale models and field studies of multi-port diffusers with varying conditions of currents and stratification.

Using published United States Environmental Protection Agency models (Baumgartner et al. 1994) minimum initial dilutions for determining NPDES permit compliance with the COP have been calculated as 166:1 for the JWPCP discharge under static (zero current) conditions. The even more extreme stratification scenario and maximized effluent flow under static conditions produce an 84:1 minimum initial dilution for HTP. The initial dilution process described above takes only minutes to form a dilute effluent plume. This plume is then advected and dispersed by ocean currents. Tidal (approximately semi-diurnal) and diurnal current reversals routinely dominate the energy spectra in the inner part of the Southern California Bight (SCB; Hendricks 1974, 1975; Winant and Bratkovitch 1981; Jones et al. 1986). Sanitation Districts' measurements of currents on the Palos Verdes Shelf near the outfalls found typical current speeds were 9-15 cm/sec (LACSD 2002). Instantaneous currents of this speed significantly increase the predicted initial dilution of the effluent when incorporated into dilution models. The Sanitation Districts' measurements found that net currents, after filtering out tidal and diurnal variability, are usually minimal in the cross-shelf direction. However, net speeds of along-shelf, coast-paralleling currents, were on average 4 cm/sec. Because along-shelf currents have coherence scales of greater than 25 km (Hendricks 1982, Winant 1983) they play an important role advecting effluent away from the discharge site. Typical net and average currents should advect the effluent plume 4-12 km or more away from the outfalls in one day. . Recent modeling of the dispersion of HTP effluent into SMB indicates that, after initial dilution, the plume can; however, stay coherent for tens of kilometers (Uchiyama et al. 2014), but these studies are ongoing. Entrainment of ambient bottom water by the buoyant effluent is implicit in the initial dilution process. Trapping of the effluent plume below the surface occurs as the rising effluent plume reaches equilibrium in the density stratified water column, typically 30 m above the discharge depth. DO concentrations and pH naturally decrease with increasing depth, associated with poor aeration due to density stratification. Entrainment of this bottom water is unavoidable and complicates assessment of these parameters for compliance determination.

When discharged to receiving waters, effluent nutrients have the potential to stimulate plant/algal growth. When this growth is excessive, it can overwhelm the receiving water ecosystems, in a phenomenon known as eutrophication. Eutrophication of coastal waters is a global environmental issue, with demonstrated links between anthropogenic nutrient inputs and the global increase in frequency and occurrence of algal blooms, including harmful algal blooms (Anderson et al. 2002, Howarth et al. 2002, Glibert 2005, Glibert et al. 2006, Glibert et al. 2008). The receiving water monitoring programs designed by California regulators and the EPA, under the provisions of the Clean Water Act (CWA), are intended to identify signs of eutrophication. Specifically, as stated in the COP, excessive and undesirable plant growth, reductions in DO due to decomposition of this plant material, and other secondary effects must be avoided.

The ocean off Los Angeles, is adjacent to an open, west facing coastline. The prevailing winds drive large-scale upwelling, both in the nearshore, as well as extending hundreds of kilometers offshore. The result of this upwelling is that vast amounts of nutrients rise into the euphotic zone, and form the basis of one of the most productive ecosystems on earth. Upwelling coastal regions occur on several continents, have been recognized for centuries as productive fishing grounds, and support huge populations of marine mammals and seabirds (Pauly and Christensen, 1995). Given the very high, immediate dilutions achieved when the JWPCP and HTP effluents are discharged through offshore outfalls located in 60-meter water depths, and the high levels of ambient nutrients in the receiving waters, it has been assumed in the past that the POTW nutrient discharges do not have a detrimental impact on the receiving waters.

The assessment of anthropogenic nutrient impacts is complex, and an area of active study. Anthropogenic nutrient loadings from POTWs into the SCB have decreased significantly over the last 40+ years. At the same time, the ecosystems in the SCB have rebounded after heavy human pressures in the early part of the last century, when many species were overfished and hunted, and later when unregulated pollutant loadings from a rapidly growing population, predating the CWA, took its toll. While the Clean Water Act addressed contaminants in US waterways, nutrient limitations were not set, except indirectly through concerns for eutrophication. Remaining questions that are being explored by researchers and POTW monitoring programs, include whether harmful algal blooms (HABs), reductions in DO levels documented over the last decade, and changes in the pH of coastal ocean waters are being caused by or significantly enhanced by anthropogenic nutrients. Finding the answers to these questions is made more challenging because global climate change and other non-local anthropogenic impacts are affecting these coastal waters simultaneously.

History of the JWPCP

The Sanitation Districts serves the wastewater and solid waste management needs of 5.7 million people. The backbone of the wastewater system is the Joint Outfall System[1] (JOS), a regional interconnected treatment system that consists of the JWPCP and six upstream WRPs serving 73 cities and unincorporated areas of Los Angeles County. In 2011, an average of 396 million gallons per day (mgd) of wastewater were collected and treated within the Sanitation Districts JOS. The upstream WRPs provided tertiary treatment to 124 mgd in 2011 (LACSD 2012a). During 2011, approximately 40% of the tertiary-treated effluent (49.5 mgd) was beneficially reused in a wide variety of applications, such as groundwater recharge and landscape irrigation (LACSD 2012b) with the remainder discharged to local creeks and rivers. Residual solids from wastewater treated at these six plants are returned to the trunk sewers, where they flow to the JWPCP for treatment along with flow from the area directly serviced by JWPCP.

The JWPCP, located in the City of Carson, is the largest wastewater treatment plant operated by the Sanitation Districts and has been the main location for wastewater treatment in the JOS service area since 1928. A description of treatment facilities, processes, and a full chronology of treatment plant upgrades over the past seven decades is provided in the JWPCP Annual Monitoring Report (LACSD 2012a). The JWPCP currently serves approximately 2.8 million people and approximately 2,300 industrial facilities. During 2011, JWPCP treated an average of 273 million gallons per day (mgd) of wastewater. Since November 2002, the JWPCP has provided FS treatment for all of its flow.

The treated effluent is disinfected via chlorination then conveyed from JWPCP through two tunnels, 9.7 kilometers (6 miles) in length, to a manifold structure at White Point on the Palos Verdes Peninsula **(Figure 1**). Four ocean outfalls originate at the manifold. Two outfalls, measuring 120 inches and 90 inches in diameter, are in regular service. A third outfall, 72 inches in diameter, is used occasionally, during heavy rains. The fourth outfall, 60 inches in diameter, serves as a standby for use in an extreme emergency. The two active outfalls discharge the wastewater through diffusers approximately 2.4 kilometers offshore at a depth of approximately 60 meters.

Solids removed during the treatment process are anaerobically digested and centrifuged, producing biosolids, which are recycled or disposed on land through soil application or in a landfill (LACSD, 2012c). No biosolids are discharged to the ocean. Methane gas generated in the anaerobic digestion process is used to produce power and digester heating steam in a Total Energy Facility that utilizes gas turbines. The on-site generation of power permits the JWPCP to be 85-90% self-sufficient with respect to its energy requirements.

History of the HTP

Currently, HTP serves the wastewater needs of an approximate population of four million residential and business customers in Los Angeles and 26 contracting cities and agencies. (CLA, 2013). Most of the wastewater treated at HTP is from domestic sources. Approximately 21% of the wastewater flow is from industrial/commercial discharges. The design capacity of HTP is 450 million gallons per day (MGD), and the

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[1] Ownership and operation of the Joint Outfall System is proportionally shared among the signatory parties to the amended Joint Outfall Agreement effective July 1, 1995. These parties include Sanitation Districts of Los Angeles County Nos. 1, 2, 3, 5, 8, 15, 16,17, 18, 19, 21, 22, 23, 28, 29, and 34, and South Bay Cities Sanitation District of Los Angeles County.

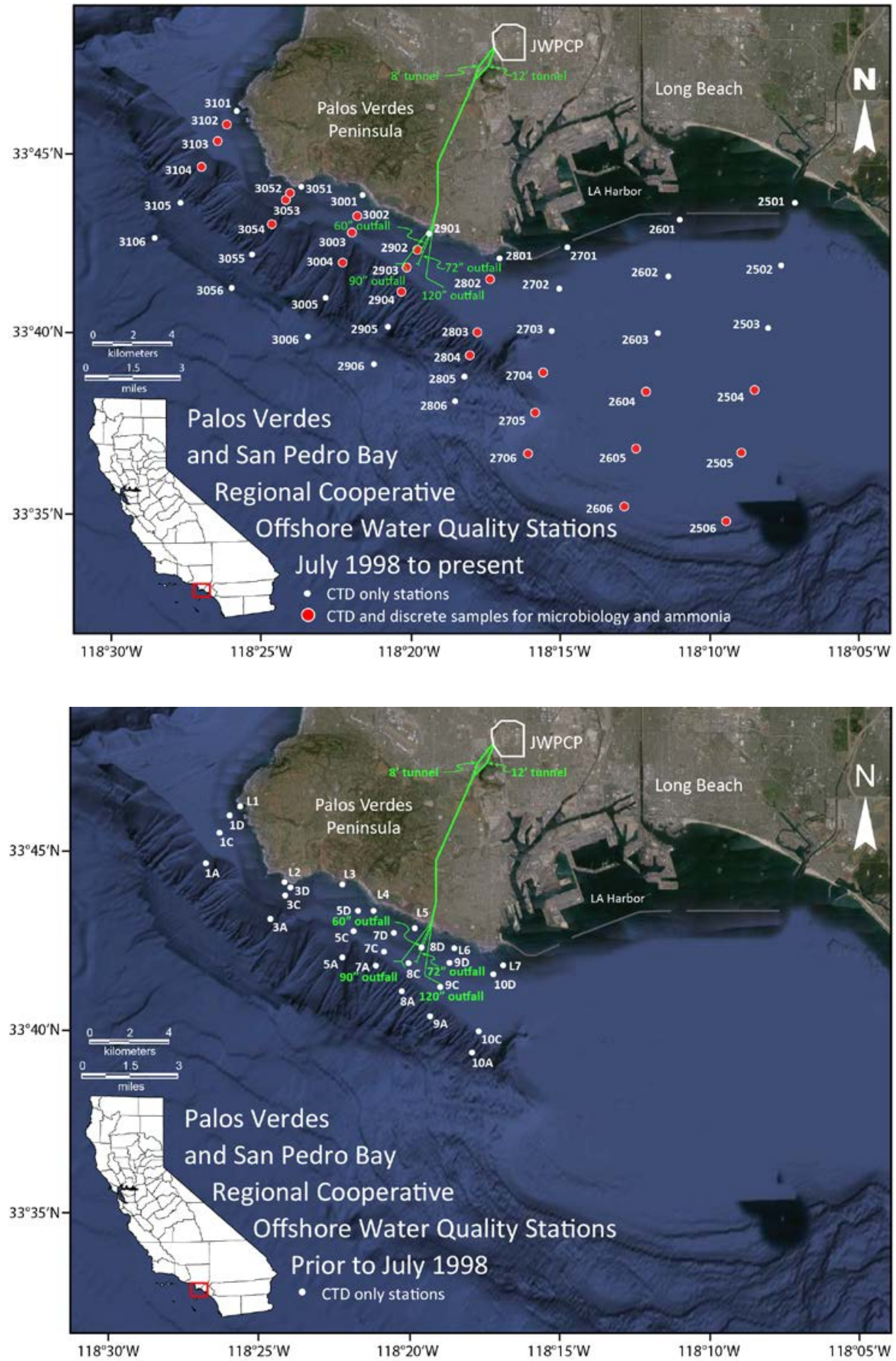


Figure 1. Location of the JWPCP, Tunnels, and Ocean Outfalls

Map of the Palos Verdes Peninsula depicting the location of the JWPCP in the City of Carson, the two tunnels (8 feet and 12 feet diameter) under the peninsula convey secondary effluent to the coast near White Point, and the four outfalls (60", 72", 90", and 120" inner diameter), which discharge the effluent into the ocean. The two continuously active outfalls (90" and 120") are approximately 2.5 kilometers offshore and lie at a depth of approximately 60 meters. The 72"outfall, and to a lesser extent the 60"outfall, are only used occasionally to relieve hydraulic pressure during heavy rain events. Upper panel depicts receiving water quality sampling stations after July 1998. Lower panel shows pre-1998 receiving water sites.

plant receives wastewater from the Los Angeles area and excess flow from the San Fernando Valley. HTP also receives solids from the primary and secondary treatment processes of the Donald C. Tillman (DCT), Los Angeles-Glendale (LAG), and Burbank WRPs. The solids from these upstream plants are discharged into sewer lines transporting wastewater to HTP. During the period from January 2011 through December 2011,HTP treated an average of 293 MGD, and discharged an average of 266 MGD of treated effluent into SMB through Serial Discharge Port No. 002 (5-Mile Outfall), and discharged approximately 26 MGD to the West Basin Municipal Water District (West Basin Facility) for recycled uses. The untreated reverse osmosis waste brine from the West Basin Facility is also discharged to SMB through HTP's 5-Mile Outfall. These treatment and discharge volumes are all slightly lower than those reported in the biennial assessment report for 2009-10.

Over five hundred wet tons of HTP biosolids are sent to Green Acres Farm in Bakersfield, to Merced County, and to Yuma, Arizona per day as fertilizer and soil amendment; 60 tons of biosolids are used per day to produce composting material; and 75 tons of biosolids are sent to Terminal Island Water Reclamation Plant (WRP) per day for the deep-well injection to produce renewable energy. During 2011, approximately 21% of the secondarily-treated effluent (73 MGD), from the City's four treatment plants, was recycled or beneficially reused to generate power and in landscape irrigation. The HTP generates 6.67 million cubic feet of biogas per day, which is converted to electricity, accounting for 85% of the energy needs of the plant.

Treated wastewater is discharged into SMB (**Figure 2**). Three ocean outfalls leave HTP: a continuously active 5-Mile Outfall, an emergency 1-Mile Outfall (both 144 in diameter), and an inactive 20-in diameter 7-Mile Outfall. The 7-Mile pipe was used for sludge discharge into Santa Monica Canyon from 1957-1987.

METHODS AND MATERIALS

Timeline of Treatment Plant Upgrades

The Sanitation Districts maintains a chronology listing of all significant projects completed at the JWPCP. The full list, beginning with the startup of the plant in 1928, is published with the most recent updates in the annual NPDES Report (LACSD 2012a, Table 2.4) and documents the evolution of improved treatment at the JWPCP. In particular, up until 1983 the JWPCP provided advanced primary treatment, in November 1983, PS treatment was introduced, and was scaled up from 60 mgd to 200 mgd, or about 60% of the total plant flow by August 1985. In November 2002, the JWPCP began FS treatment of all flow.

The CLA originally began discharging FS-treated effluent at HTP in 1951; however, by 1957, the influent volume had increased to a level where discharged effluent had regressed to a mixture of primary and secondary effluent. On November 23, 1998, full-secondary treatment process was once again implemented at HTP; thereby, significantly improving the quality of the treated wastewater being discharged into the marine environment. The full-secondary process was augmented in calendar years 1998–1999 with additional pure oxygen-activated sludge modules, secondary clarifiers, and egg-shaped digesters to achieve a very high quality effluent. The impact of this has been a noticeable improvement in the environment in the vicinity of the ocean outfall. A description of treatment facilities, processes, and full chronology of treatment plant upgrades is provided in the Santa Monica Bay Biennial Assessment Report (CLA, EMD 2013).

Time Frame of Study

The JWPCP began providing PS treatment in 1983, and from 1985 until 2002, approximately 60% of the flow was secondary treated and the remainder received advanced primary treatment. In November 2002, the JWPCP began FS treatment of all flow. At HTP, FS treatment was begun in November 1998. In order to compare effects of changes in treatment, distinct time periods prior to and following the introduction of FS, were defined for each plant; HTP PS (1994-1998) and HTP FS (1999-2011), and JWPCP PS (1994-2002) and JWPCP FS (2003-2011).

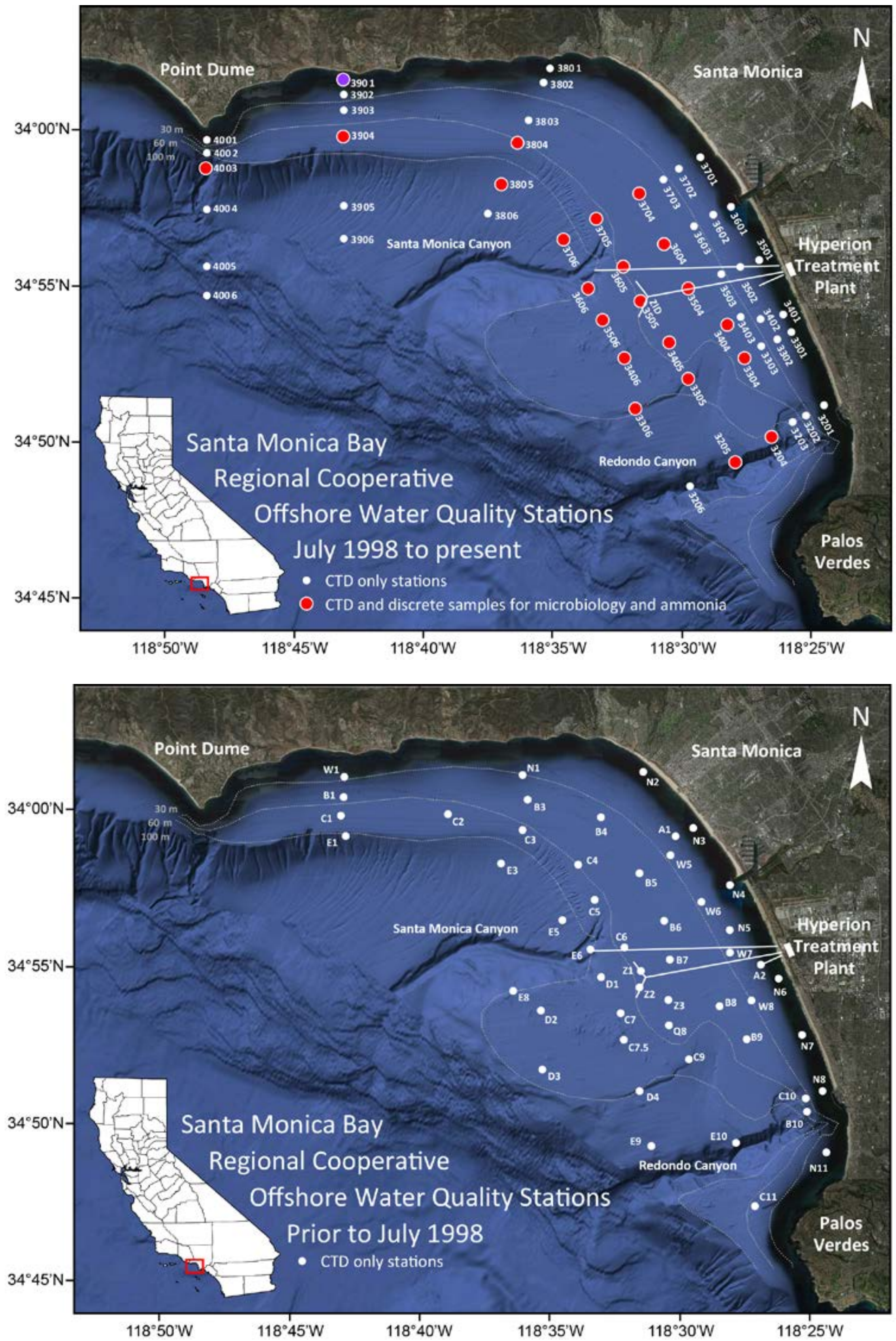


Figure 2. Location of the HTP Ocean outfalls

Map of Santa Monica Bay depicting the location of the HTP in the community of Playa Del Rey within the City of Los Angeles and the two outfall pipes (1-Mile and 5-Mile) which leave the plant. The 5-Mile continuously active outfall is a 12-foot diameter pipe terminating approximately 26,525 feet (8.1 km) west-southwest of the treatment plant at a depth of approximately 187 feet (57 m). The outfall ends in a “Y”-shaped diffuser consisting of two 3,840-foot legs. Upper panel depicts receiving water quality sampling stations after July 1998. Lower panel shows pre-1998 receiving water sites.

Effluent Data

The Sanitation Districts publishes annual NPDES Reports for each permitted facility. Each annual report includes results from all effluent analyses completed during that year, as required under the permit in effect. In the current JWPCP permit, effluent nutrient analyses are required on 24-hour composite samples of final effluent at either a monthly (ammonia nitrogen) or quarterly (nitrate nitrogen, nitrite nitrogen, organic nitrogen, and total phosphorous) frequency. In each annual NPDES Report, all required sampling for the complete calendar year is reported (LACSD 2012a, Table 4.3). The JWPCP NPDES permit also includes extensive effluent monitoring requirements for a large number of other pollutants. Conventional pollutants used to characterize effluent quality are sampled daily, with flow measured continuously, BOD, TSS, and turbidity measured on 24-hour composites, and pH and settleable solids measured on grab samples.

Annual average effluent nutrient data, BOD, TSS, turbidity, and pH are also reported in the annual NPDES Report (LACSD 2012a, Table 5.1) which includes annual average values back to 1975. The data presented in this Report are taken from the 2011 annual NPDES Report (LACSD 2012a). Averages for each treatment level time period were calculated by averaging the annual averages.

The CLA publishes annual NPDES reports that fully summarize all effluent analyses. The City also publishes a Santa Monica Bay Biennial Assessment Report that summarizes and analyzes all receiving water data. The current HTP NPDES permit requires weekly nutrient analyses on 24-hour composite samples of final effluent for ammonia nitrogen and quarterly analyses for nitrate nitrogen, nitrite nitrogen, organic nitrogen, and total phosphorous. All required influent and effluent monitoring data for the complete calendar year are reported in the annual HTP NPDES report. Additionally, HTP plant data are uploaded monthly to CIWQS. The HTP permit is closely comparable to the JWPCP permit, and also includes extensive effluent monitoring requirements for a large number of other pollutants. Conventional pollutants (BOD, TSS, turbidity, and settleable solids) used to characterize effluent quality are sampled daily, with flow measured continuously, BOD, TSS, and turbidity measured on 24-hour composites, and pH and settleable solids measured on grab samples.

Annual average effluent nutrient data, BOD, TSS, turbidity, and pH are reported in the annual NPDES Report. The data presented in this Report are taken from the 2011 annual NPDES Report (HTP Annual Report, 2011) and from previous reports going back to 1994. Averages for each treatment level time period were calculated from the annual averages. Annual average values for each treatment period were also compared statistically, and where there was a significant (95% confidence level) change between PS and FS, it is indicated on tables and graphics.

Receiving Water Ammonia

Under the current NPDES permit, the Sanitation Districts publishes a JWPCP Biennial Receiving Water Monitoring Report (LACSD 2012d). This Report includes appendices listing results of all discrete receiving water ammonia nitrogen required by the permit. Collection of discrete water samples at various sites and depths for low level ammonia analysis has been required since the late 1980s. The sites, depths, and frequency of the sampling have changed between permits, but have been constant since the Sanitation Districts and other southern California POTWS implemented the Central Bight Cooperative Water Quality (CBCWQ) program in July of 1998.

The CLA is also required to publish a biennial assessment report of the impact of effluent on receiving waters of SMB (CLA, EMD 2013). Chapter 4 of this report lists results of all discrete receiving water ammonia nitrogen analyses. Sampling of discrete receiving water ammonia was first required in the late 1980s, and was implemented in 1988 after EMD was successful in developing an ammonia-selective electrode method for detecting low levels of ammonia in ocean matrix. A standardized monitoring program was initiated in 1998 with the implementation of the CBCWQ program The JWPCP and HTP permits do not require sampling of any nutrients other than ammonia in the receiving waters.

All receiving water ammonia results collected between 1994 and 2011 were extracted from the Sanitation Districts and CLA water quality databases, and were processed to produce annual averages and upper 95th % values. During every survey where discrete samples of ammonia were collected, some of the samples were reported as less than the reporting limit (RL). In these cases, for purposes of averaging and statistical determinations, below-RL data were substituted with values set to half the RL. Between 1994 and 2011, the Sanitation Districts and CLA RL for sea water ammonia was unchanged at 0.02 mg/L. The annual average and upper 95th % values for each treatment period were compared statistically, and where there was a significant (95% confidence level) change between PS and FS, it is indicated on tables and graphics.

Receiving Water Quality (CTD) Data

Since July 1998, both the Sanitation Districts and CLA have completed quarterly offshore water quality surveys at 48 sites extending over the Palos Verdes, and San Pedro shelves and 54 sites in SMB respectively (Figure 1 and Figure 2). Between January 1994 and June 1998, the Sanitation Districts completed monthly CTD surveys at 28 sites over the Palos Verdes shelf. These earlier surveys did not include the San Pedro shelf or further offshore areas. In total, the earlier surveys only encompassed about one quarter the geographic area compared with surveys from July 1998 forward. The CLA conducted weekly surveys through June 1994, then monthly surveys through July 1998 at 36 sites.

Receiving water measurements were collected with a Conductivity, Temperature, Depth (CTD) profiler. Additional parameters collected were dissolved oxygen (DO), temperature, salinity, fluorescence (Chla-*a*, and CDOM), transmissivity, and pH. Sampling was conducted from the surface to a maximum depth of 100 m (occasionally 75 m due to operational limitations of hand-deployed “live-wire” cable), or to 2 meters above the seafloor at shallower sites.

Time Series Assessment

To identify and quantify effluent effects on receiving waters, each individual survey was subjected to an analysis to distinguish between reference and effluent plume impacted waters. The plume was identified using either salinity anomaly or CDOM, depending on availability. Salinity anomaly is a measurement of the deviation of salinity at a particular station and depth from a mean salinity value (Dalkey and Shisko 1996). Salinity anomaly (SA) was calculated using the following formula:

$$S_{Ai} = \left(1 - \frac{S_i}{S_{\bar{x}i}}\right) * 100$$

Where S_{Ai} is the calculated salinity anomaly for a given station at depth *i*, S_i is the salinity value from a given station at depth *i*, and $S_{\bar{x}i}$ is the calculated mean salinity at depth *i*. The relationship between salinity anomaly and wastewater dilution was developed utilizing theoretical SA values computed for several wastewater dilutions ranging from 100:1 to 1000:1. Assuming a typical reference salinity of 33.4‰ (parts per thousand) and effluent salinity of zero (effluent normally has a salinity of 0.1 psu), then as dilution increases from 100:1 to 1000:1, SA decreases from 1.0 to 0.1. The plume is defined as having a salinity anomaly ≥0.3, with an estimated dilution range of >125:1. The threshold of 0.3 was verified empirically by confirming plume identification by visual inspection using temperature-salinity (T-S) diagrams. When using CDOM to identify plume stations, measurements were normalized within each survey because instrument standardization was not possible. Below the pycnocline (>25.25σ_θ), normalized CDOM greater than the 95th percentile consistently identified the wastewater plume, which was also verified by T-S diagrams. Plume identification was conducted using MATLAB (The MathWorks, Inc.).

Using the above approach, water quality measurements between the depths of 20-60 meters at all stations within 7 kilometers from the outfall (sample constraints taken from Nezlin et al., *in prep*) were assessed for the presence of the plume. Average values of selected water quality parameters for the reference and plume sites at the depth with the strongest plume signal were calculated for every survey. Time series plots showing the range of values measured at the plume depth of all reference and plume stations were developed. Average reference and plume values for each treatment period were summarized in tables, and graphically in bar charts, which also include the average value at the ZID site.

Spatial Assessment

It was originally proposed that graphical representations of alongshelf and cross-shelf average spatial patterns of receiving water data would be compared between treatment periods, and that an average anomaly representation, produced by subtracting the mean survey profile from each individual site profile would be used to compare differences in any plume effect between treatment periods. However, during the analysis it became apparent that such comparisons would be limited by changes in the sampling grids at both agencies. Unfortunately, the year of transition to FS at HTP coincided with a significant change in the sites and sampling frequency of offshore receiving water sampling at the HTP. A major El Niño event, and a possible oceanographic regime shift also occurred in 1998; therefore, the time series analyses are felt to provide a better comparison of changes in effects associated with treatment or background oceanography, and allow a more quantitative assessment of any changes.

The spatial assessment is still being used with the average of all 2003-2011 receiving water data, during which period both JWPCP and HTP were providing FS. Hence, the average graphical representations use data from the 2003-2011 period when both plants had FS treatment. The anomaly graphics show the average spatial extent and the amount of alteration during the period of FS discharges.

Between 2003-2011, the JWPCP completed 34 receiving water surveys – these surveys were done in all four quarters, and always visited the same 48 sites, sampling from the surface to a maximum depth of 100 m. During 2003-2011 the HTP completed 32 receiving water surveys at a fixed grid of 54 sites. Most surveys were done by both agencies during the same week in each quarter, as part of the Central Bight Cooperative Water Quality Survey (CBCWQS) effort. To produce a 2003-2011 average survey, the 1-m depth bins for all measured parameters at each site from every survey were averaged.

All JWPCP and HTP CTD sensors are returned to the factory for annual recalibration, and selected sensors (pH and transmissometer) are calibrated prior to each use in the field. Data were processed using Sea-Bird Inc. software to produce appropriately time shifted and calibrated engineering unit output. Interactive Graphical Ocean database (IGODs) software is used to produce standard format files of downcast data averaged to 1 m depths from surface (1 m) to maximum depths of 100 m at deeper offshore sites. At all sites shallower than 100 m, samples are collected from surface to 2 m above bottom. Details of the data processing are included in the JWPCP Biennial Receiving Water Report (LACSD 2012d) and the Santa Monica Bay Biennial Assessment Report (CLA, EMD 2013).

A subset of the average data for 2003-2011 were used to create an alongshore transect linking 17 sites that roughly follow the 60-m isobath from the north-west edge of SMB off Pt. Dume, southward across the Bay, and then out and around to Palos Verdes, and offshore across the San Pedro shelf to end offshore of Seal Beach. The total distance spanned by this transect is 84 kilometers. Approximately in the center of these transects is site 2903 of the Sanitation Districts and site 3505 of the CLA (Figure 1 and Figure 2). These respective sites are located within the zone of ongoing initial dilution (ZID) and mixing of the effluent field with the receiving water. Although excluded from regulatory compliance objectives, the data from the ZID sites were included to more clearly discern the effects of the effluent field.

Cross-shelf transects were also produced using sites spanning from the 10-m isobath, inshore of the active outfalls (just a few hundred meters from the shoreline), through a total of six sites extending offshore about 7 kilometers at JWPCP and 10 kilometers at HTP. These cross-shelf transects also include the ZID sites to show the core effluent feature.

To illustrate the average horizontal and vertical extent of the effluent plume, the three most effective plume indicator parameters, salinity, CDOM, and ammonia, were plotted for each transect. These plume indicators also direct attention to the areas where a corresponding direct effluent effect would be most likely for DO, pH, and LT.

Alongshelf and cross-shelf transects of DO, pH, and LT data were plotted using a fixed scale for each parameter. To graphically highlight any effect due to the effluent discharge, alongshelf and cross-shelf anomaly plots were assembled by differencing each depth point at each site from an average profile produced using the entire survey data set. The anomaly is plotted using the same units as the parameter. A percent anomaly was also calculated by taking the percent differences between the values at each integer depth at each site, and the average value of the parameter at each integer depth using all sites. The percent anomaly calculation is shown below:

$$X_{anom} = \left(1 - \frac{X_{site}}{X_{avg}}\right) * 100$$

Water Reclamation Data

The Sanitation Districts publishes an annual status report on recycled water use (LACSD 2012b). Data from this Report was compiled to document the amount of water beneficially reused for such purposes as irrigation and groundwater recharge. Other recycled water is discharged to rivers, but has the potential to be beneficially reused in the future.

The Bureau of Sanitation of CLA releases various monthly performance reports for all of its four wastewater treatment plants and annual recycled water tables (CLA 2004-2012), which detail recycled water supplied to its customers and redirected for in-plant use.

Service Area Population

The Sanitation Districts reviewed internal records to obtain best available data on the population within the service area tributary to the JWPCP for each year from 1994 to 2011. These population data were then used to calculate the per capita rates of reclaimed and beneficially reused water, as well as the per capita rates of nutrient discharges from the JWPCP to the ocean. The population data for the HTP service area was extracted from the website of the Department of Finance, State of California. The CLA population data includes 90% of the total HTP service area population including 10% from the contract cities but excludes the population in the Terminal Island (TI) WRP service area. Per capita effluent flow to ocean, per capita recycled water flow, and nutrient mass emission rates were calculated using the population data.

RESULTS

Effluent Nutrients

Table 1 lists JWPCP annual mass emission rates (MERS) of nutrients to the ocean receiving waters (in metric tons) for 1994-2011. At the bottom of the table, the average annual values for each treatment level time period are presented, along with the percent increase or decrease (indicated by parentheses) between periods. Statistically significant changes are shown on the table.

Comparing the JWPCP MERs for the period 1994-2002, prior to the implementation of FS treatment, with the 2003-2011 period during which FS was continuous, the total nitrogen MER declined by 9% from 17,638 mtons/yr to 16,030 mtons/yr. At the same time, ammonia nitrogen, which is the most prevalent form of nitrogen in the effluent, remained nearly constant, only increasing by 1.4%, from 14,488 to 14,691 mtons/yr, and organic nitrogen declined by 58% from 2,997 mtons/yr to 1,271 mtons/yr. Nitrate and nitrite declined by 70% and 36%, respectively, however neither represents more than 1% of the total nitrogen loading. Total phosphate declined by 78%, from 4,515 mtons/yr to 1,008 mtons/yr. The small increase in ammonia was not statistically significant, however the declines in all other nutrients were significant.

Table 2 compares the HTP MERs for the period 1994-1998, prior to the implementation of FS treatment, with the 1999-2011 period during which FS was continuous. The total nitrogen MER increased by 9% from 15,096 mtons/yr to 16,435 mtons/yr. At the same time, ammonia nitrogen, which constitutes the most prevalent form of nitrogen in the effluent, increased 18%, from 12,426 to 14,713 mtons/yr. The increase in FS ammonia nitrogen, which largely occurred in 2001-02, was most likely due to in-plant process modifications to produce improved Class A biosolids. After implementing FS, organic nitrogen declined by 42%, from 2,526

Table 1 JWPCP Effluent Nutrient MERs

All values are annual averages in units of metric tons per year

Year	Treatment Level	Ammonia Nitrogen	Organic-Nitrogen	Nitrate-Nitrogen	Nitrite-Nitrogen	Total Nitrogen	Total Phosphate
1994	PS	15928	2964	118	20	19030	4974
1995	PS	15447	2935	169	128	18678	4894
1996	PS	13712	2857	165	105	16838	4713
1997	PS	14325	3027	38	67	17458	4895
1998	PS	13707	3186	58	85	17037	4643
1999	PS	13790	2808	96	59	16753	3955
2000	PS	14033	3102	46	46	17228	4167
2001	PS	14321	3446	72	54	17892	4779
2002	PS	15128	2649	22	31	17831	3613
2003	FS	14041	1391	27	44	15503	2311
2004	FS	14458	2538	22	22	17040	1069
2005	FS	14638	1740	27	49	16454	1188
2006	FS	14829	1356	22	26	16233	897
2007	FS	14661	983	38	47	15730	994
2008	FS	15009	1022	20	57	16110	914
2009	FS	14598	738	19	70	15425	249
2010	FS	15011	731	19	39	15800	710
2011	FS	14975	939	38	26	15978	739
Time Period							
94-02	PS	14488	2997	87	66	17638	4515
03-11	FS	14691	1271	26	42	16030	1008
Change		1.4%	-58%*	-70%*	-36%*	-9%*	-78%*

Partial Secondary (PS), Full Secondary (FS).Negative percentages indicate reductions.
** indicates statistical difference between treatment periods (95% confidence level).*

mtons/yr to 1,468 mtons/yr, nitrate decreased by 11%, and nitrite increased by 26%, however, neither represents more than 2% of the total nitrogen loading. Total phosphate declined by 33%, from 5709 mtons/yr to 3805 mtons/yr. The declines in organic and nitrate nitrogen and phosphate, and the increases in ammonia and total nitrogen were statistically significant.

Figure 3 shows the annual average MERs of total nitrogen, total phosphate, ammonia nitrogen, organic nitrogen, nitrate and nitrite, from 1994 to 2011 in JWPCP (panel A) and HTP (panel B) effluent. The period of PS and FS treatment at each plant is separated by a vertical line.

Figure 3 and **Figure 4**, shows that at the JWPCP the MER of ammonia nitrogen was essentially unchanged by the implementation of FS; however, MERs of organic nitrogen, nitrate, and nitrite nitrogen, which represented only a small fraction of the total nitrogen, were significantly reduced, largely accounting for the overall 9% decline in total nitrogen. The JWPCP total phosphate MER was reduced 78%, approximately proportional to the reduction in total suspended solids (TSS) between PS and FS.

In panel B of Figure 4, the MER of nutrients from HTP is compared between the periods of PS and FS. At HTP, the MER of ammonia nitrogen increased about 18% after FS, despite a 42% decline in organic nitrogen. The total nitrogen MER for HTP increased 9% between the PS to FS periods. The HTP total phosphate MER was reduced 33% between PS and FS. This reduction in total phosphate is comparable to 34% reduction in TSS. The legends in each panel indicate which changes were found to be statistically significant.

Table 2 HTP Effluent Nutrient MERs

All values are annual averages in units of metric tons per year

Year	Treatment Level	Ammonia Nitrogen	Organic-Nitrogen	Nitrate-Nitrogen	Nitrite-Nitrogen	Total Nitrogen	Total Phosphate
1994	PS	11268	2508	77	NS	13853	5545
1995	PS	12135	2865	50	NS	15051	5629
1996	PS	13021	2345	80	NS	15447	5594
1997	PS	12849	2461	98	78	15487	5970
1998	PS	12858	2450	139	198	15645	5809
1999	FS	12715	1293	451	450	14908	4439
2000	FS	13125	1411	196	391	15123	4157
2001	FS	14065	1177	125	321	15688	3889
2002	FS	13806	1363	44	304	15517	3381
2003	FS	15150	1614	9	140	16912	3350
2004	FS	15589	1685	8	32	17313	4247
2005	FS	16079	1758	22	62	17920	3853
2006	FS	15973	1797	0	21	17791	4156
2007	FS	14910	1560	4	13	16487	3994
2008	FS	15244	1227	41	28	16539	3335
2009	FS	15307	1347	40	246	16940	3615
2010	FS	14591	1524	52	175	16342	3684
2011	FS	14716	1328	37	91	16173	3368
Time Period							
94-98	FS	12426	2526	89	138	15096	5709
99-11	FS	14713	1468	79	175	16435	3805
Change		18%*	-42%*	-11%	26%	9%*	-33%*

Partial Secondary (PS), Full Secondary (FS).NS – Not Sampled (not required in active permit at the time).Negative percentages indicate reductions.
** indicates statistical difference between treatment periods (95% confidence level).*

Effluent Quality

Average daily effluent flow and annual average measures of effluent quality (turbidity, TSS, BOD, and pH) for the years 1994 – 2011, and for the periods of PS and FS treatment at JWPCP and HTP are summarized in **Table 3** and **Table 4**, respectively. Trends in effluent quality with time and with changes in treatment are presented using annual average values in **Figure 5** and **Figure 6**, respectively.

Comparing the JWPCP effluent properties for the PS period 1994-2002, with the FS period of 2003-2011, the total flow declined by 9%, from 332 MGD to 302 MGD, reflecting increases in water conservation. Turbidity declined by 89%, from 51 NTU to 5 NTU, TSS declined 78%, from 65 mg/L to 15 mg/L, BOD declined 94%, from 94 mg/L to 6 mg/L, and pH increased from 6.8 to 7.1. Changes in all these effluent properties were statistically significant.

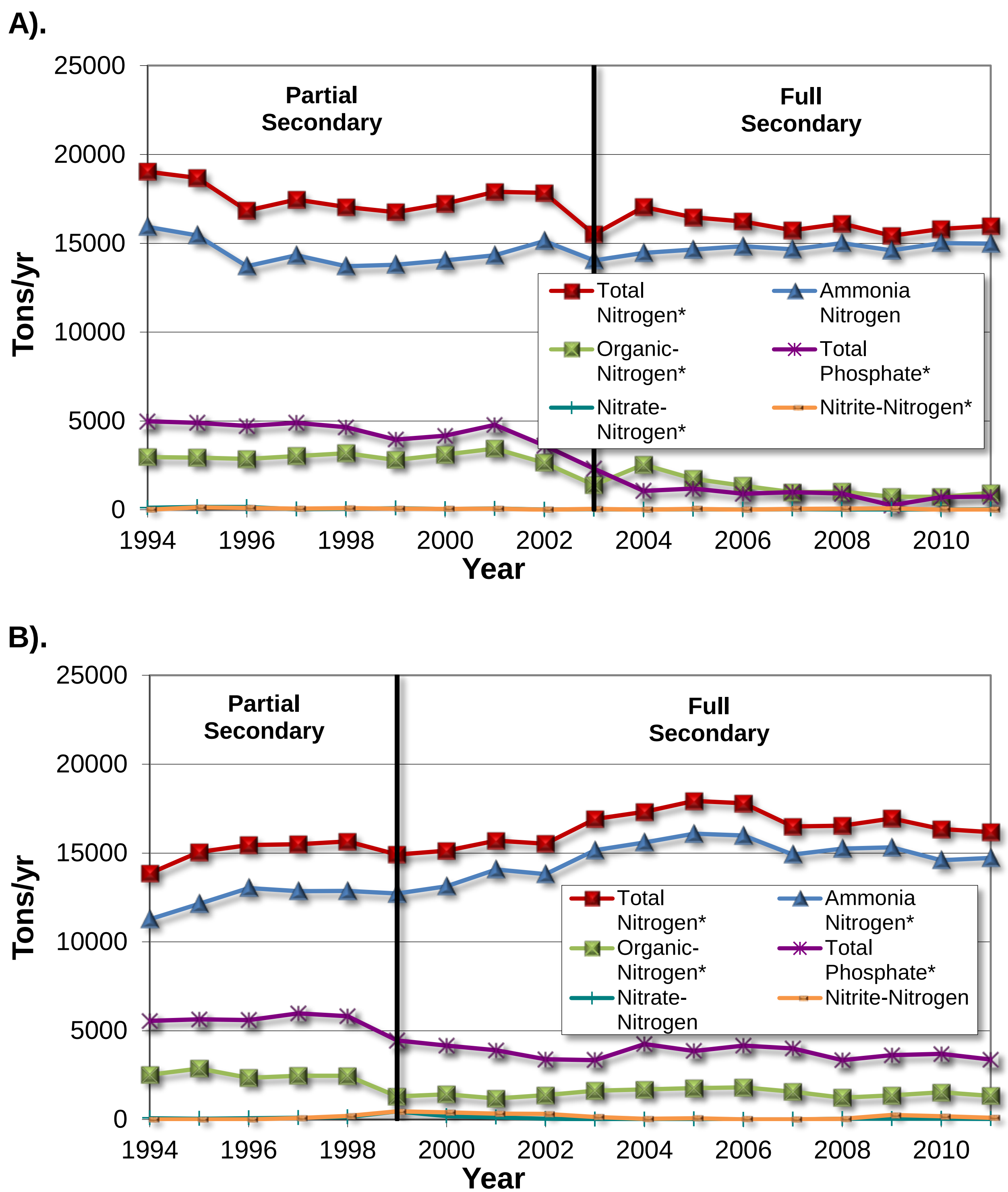


Figure 3 JWPCP and HTP Effluent Nutrient MERs 1994-2011

Annual average metric tons of nutrients discharged in effluent from JWPCP (A) and HTP (B)

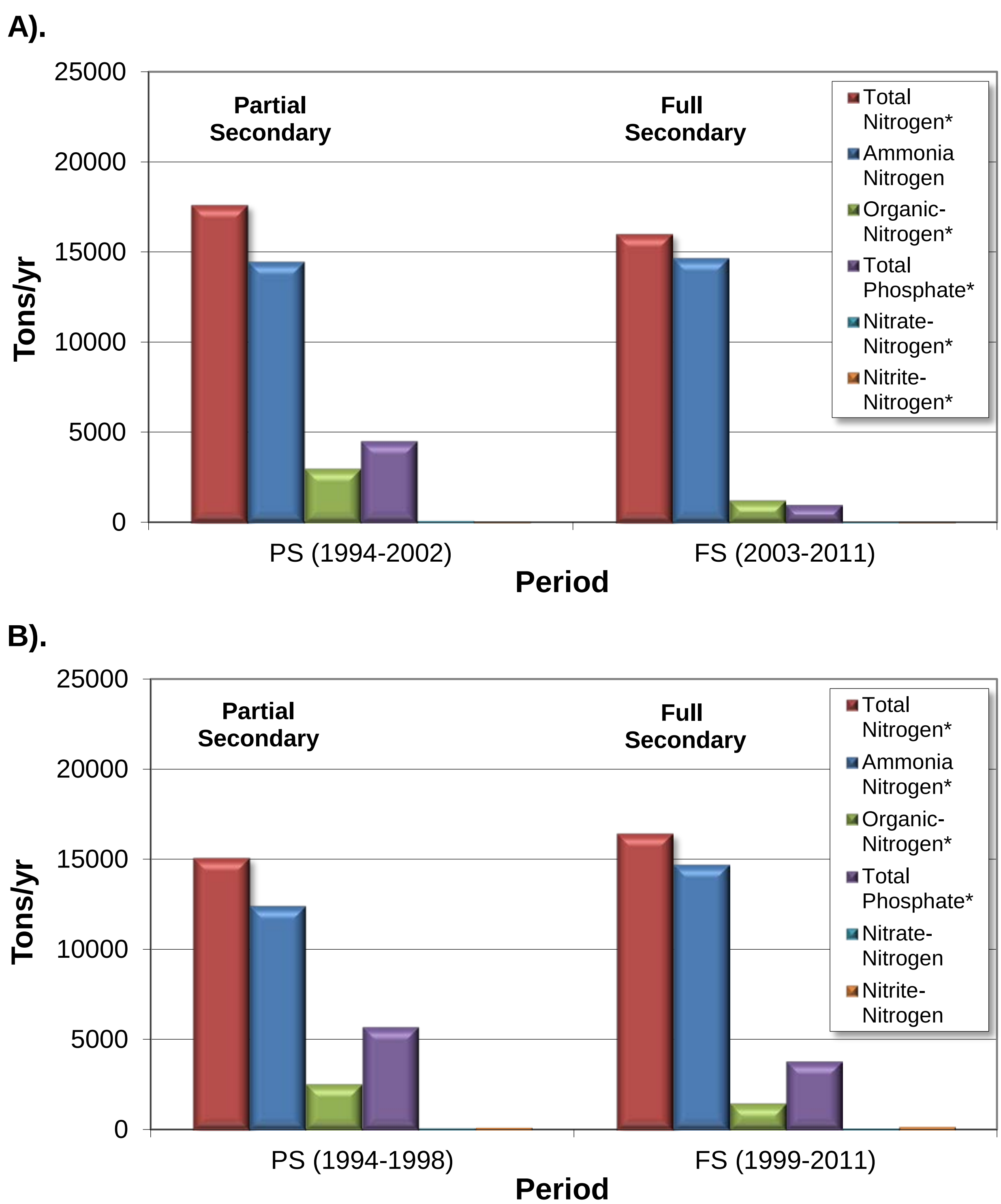


Figure 4 JWPCP and HTP Effluent Nutrient MER by Treatment Period
Annual average metric tons of nutrients discharged in effluent from JWPCP (A) and HTP (B).
* indicates statistical difference between treatment periods (95% confidence level).

Table 3 JWPCP Effluent Properties

Annual average values

Year	Treatment Level	Total Flow (MGD)	Turbidity (NTU)	TSS (mg/L)	Total BOD (mg/L)	pH (pH units)
1994	PS	328	55	64	99	6.85
1995	PS	330	59	69	97	6.77
1996	PS	331	52	66	93	6.79
1997	PS	346	51	69	102	6.76
1998	PS	342	52	68	97	6.76
1999	PS	329	48	61	85	6.67
2000	PS	334	48	65	94	6.74
2001	PS	324	55	72	111	6.75
2002	PS	325	35	50	69	6.90
2003	FS	322	7	17	8	7.04
2004	FS	320	6	15	6	7.13
2005	FS	323	6	16	6	7.12
2006	FS	317	6	16	5	7.21
2007	FS	309	5	15	6	7.23
2008	FS	296	5	15	6	7.19
2009	FS	281	5	13	7	7.10
2010	FS	280	5	12	6	7.06
2011	FS	273	4	12	4	7.07
94-02	PS	332	51	65	94	6.8
03-11	FS	302	5	15	6	7.1
Change		-9%*	-89%*	-78%*	-94%*	5%*

Partial Secondary (PS), Full Secondary (FS).Negative percentages indicate reductions.
** indicates statistical difference between treatment periods (95% confidence level).*

A comparison of the HTP effluent properties for the PS period 1994-1998 with the FS period from 1999-2011 revealed that the total flow declined by 13%, from 348 MGD to 304 MGD. Turbidity declined by 65%, from 26 NTU to 9 NTU, TSS declined 34%, from 30 mg/L to 20 mg/L, BOD declined 74%, from 73 mg/L to 19 mg/L, and pH declined from 7.1 to 7.0. Changes in all these effluent properties were statistically significant.

Figure 5 shows the annual average effluent flow, turbidity, TSS, BOD, and pH from 1994 to 2011 in JWPCP and HTP effluent. The period of PS and FS treatment is separated by a vertical line. As summarized graphically in Panel A of Figure 5, the flow to the JWPCP has been declining for most of the period from 1994 to 2011. The implementation of FS dramatically reduced levels of TSS, BOD, and turbidity in the JWPCP effluent. The switch to FS also slightly decreased pH, reducing the differential between the effluent and the receiving water, where the typical surface seawater pH is about 8.

Figure 6 summarizes the changes in effluent properties between treatment periods. Panel A of Figure 6 shows that at the JWPCP, the flow levels dropped by about 9% between the period of PS and FS. Levels of the conventional pollutants turbidity, TSS, and BOD all declined dramatically, while pH increased slightly.

In the panel B of Figure 6, the HTP effluent flow rates also declined by about 13%, between the periods of PS and FS. At HTP, levels of conventional pollutants turbidity, TSS, and BOD all declined, although not as dramatically as at the JWPCP. The legends in each panel indicate which changes were found to be statistically significant.

Table 4 HTP Effluent Properties

Annual average values

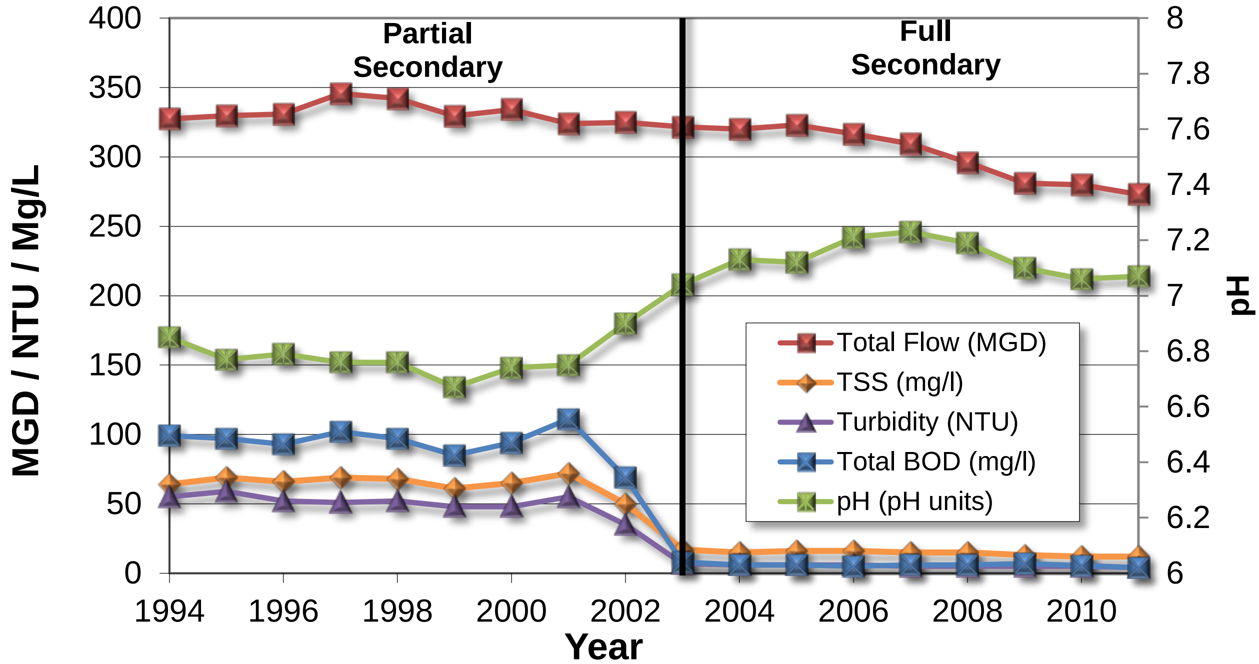
Year	Treatment Level	Total Flow (MGD)	Turbidity (NTU)	TSS (mg/L)	Total BOD (mg/L)	pH (pH units)
1994	PS	326	27	30	82	7.18
1995	PS	347	30	34	84	7.13
1996	PS	357	23	27	61	7.10
1997	PS	358	22	30	69	7.04
1998	PS	352	25	30	70	7.03
1999	FS	337	10	30	26	6.98
2000	FS	325	8	18	20	7.08
2001	FS	327	7	16	15	7.02
2002	FS	307	8	18	16	7.00
2003	FS	315	8	19	18	7.08
2004	FS	320	9	20	19	7.03
2005	FS	332	10	21	20	7.02
2006	FS	317	11	22	20	7.06
2007	FS	288	10	19	19	7.02
2008	FS	287	9	19	18	6.96
2009	FS	269	9	18	19	6.98
2010	FS	268	10	20	21	6.97
2011	FS	267	9	20	19	7.01
94-98	PS	348	26	30	73	7.1
99-11	FS	304	9	20	19	7.0
Change		-13%*	-65%*	-34%*	-74%*	-1%*

Partial Secondary (PS), Full Secondary (FS).Negative percentages indicate reductions.
** indicates statistical difference between treatment periods (95% confidence level).*

Influent versus Effluent

The JWPCP and HTP are the two largest wastewater treatment plants on the west coast of the United States. Together the plants are designed to treat 850 MGD of wastewater per day. Because of differences in the details of treatment processes, the ratios of influent to effluent of some parameters vary between the two plants. However, the secondary treatment provided at the JWPCP and HTP produces a very clean final effluent. Data collected throughout 2011 are used to describe the changes from influent to effluent, both for effluent quality and for effluent nutrient levels. In 2011 the average influent concentrations of TSS and BOD at JWPCP were 467 mg/L and 403 mg/L, respectively, and effluent values were 12 mg/L and 4 mg/L, respectively. These are both much lower than permitted secondary effluent standards for TSS and BOD of 30 mg/L each. At JWPCP, removal efficiencies for TSS and BOD during 2011 were 97% and 99%, respectively. In 2011, the average influent concentrations of TSS and BOD at HTP were 448 mg/L and 362 mg/L, respectively, and effluent values were 20 mg/L and 19 mg/L, respectively. At HTP, removal efficiencies for TSS and BOD during 2011 were 96% and 95%, respectively.

A).



B).

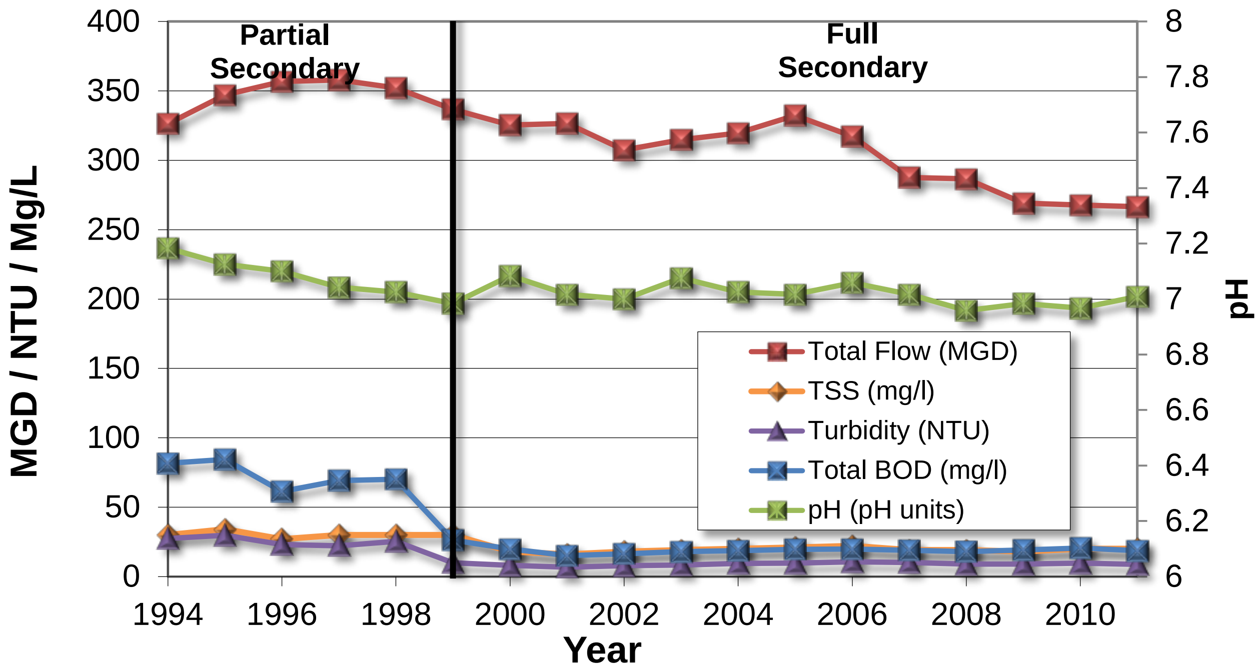


Figure 5 Effluent Flow and Quality 1994-2011

Average daily flow (mgd) and annual average levels of turbidity, TSS, BOD, and pH at JWPCP (A) and HTP (B)

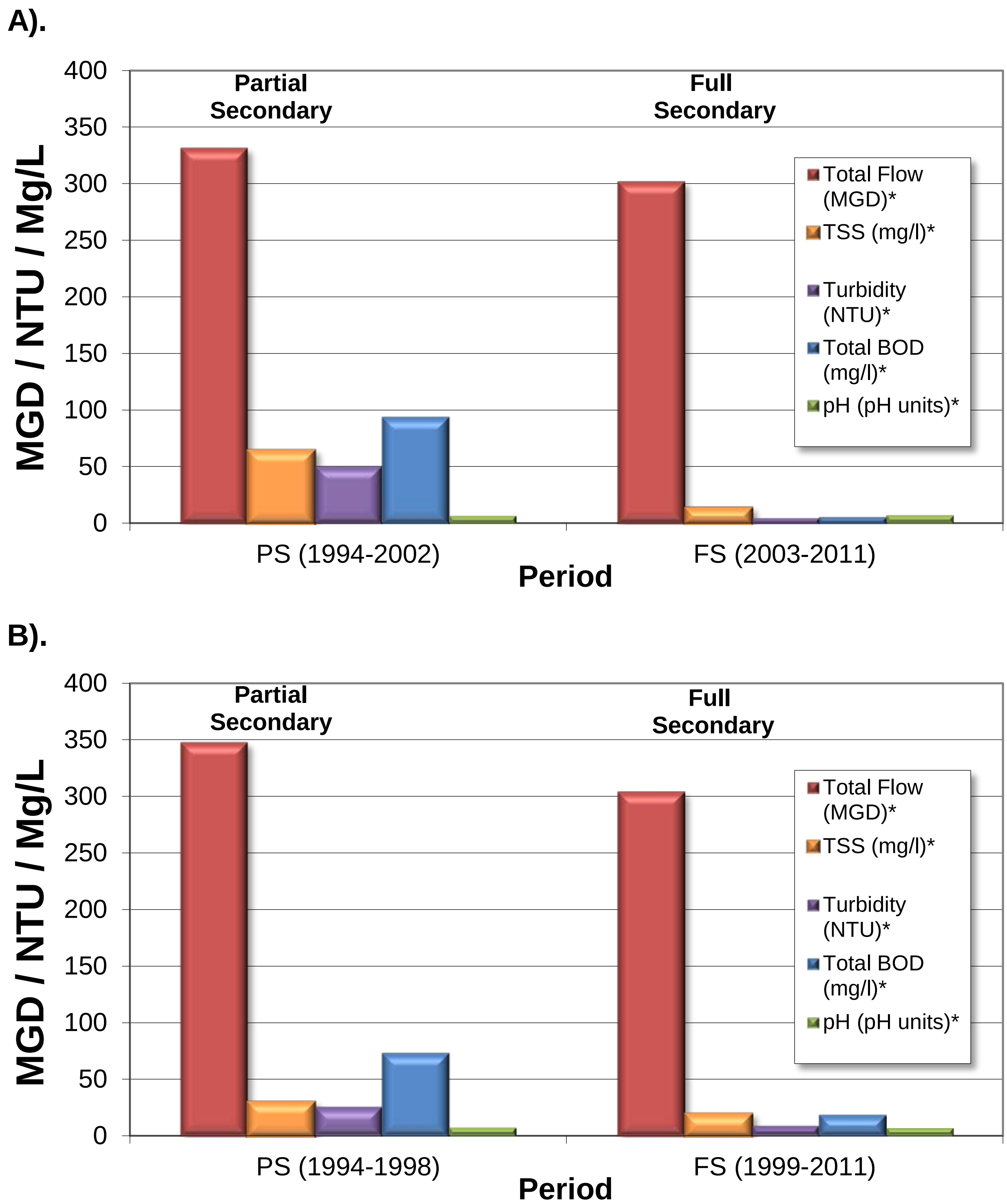


Figure 6 JWPCP and HTP Effluent Flow and Quality by Treatment Period
Average daily flow (mgd) and annual average levels of turbidity, BOD, and pH at JWPCP (A) and HTP (B)
* indicates statistical difference between treatment periods (95% confidence level).

During all of 2011, the average influent concentrations of total nitrogen and total phosphate at JWPCP were 61.9 mg/L and 26.2 mg/L, respectively. Final effluent concentrations were 42.4 mg/L and 1.96 mg/L, respectively. The removal efficiencies for total nitrogen and total phosphate were 32% and 93%, respectively. The influent contained a significant concentration of organic nitrogen, 21.1 mg/L; however, organic nitrogen was reduced to 2.49 mg/L in final effluent. The influent contained low levels of nitrate and nitrite nitrogen, 1.0 mg/L and 0.58 mg/L, respectively, which were both reduced by 90%, to concentrations of 0.1 mg/L and 0.07 mg/L, respectively in final effluent. Ammonia nitrogen concentrations were nearly unchanged through the treatment process; in 2011, influent was 39.2 mg/L, and effluent was 39.7 mg/L, for a net increase of only 1%.

During all of 2011, the average influent concentrations of total nitrogen and total phosphate at HTP were 44.9 mg/L and 21.1 mg/L, respectively. Final effluent concentrations were 43.9 mg/L and 9.19 mg/L, respectively. The removal efficiencies for total nitrogen and total phosphate were 2% and 57%, respectively. As at the JWPCP, the HTP influent contained a significant concentration of organic nitrogen, 16.5 mg/L; however, organic nitrogen was reduced to 3.61 mg/L in final effluent. Since it is not a permit requirement, HTP did not measure levels of nitrite and nitrate in influent in 2011. In effluent, nitrate and nitrite concentrations were 0.1 mg/L and 0.25 mg/L, respectively. Ammonia nitrogen concentration increased 41%, from influent at 28.4 mg/L to effluent at 40.0 mg/L.

Receiving Water Nutrients

Table 5 lists the annual average concentration and upper 95th % of ammonia in mg/L for the entire JWPCP receiving water sampling area for each year 1994-2011. At the bottom of the table the average values for each of the time periods are presented. Panel A of **Figure 7** and **Figure 8** illustrate the same data geographically.

A comparison of the JWPCP receiving water ammonia concentrations between the period of PS (1994-2002) and the FS period (2003-2011) indicates that the average concentration remained unchanged at 0.031 mg/L. The upper 95th % ammonia level was reduced by 2% from 0.127 mg/L to 0.124 mg/L. The changes were not statistically significant.

HTP receiving water ammonia concentrations **(Table 6**) showed small changes between the period of PS (1994-1998), and FS (1999-2011). Although average receiving water ammonia levels declined 20%, from 0.031 mg/L down to 0.025 mg/L, the upper 95th % ammonia concentrations actually increased 4%, from 0.085 mg/L to 0.089 mg/L. These small differences probably reflect variability in the water column sampling data, since as reported in Table 2, the average MER of ammonia actually increased, from 12,426 mtons/yr to 14,713 mtons/yr, between these time periods. The decline in average receiving water ammonia between periods was statistically significant, but is probably due to changes in the offshore survey geographic coverage.

Figure 7 shows the annual average and upper 95th % receiving water ammonia concentration from all discrete samples collected during offshore surveys completed to meet JWPCP and HTP permit requirements. Each year approximately 300 samples, collected between the surface and 45 meters, are analyzed for ammonia by each agency. The laboratory reporting level (RL) for all sampling was 0.02 mg/L. To calculate annual average and upper 95th %, ½ the RL was substituted for results below the RL. The period of PS and FS treatment is separated by a vertical line.

As summarized graphically in panel A of Figure 8, average and upper 95th % ammonia concentrations in the receiving water around the JWPCP discharge were almost unchanged between the PS and FS treatment periods. Panel B of Figure 8 shows that the average ammonia concentrations in the receiving water around the HTP discharge declined by 12%, while the upper 95th % increased by 4%, between the PS and FS treatment periods.

Per Capita Flow and Nutrient Data

Both the CLA and the JOS collect and treat a portion of their wastewater at inland WRPs. In this report, all inland populations are included in the per capita analyses if they are served as part of the collection system that ultimately includes the ocean discharging HTP and JWPCP facilities. In particular, this is appropriate because a significant fraction of the nutrients from these WRPs is passed onto the centralized solids processing at the HTP and JWPCP plants. Also, the WRPs use tertiary-treated effluent for various beneficial reuse purposes, as well as discharging it under NPDES permits to inland water bodies. In the following discussion, the

Table 5 JWPCP receiving Water Ammonia
Annual average and upper 95th % concentration in survey area

Year	Treatment Level	Ammonia - average all sites/depths (mg/L)	Standard Deviation (mg/L)	Upper 95th % (mg/L)
1994	PS	0.043	0.063	0.180
1995	PS	0.042	0.053	0.151
1996	PS	0.029	0.036	0.110
1997	PS	0.030	0.043	0.150
1998	PS	0.025	0.035	0.090
1999	PS	0.023	0.030	0.090
2000	PS	0.028	0.040	0.120
2001	PS	0.032	0.044	0.140
2002	PS	0.023	0.032	0.110
2003	FS	0.029	0.037	0.120
2004	FS	0.034	0.047	0.150
2005	FS	0.026	0.039	0.113
2006	FS	0.036	0.049	0.140
2007	FS	0.034	0.045	0.120
2008	FS	0.034	0.042	0.130
2009	FS	0.034	0.046	0.150
2010	FS	0.031	0.044	0.130
2011	FS	0.023	0.034	0.064
94-02	PS	0.031	0.042	0.127
03-11	FS	0.031	0.042	0.124
Change		0%	0%	-2%

Partial Secondary (PS), Full Secondary (FS). Negative percentages indicate reductions. indicates statistical difference between treatment periods (95% confidence level).*

intent is to show the per capita nutrient contributions of the full service area population to each ultimate disposal option, including ocean, biosolids, and recycling/reuse.

While the majority of all influent from both the CLA and JOS collection systems reaches the ocean as discharge from the HTP or the JWPCP, there are some differences in the way that inland WRP effluents are accounted for between agencies. The JOS includes a significant distribution system that conveys tertiary -treated effluent from the WRPs to a wide variety of reuse options, such as landscape irrigation, agricultural irrigation, industrial process water, groundwater saltwater intrusion barrier, and groundwater replenishment. For the latter, effluent is routed to spreading grounds and percolates down to replenish the aquifer. The CLA directly reclaims a fraction of the effluent from the HTP by routing it to the HTP Service Water Facility and West Basin Recycling Facility for selective additional treatment prior to in-plant use and distribution for all the same types of beneficial reuse options listed above. In addition to these beneficial uses, both the JOS and the CLA use recycled water (effluent) from their WRPs to serve recreational impoundments and wildlife habitat maintenance. These last two uses may also be counted as river discharge, since that is often the ultimate fate of the effluent discharged to inland water bodies. A distinction is that some of the WRPs discharge recycled water to portions of the rivers that were historically altered to concrete-lined channels for flood control. In these cases, that water is counted as river discharge; however, in other cases, such as the discharges that CLA inland plants make to Balboa Lake, Wildlife Lake, and the Japanese Garden, the discharges are appropriately counted as beneficial

Table 6 HTP receiving Water Ammonia

Annual average and upper 95th % concentration in survey area

Year	Treatment Level	Ammonia - average all sites/depths (mg/L)	Standard Deviation (mg/L)	Upper 95th % (mg/L)
1994	PS	0.018	0.026	0.057
1995	PS	0.038	0.053	0.134
1996	PS	0.045	0.043	0.101
1997	PS	0.032	0.024	0.075
1998	PS	0.023	0.017	0.060
1999	FS	0.022	0.033	0.081
2000	FS	0.028	0.039	0.098
2001	FS	0.045	0.063	0.153
2002	FS	0.037	0.058	0.119
2003	FS	0.030	0.038	0.100
2004	FS	0.027	0.044	0.118
2005	FS	0.023	0.034	0.081
2006	FS	0.016	0.027	0.044
2007	FS	0.022	0.033	0.081
2008	FS	0.016	0.021	0.054
2009	FS	0.020	0.035	0.090
2010	FS	0.018	0.027	0.074
2011	FS	0.019	0.031	0.060
94-98	PS	0.031	0.033	0.085
99-11	FS	0.025	0.037	0.089
Change		-20%*	14%	4%

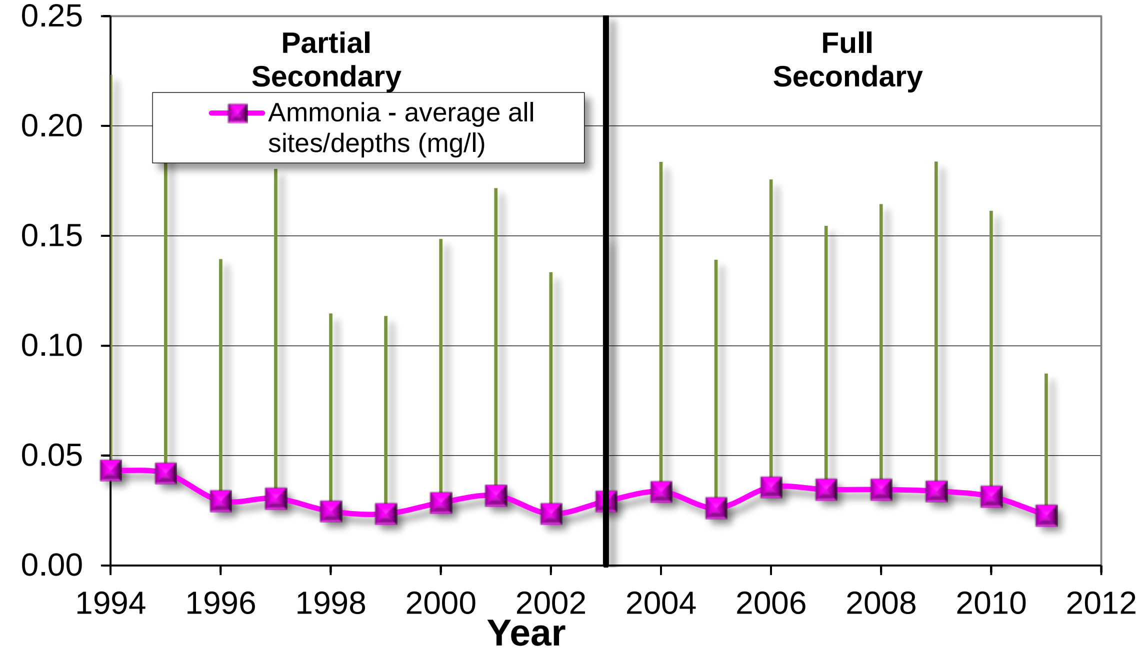
Partial Secondary (PS), Full Secondary (FS). Negative percentages indicate reductions. indicates statistical difference between treatment periods (95% confidence level).*

reuse. Both the CLA and the Sanitation Districts continue to seek and develop additional opportunities to beneficially reuse recycled water.

The Sanitation Districts service area population data documents the changes in the entire JOS and show the average JOS service area population has increased 4% from 4,614,076 to 4,800,532 between the PS and FS treatment periods. For the HTP's service area population, data for the CLA and contract cities were taken from the Department of Finance, State of California website. The CLA population count represents the geographical areas in the CLA as well as in the contract cities that are serviced by HTP and the upstream plants, Tillman WRP and Los Angeles-Glendale (LAG) WRP. The population count for the CLA excludes the population served by the essentially independent Terminal Island WRP, a separate collection system and ocean discharge facility. The average CLA service area population has increased 5% from 3,725,944 to 3,919,308 between the PS and FS treatment periods.

Table 7 below summarizes the total amount of tertiary-treated effluent produced in the JOS, and the amount of this flow beneficially reused in each year 1994 to 2011. The per capita daily flow to the ocean from the JWPCP and the beneficial reuse flows in Table 7 are based on total JOS population. The amount of tertiary-treated flow produced at inland plants, and available for reuse, has declined 12%, from 157 to 138 gallons per capita daily (gpcd) between the PS period and FS period in the JOS. This reduction in flow is similar to the reduction at the JWPCP and reflects system-wide water conservation. This reduction in flow occurred despite a continued increases in the population in the JOS service area. As a result of these changes in flow and

A).



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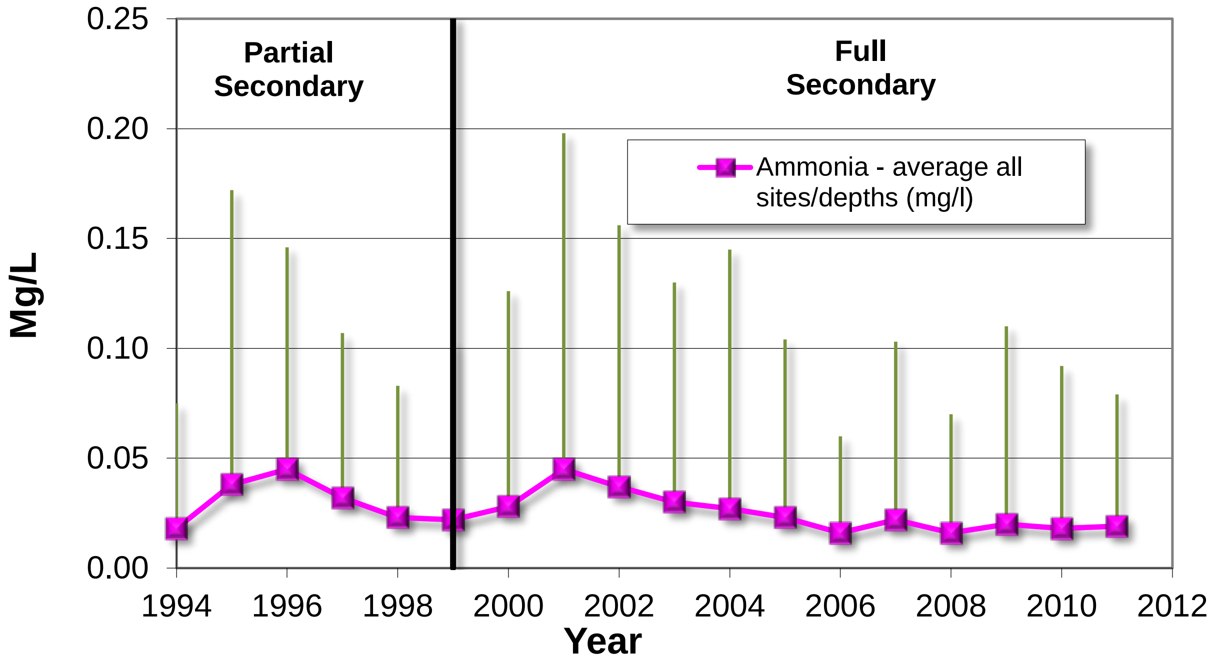


Figure 7 JWPCP and HTP Receiving Water Ammonia Concentrations

Annual average and upper 95th % ammonia concentrations (mg/L) for JWPCP (A) and HTP (B)

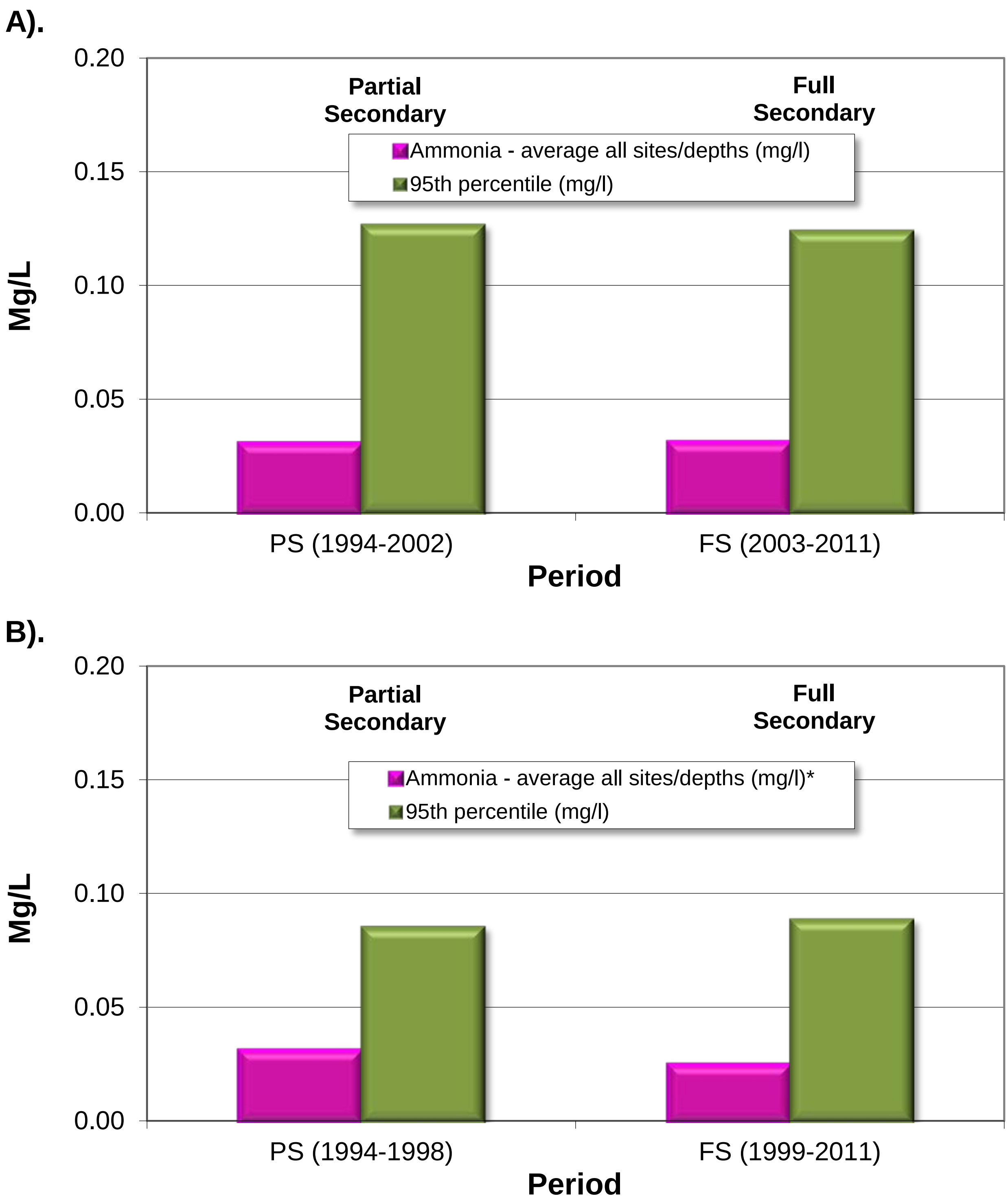


Figure 8 JWPCP and HTP Receiving Water Ammonia vs. Treatment Level
Time-period average concentrations and upper 95th % values in mg/L at JWPCP (A) and HTP (B).
* indicates statistical difference between treatment periods (95% confidence level).

population, **Table 7** shows that between the PS and FS treatment periods, the gpcd flow of treated effluent to the ocean declined 13%, from 72 gpcd to 63 gpcd. At the same time, the amount of water beneficially reused each day on a per capita basis declined 11%, from approximately 34 gpcd to 29 gpcd.

Table 7 JOS Flows, Population, and Per Capita Flows

Annual average values

Year	Treatment Level	All JOS tertiary treated flow (mgd)	Beneficial Reuse Flow (Recharge + Direct) (mgd)	Service Area Population	Daily per capita Flow to Ocean (gpcd)	Daily per capita Recycled Flow (gpcd)
1994	PS	151	49	4496368	73	34
1995	PS	159	53	4526670	73	35
1996	PS	156	61	4522572	73	34
1997	PS	155	68	4541925	76	34
1998	PS	164	50	4571712	75	36
1999	PS	158	61	4625382	71	34
2000	PS	159	59	4698983	71	34
2001	PS	163	56	4751550	68	34
2002	PS	150	85	4791523	68	31
2003	FS	151	57	4824107	67	31
2004	FS	151	51	4839717	66	31
2005	FS	151	44	4835531	67	31
2006	FS	139	61	4811948	66	29
2007	FS	129	61	4787793	65	27
2008	FS	134	54	4776065	62	28
2009	FS	128	61	4773457	59	27
2010	FS	129	65	4773947	59	27
2011	FS	127	49	4782223	57	27
94-02	PS	157	60	4614076	72	34
03-11	FS	138	56	4800532	63	29
Change		-12%	-7%	4%	-13%	-11%

Partial Secondary (PS), Full Secondary (FS).Negative percentages indicate reductions

Table 8 presents the CLA reuse, recycling, and per capita annual average values for 1994 to 2011. The amount of tertiary-treated recycled water produced at HTP and inland plants, and available for reuse, has increased 7%, from 82 to 88 gpcd between the PS period and FS period at the HTP. The beneficial reuse flow has increased 56% between the PS period and the FS period at the HTP. Table 8 shows that between the PS and FS treatment periods the gpcd flow of treated effluent to the ocean declined 17%, from 93 gpcd to 78 gpcd despite a 5% increase in the population in the CLA service area. At the same time, the amount of water beneficially reused each day on a per capita basis increased 48%, from approximately 12 gpcd to 18 gpcd. In 2011, the sum of ocean discharge and recycling in the JOS adds up to 84 gpcd, while for the CLA the 2011 sum is 85 gpcd.

Figure 9 shows the annual average gpcd flows to the ocean and gpcd directed to beneficial reuse for each year 1994 to 2011. Panel A is for the JOS service area, and panel B is for the CLA service area. The total combined population of both service areas as of 2011 was slightly less than nine million. The period of PS and FS treatment is separated by a vertical line.

Table 1 CLA Flows, Population, and Per Capita Flows

Annual average values

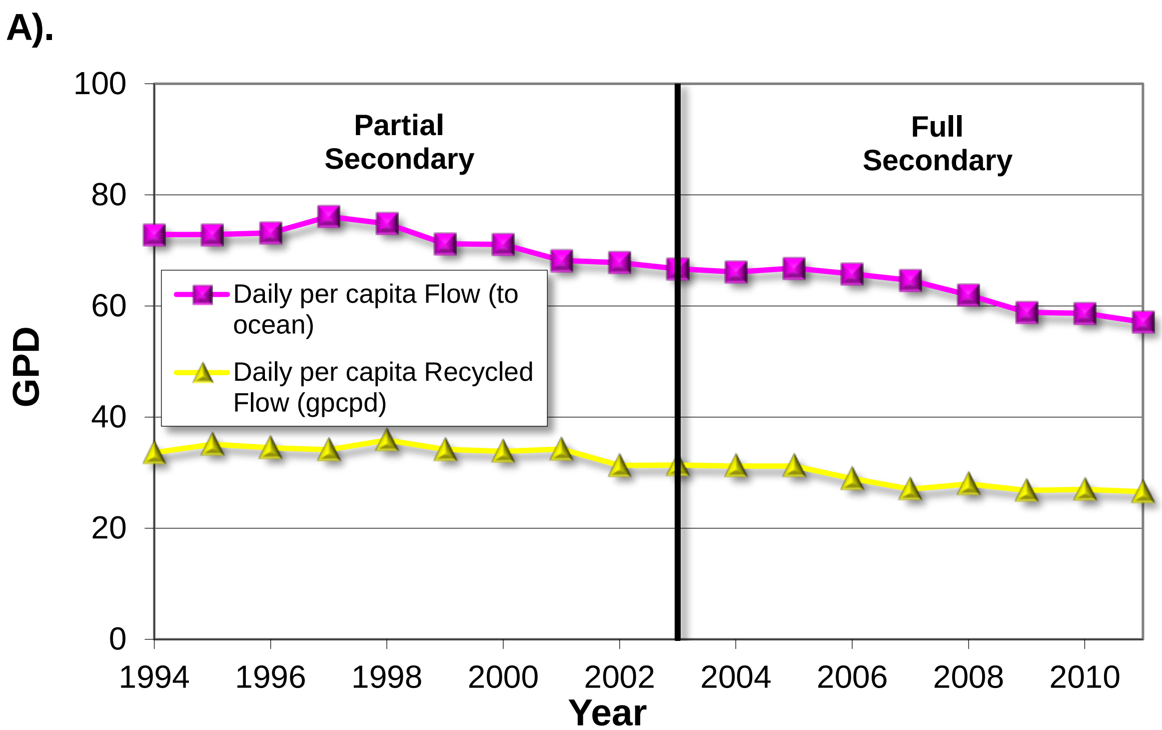
Year	Treatment Level	All HTP & upstream tertiary-treated flow (mgd)	Beneficial Reuse Flow (Recharge + Direct) (mgd)	Service Area Population	Daily per capita Flow to Ocean (gpcd)	Daily per capita Recycled flow (gpcd)
1994	PS	76	41	3740656	87	11
1995	PS	79	41	3711578	93	11
1996	PS	78	41	3706853	96	11
1997	PS	81	41	3721110	96	11
1998	PS	96	58	3749525	94	16
1999	FS	84	61	3790309	89	16
2000	FS	104	65	3844753	85	17
2001	FS	92	65	3881782	84	17
2002	FS	93	70	3911176	79	18
2003	FS	89	65	3932538	80	17
2004	FS	82	66	3946824	81	17
2005	FS	82	66	3941670	84	17
2006	FS	89	75	3938367	81	19
2007	FS	90	77	3932268	73	20
2008	FS	87	74	3941805	73	19
2009	FS	88	76	3950565	68	19
2010	FS	81	69	3963169	68	17
2011	FS	81	72	3975783	67	18
94-98	PS	82	44	3725944	93	12
99-11	FS	88	69	3919308	78	18
Change		7%	56%	5%	-17%	48%

Partial Secondary (PS), Full Secondary (FS).Negative percentages indicate reductions

Using annual average per capita flow rates and JWPCP effluent nutrient MERs, the JOS per capita nutrient MERs to the ocean are calculated and reported as annual average values in **Table 9**. The per capita rates are presented in units of kilograms per year.

In JWPCP effluent, the per capita MERs for all nutrients declined between the PS period 1994-2002 and the FS period 2003-11. Total nitrogen was reduced by 13%, and total phosphate was reduced 79%. The reductions in total nitrogen occurred across all species, but the major reductions were seen in nitrate, nitrite, and organic nitrogen. The drops in these three species are due to the changes in treatment. When the plant went to FS the per capita decline in the MER of the dominant form of nitrogen in the JWPCP effluent, ammonia, was only 3%. As presented earlier, the total effluent MER of ammonia remained almost unchanged between treatment periods, so the 3% reduction in the per capita rate is largely explained by the increase in the average service area population. Per capita reductions in total phosphate are due to the improved solids removal achieved by FS treatment. Changes in all per capita MERs were statistically significant.

Using annual average per capita flow rates and HTP effluent nutrient MERs, the CLA per capita nutrient MERs to the ocean are calculated and reported as annual average values in **Table 10**. The per capita rates are presented in units of kilograms per year. Changes in per capita MERs from HTP to the ocean were more variable than at JWPCP between the PS period (1994-1998) and the FS period (1999-2011). Total nitrogen increased 3%, while total phosphate decreased 37%. Ammonia per capita MERs increased 12%, but organic



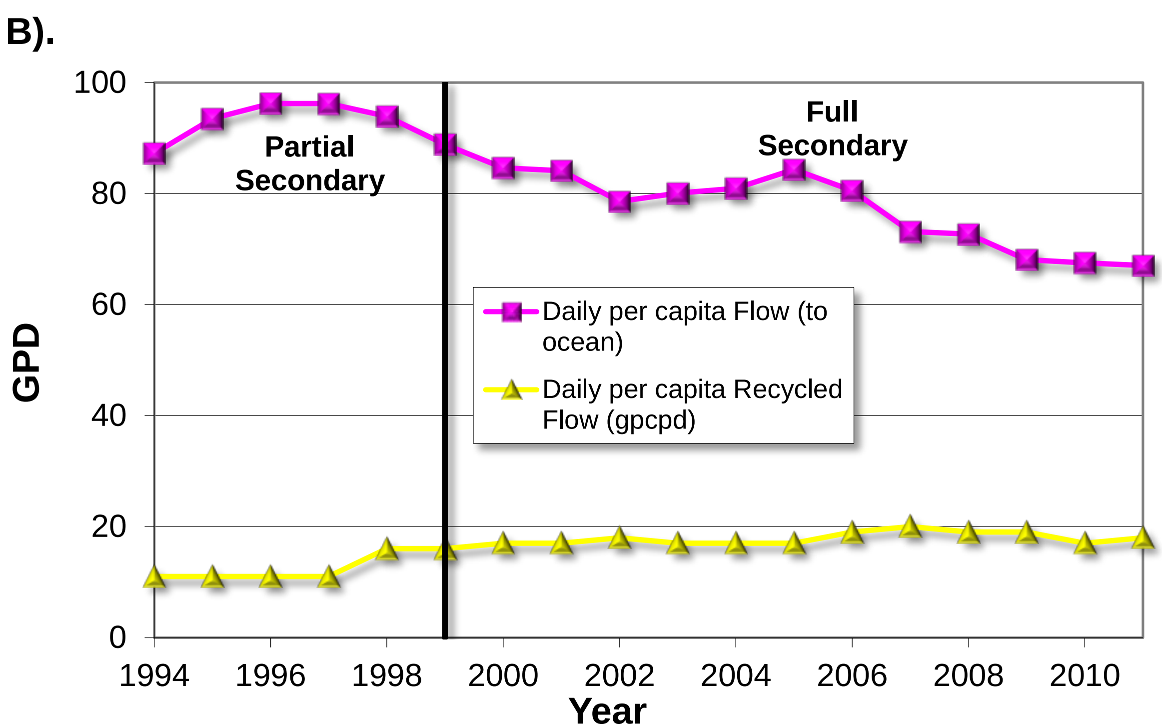


Figure 9 JOS and CLA Per Capita Flow Data 1994-2011

Annual average gallons per capita per day to ocean or to recycling for JOS (A) and CLA (B)

Table 9 JWPCP Nutrient MERs

Annual per capita rates in kilograms/year based on JOS population

Year	Treatment Level	Ammonia Nitrogen	Organic-Nitrogen	Nitrate-Nitrogen	Nitrite-Nitrogen	Total Nitrogen	Total Phosphate
1994	PS	3.54	0.66	0.03	0.00	4.23	1.11
1995	PS	3.41	0.65	0.04	0.03	4.13	1.08
1996	PS	3.03	0.63	0.04	0.02	3.72	1.04
1997	PS	3.15	0.67	0.01	0.01	3.84	1.08
1998	PS	3.00	0.70	0.01	0.02	3.73	1.02
1999	PS	2.98	0.61	0.02	0.01	3.62	0.86
2000	PS	2.99	0.66	0.01	0.01	3.67	0.89
2001	PS	3.01	0.73	0.02	0.01	3.77	1.01
2002	PS	3.16	0.55	0.00	0.01	3.72	0.75
2003	FS	2.91	0.29	0.01	0.01	3.21	0.48
2004	FS	2.99	0.52	0.00	0.00	3.52	0.22
2005	FS	3.03	0.36	0.01	0.01	3.40	0.25
2006	FS	3.08	0.28	0.00	0.01	3.37	0.19
2007	FS	3.06	0.21	0.01	0.01	3.29	0.21
2008	FS	3.14	0.21	0.00	0.01	3.37	0.19
2009	FS	3.06	0.15	0.00	0.01	3.23	0.05
2010	FS	3.14	0.15	0.00	0.01	3.31	0.15
2011	FS	3.13	0.20	0.01	0.01	3.34	0.15
94-02	PS	3.14	0.65	0.02	0.01	3.83	0.98
03-11	FS	3.06	0.26	0.01	0.01	3.34	0.21
Change		-3%*	-59%*	-72%*	-39%*	-13%*	-79%*

Partial Secondary (PS), Full Secondary (FS).Negative percentages indicate reductions.
** indicates statistical difference between treatment periods (95% confidence level).*

nitrogen decreased 45%, while nitrate decreased 14% and nitrite remained unchanged. Changes in per capita MERs of ammonia, organic, and total nitrogen, and total phosphate were statistically significant.

Figure 10 shows the annual average per capita MERs of total nitrogen, total phosphate, ammonia, nitrogen, organic nitrogen, nitrate, and nitrite from 1994 to 2011 in JWPCP (panel A) and HTP (panel B) effluent. The period of PS and FS treatment is separated by a vertical line.

As summarized graphically in panel A of Figure 10, the JWPCP average per capita MER of ammonia nitrogen was reduced by just 3% by the implementation of FS. However, per capita MERs of organic nitrogen, nitrate, and nitrite nitrogen, which represent only a small fraction of the total nitrogen in the effluent, were significantly reduced, accounting for the 13% decline in per capita total nitrogen. The JWPCP total phosphate per capita MER was reduced by 78%, approximately proportional to the reduction in TSS between PS and FS.

In panel B of **Figure 11**, the average per capita MER of nutrients from HTP is compared between the periods of PS and FS. At HTP, the MER of ammonia nitrogen increased about 12% after FS (most likely due to conversion from a mesophilic Class B biosolids process to a thermophilic Class A biosolids process), and despite a 45% decrease in the per capita MER of organic nitrogen, total nitrogen per capita MERs from HTP increased by 3%. The HTP total phosphate per capita MER was reduced by 37%, approximately proportional to the reduction in TSS between PS and FS. The legends in each panel indicate which changes were found to be statistically significant.

Table 10 HTP Nutrient MERs

Annual per capita rates in kilograms/year

Year	Treatment Level	Ammonia Nitrogen	Organic-Nitrogen	Nitrate-Nitrogen	Nitrite-Nitrogen	Total Nitrogen	Total Phosphate
1994	PS	3.01	0.67	0.02	NS	3.70	1.48
1995	PS	3.27	0.77	0.01	NS	4.06	1.52
1996	PS	3.51	0.63	0.02	NS	4.17	1.51
1997	PS	3.45	0.66	0.03	0.02	4.16	1.60
1998	PS	3.43	0.65	0.04	0.05	4.17	1.55
1999	FS	3.35	0.34	0.12	0.12	3.93	1.17
2000	FS	3.41	0.37	0.05	0.10	3.93	1.08
2001	FS	3.62	0.30	0.03	0.08	4.04	1.00
2002	FS	3.53	0.35	0.01	0.08	3.97	0.86
2003	FS	3.85	0.41	0.00	0.04	4.30	0.85
2004	FS	3.95	0.43	0.00	0.01	4.39	1.08
2005	FS	4.08	0.45	0.01	0.02	4.55	0.98
2006	FS	4.06	0.46	0.00	0.01	4.52	1.06
2007	FS	3.79	0.40	0.00	0.00	4.19	1.02
2008	FS	3.87	0.31	0.01	0.01	4.20	0.85
2009	FS	3.87	0.34	0.01	0.06	4.29	0.92
2010	FS	3.68	0.38	0.01	0.04	4.12	0.93
2011	FS	3.70	0.33	0.01	0.02	4.07	0.85
94-98	PS	3.34	0.68	0.02	0.04	4.05	1.53
99-11	FS	3.75	0.37	0.02	0.04	4.19	0.97
Change		12%*	-45%*	-14%	0%	3%*	-37%*

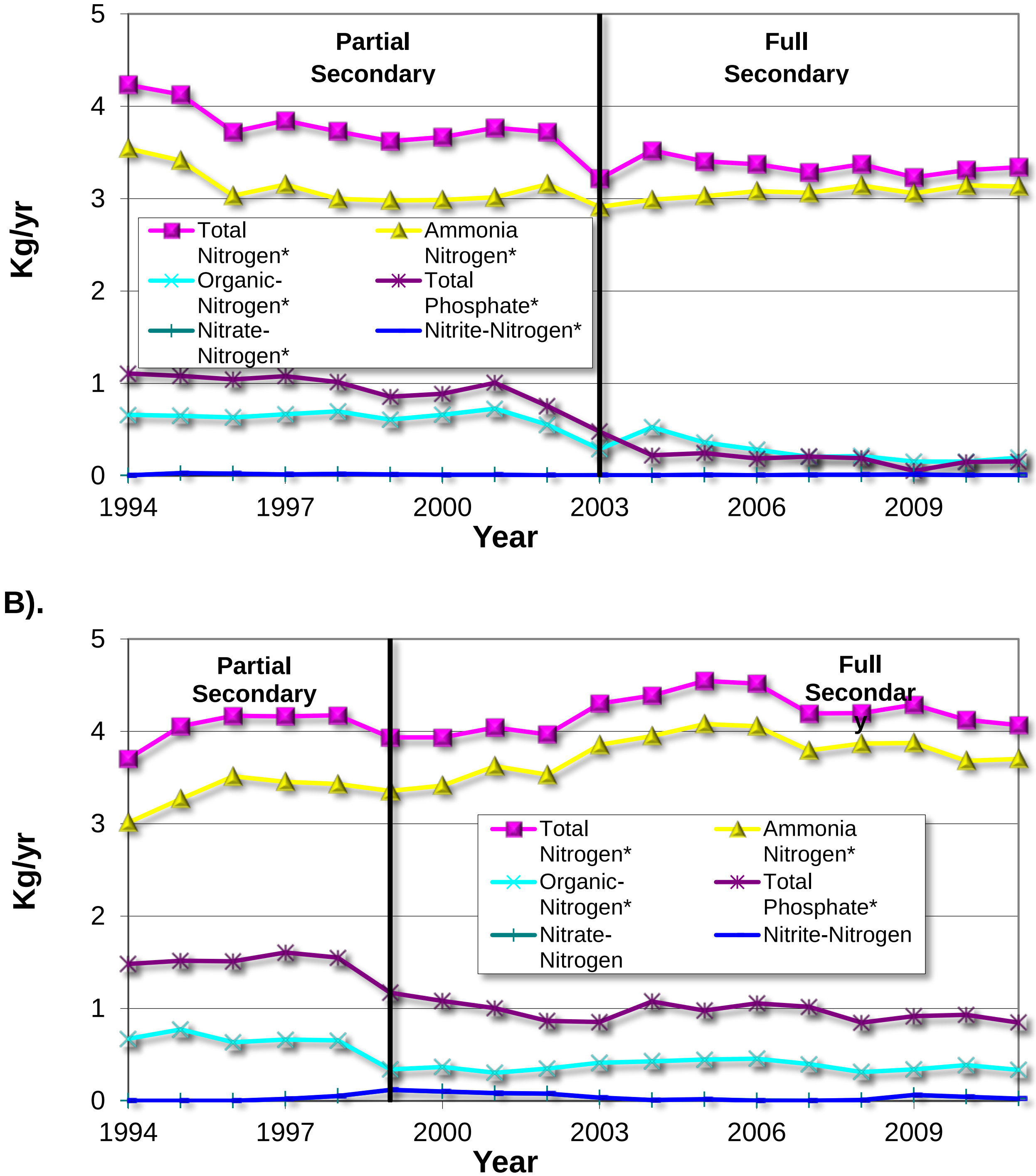
NS – *Not Sampled (not required in active permit at the time). Partial Secondary (PS), Full Secondary (FS).Negative percentages indicate reductions*
** indicates statistical difference between treatment periods (95% confidence level).*

Distribution and Fate of Nutrients

The JOS system collects wastewater from residential and commercial sources, serving a total population of about 4.8 million in 2011. In 2011, the six upstream WRPs captured and provided tertiary treatment to a daily average of 127 MGD of wastewater. About 49 MGD of this recycled water was beneficially reused for irrigation or groundwater recharge. The remaining water was discharged to inland waters. Solids from the WRPs are sent to the JWPCP through the collection system, where a central solids-processing facility treats the biosolids, which are then transported offsite for a variety of final disposal options. **Table 11** summarizes the amounts and percentage of each nutrient species going to each end point for the JOS system. In 2011, 68% of total nitrogen went to the ocean (JWPCP effluent), 27% went to various biosolids disposal end points, and 5% was distributed in recycled water, including a fraction that was discharged under NPDES permits to inland waterways. By contrast, 92% of total phosphate went to biosolids, with only 7% to the ocean, and 1% to recycling uses and inland waterways.

The CLA system is similar to that of the LACSD, in that inland wastewater is captured and given tertiary treatment at two WRPs. In addition, a portion of the effluent produced at the HTP is routed to the in-house Service Water Facility and externally to West Basin Municipal District (West Basin Facility) where it receives further treatment before being beneficially reused. **Table 12** shows that in 2011, 82% of total nitrogen went to the ocean (HTP effluent), 15% went to various biosolids disposal end points, and 2% was distributed in

A).

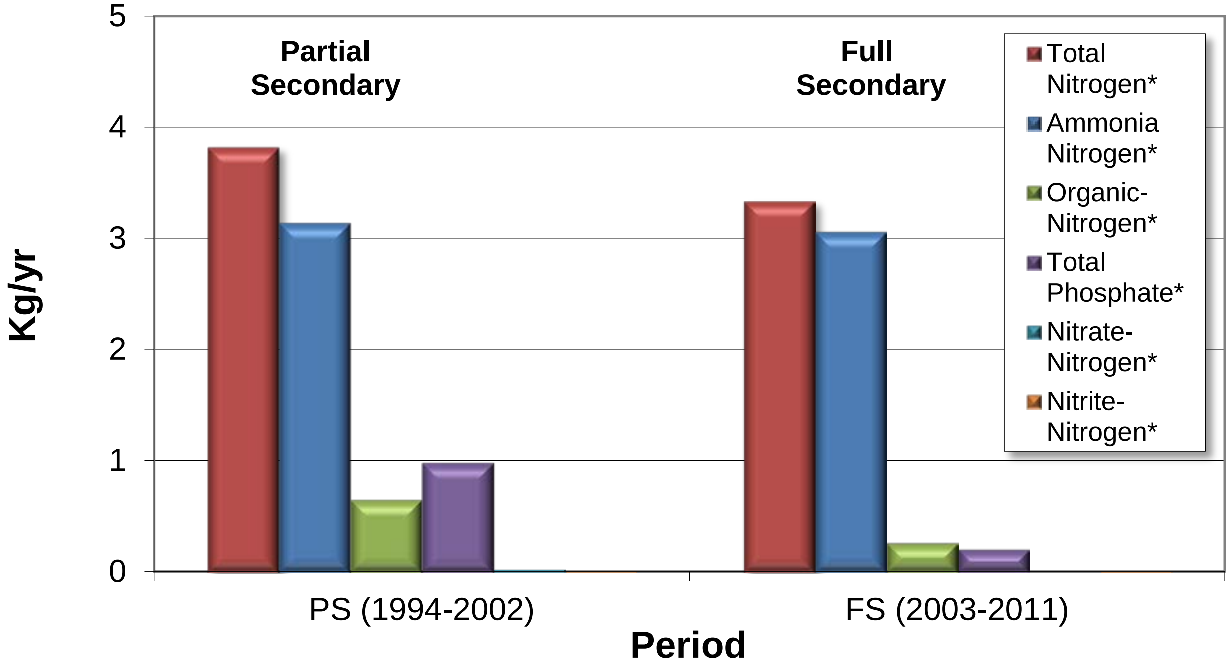


B).

Figure 10 JOS and CLA Per Capita Nutrient MER Data 1994-2011

Annual average kilograms/year per capita to ocean for JOS (A) and CLA (B) service area populations

A).



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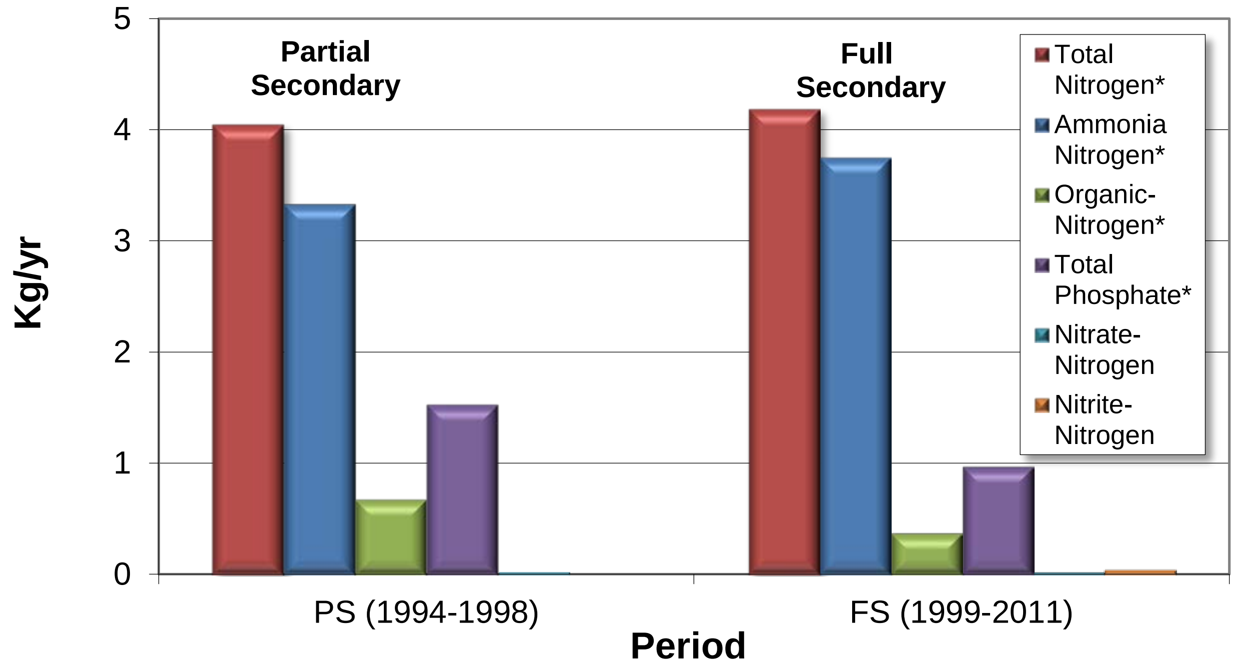


Figure 11 JOS and CLA Per Capita Nutrient MER Data 1994-2011
Annual average kilograms/year per capita to ocean for JOS (A) and CLA (B) by treatment period
* indicates statistical difference between treatment periods (95% confidence level).

recycled water, including a portion discharged under NPDES permits to inland waterways. 62% of total phosphate went to biosolids, and 37% went to the ocean.

Note that biological processes used at the WRP plants, including nitrification/denitrification (NDN), may shift nitrogen between species, and also reduce the overall nitrogen load in the system, since some nitrogen is expected to be released in the atmosphere through the NDN process.

Table 11 JOS Nutrient Distribution in 2011

Annual loading (mtons/yr) and percentage of each species to each end point

Species	JWPCP Effluent (mtons/yr)	Biosolids (mtons/yr)	Recycled water (mtons/yr)	JWPCP Effluent (%)	JWPCP Biosolids (%)	Upstream NPDES (%)
Ammonia-N	14975	918	142	93%	6%	1%
Organic Nitrogen	939	5437	174	14%	83%	3%
Nitrate-N	38	ND	879	4%	ND	96%
Nitrite-N	26	1	9	72%	2%	25%
Total Nitrogen	15978	6355	1221	68%	27%	5%
Total Phosphate	739	9637	114	7%	92%	1%

Due to rounding error some numbers do not sum to 100%

Table 12 CLA Nutrient Distribution in 2011

Annual loading (mtons/yr) and percentage of each species to each end point

Species	HTP Effluent (mtons/yr)	Biosolids (mtons/yr)	Recycled water (mtons/yr)	HTP Effluent (%)	HTP Biosolids (%)	Upstream NPDES (%)
Ammonia-N	14716	512	64	96%	3%	0%
Organic Nitrogen	1328	2461	107	34%	63%	3%
Nitrate-N	37	ND	318	10%	ND	90%
Nitrite-N	91	1	0	99%	1%	0%
Total Nitrogen	16173	2975	489	82%	15%	2%
Total Phosphate	3368	6143	93	35%	64%	1%

Due to rounding error some numbers do not sum to 100%

Figure 12 panel A shows how the JOS nutrient MER for total nitrogen and total phosphate was distributed in 2011 between the JWPCP effluent that goes to the ocean, biosolids, and the various uses of recycled water, including upstream NPDES permitted discharges to rivers. Figure 12 panel B shows the CLA nutrient MER distributions of total nitrogen and total phosphate to the ocean, biosolids, and recycled uses for the CLA system.

Receiving Water Effects

The Sanitation Districts and the CLA sample the offshore waters around their respective outfalls using a CTD equipped with multiple sensors. During each survey, the CTD is lowered vertically from the surface to a maximum of 100 meters (or shallower when limited by seafloor). Using the procedures described above, these survey data were processed to produce time series showing trends and patterns in the receiving water and differentiate between reference and impacted areas.

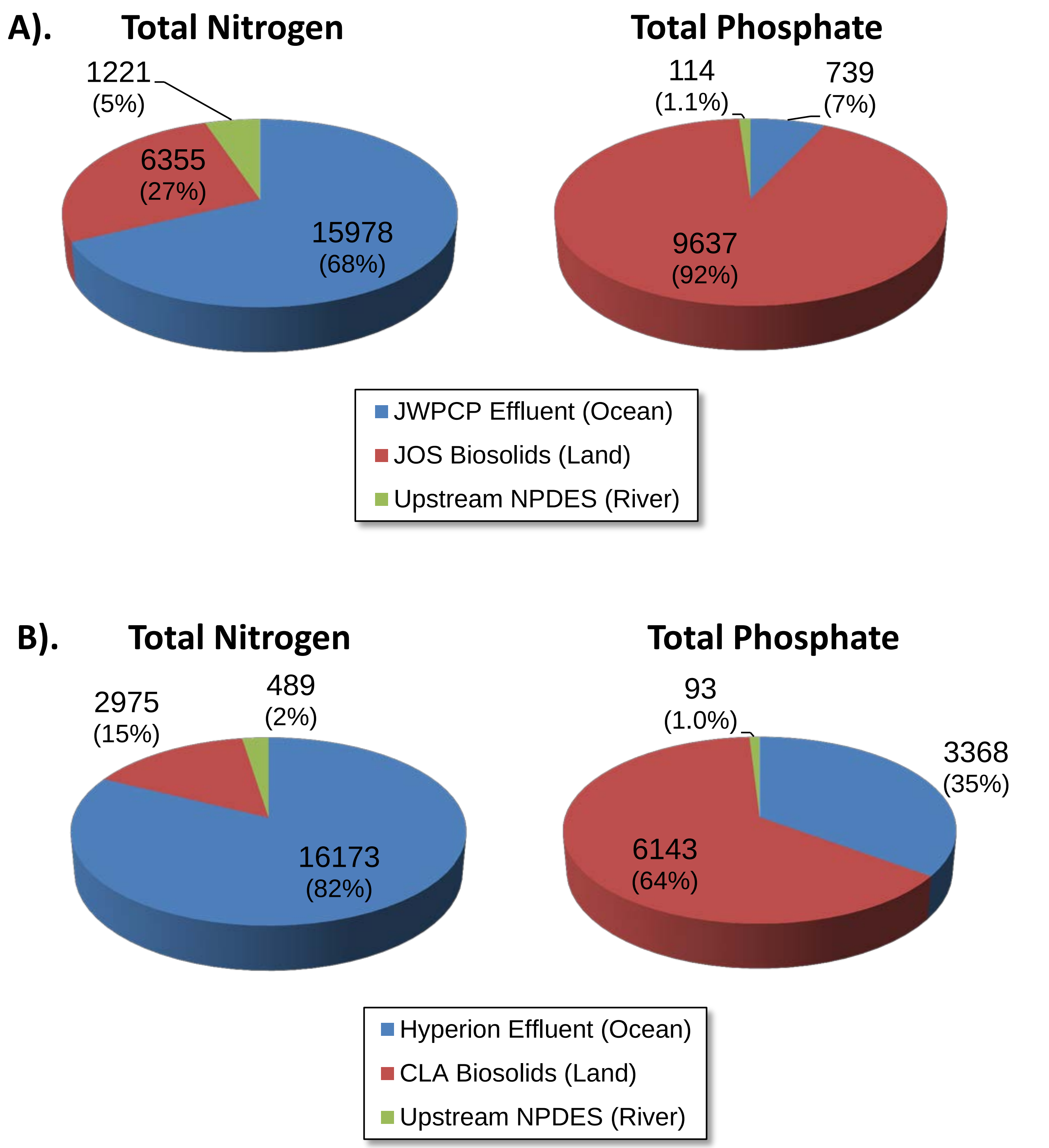


Figure 12 JOS and CLA Nutrient Distributions in 2011
Annual metric tons of total nitrogen and total phosphate to ocean, biosolids, and reuse from JOS (A) and CLA (B)

Figure 13 shows the patterns of DO, pH, and light transmittance observed between 1994 and 2011 in a subset of the receiving water sampling data for the JWPCP. The period of PS is colored in red and the period of FS is colored blue. For every survey, all values at the plume centerline depth are shown as points. To assist in interpretation of these time series, a moving filter line was created using a non-parametric regression function (Loess) that traces the reference and plume averages. The overall average values for reference and plume areas corresponding to each treatment period are shown as a level, solid and dashed line, respectively. These average values are also identified at the top of each of the three graphics.

The DO, pH, and LT values show a high degree of variability during individual surveys, where the levels at all the reference and plume stations at the plume depth are shown as either dots or asterisk symbols. The DO and pH both have a net trend of decreasing values between 1994 and 2011. The LT has a slight positive trend (increasing water clarity) over the period. The moving average lines show that the variability is matched closely between the reference and plume. Although typically, the plume values are slightly lower than the reference.

Figure 14 presents the same analysis for the receiving water data collected around the HTP outfall. The overall trends are similar between the JWPCP and HTP data, although the HTP facility began FS treatment earlier than JWPCP.

The temperature, salinity, and spiciness of the respective receiving water masses are presented in **Figure 15** and **Figure 16**. 'Spice' is an oceanographic parameter that combines salinity and temperature into one metric that allows the discernment of water masses without the limitations of using density, where changes in both parameters may cancel each other out. Higher numbers indicate water that is warmer and saltier; and lower numbers are cooler and fresher. These fundamental water properties illustrate regional patterns. The HTP receiving water temperature and salinity patterns are similar to those for the JWPCP.

The temperature data from both agencies shows a trend of declining water temperature, and also the response to a strong El Niño in 1998 (Booth et al., 2014). The salinity data suggest a roughly decadal oscillation, with peaks in 1999 and 2008 during strong La Niñas (**Figure 17**).

During the period of PS treatment at the JWPCP, the average DO and pH at the plume depth was 0.51 mg/L and 0.06 pH units lower, respectively, in plume waters than in the reference. The temperature was 0.33 degrees lower, and the salinity was 0.16 psu lower in the plume. During the period of FS treatment, the DO and pH reductions in plume waters were similar, 0.42 mg/L and 0.05 pH units, respectively. Temperature and salinity differences were 0.27 ° C and 0.10 psu, respectively. The LT in plume waters was reduced 5.3% during the PS period. During FS, the average reduction between plume and reference water was 1.7%. The average ZID values are calculated from measurements made over the outfalls where the effluent is actively mixing with the receiving water, and where the initial dilution process has not completed. Generally, the ZID and plume values are comparable, illustrating that even directly over the outfalls, there is no more concentrated effect from the discharge.

During the period of PS treatment at HTP, the average DO and pH at the plume depth was 0.40 mg/L and 0.03 pH units lower, respectively, in plume waters than in the reference. Likewise, the temperature was 0.39 degrees lower and the salinity was 0.15 psu lower in the plume. During the period of FS treatment, the DO and pH reductions in plume waters were 0.48 mg/L and 0.07 pH units, respectively. Temperature and salinity differences were 0.36 °C and 0.10 psu, respectively. LT in plume waters was reduced 3.7% during the PS period. During FS, the average LT reduction between plume and reference water was 0.8%. As is the case for the JWPCP, the ZID data for the HTP show that the DO and pH levels are close to the average plume levels, and show that even directly over the outfall there is no more concentrated effect.

The mean values from the analyses of the receiving water data are summarized in **Table 13** and **Table 14**. **Figure 18** graphically presents the numeric differences summarized in Table 13 and Table 14. The level of Reference DO was nearly the same at both agencies during the period of PS treatment. The relatively lower levels of DO at the plume and ZID were also comparable at both agencies in the PS period. During the FS period, despite a drop in effluent BOD (Table 3 and Table 4), the difference among the Reference and the Plume and ZID remained almost the same; however, the DO level of the reference water dropped well below the level of the PS period. In fact, the FS period reference DO levels were well below the Plume and ZID levels during PS period. The PS to FS drop in the Reference level was greater at the JWPCP than at the HTP. This may be due to intensified upwelling on the Palos Verdes Peninsula, or to the different averaging period for FS between JWPCP and HTP, while significant regional changes were occurring.

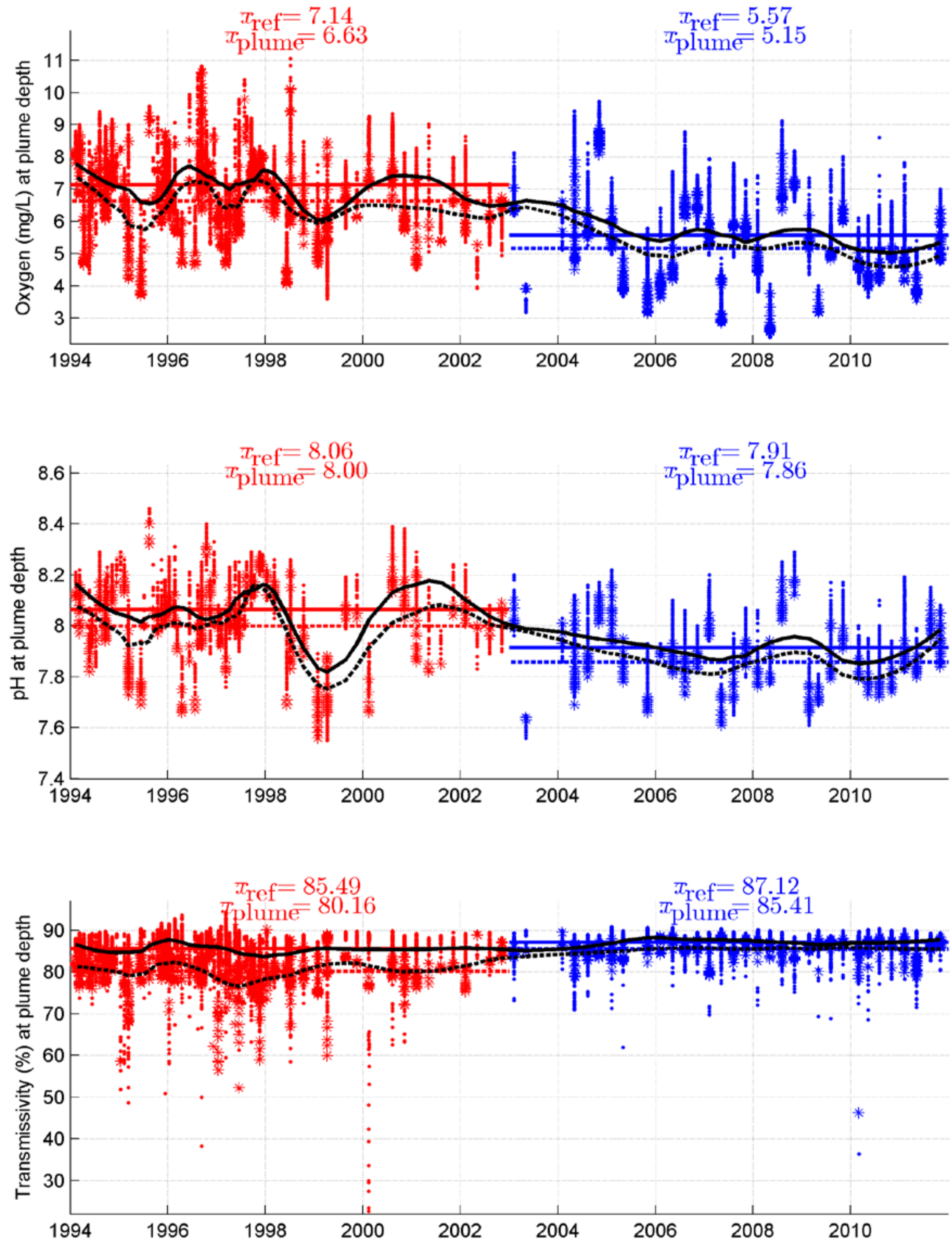


Figure 13 JWPCP Receiving Water Time Series

Reference and Plume levels of DO (mg/L), pH, and Transmissivity (%) for PS (red) and FS (blue) treatment periods. Points show all values at plume depth at all Reference and Plume sites from all surveys in each period. Moving average reference (black, solid) and plume (black dashed) lines are overlaid. Mean values of Reference (solid line) and Plume (dashed line) at plume depth are shown on each graph for PS (red) and FS (blue) treatment periods. Mean values are also labelled above each graph.

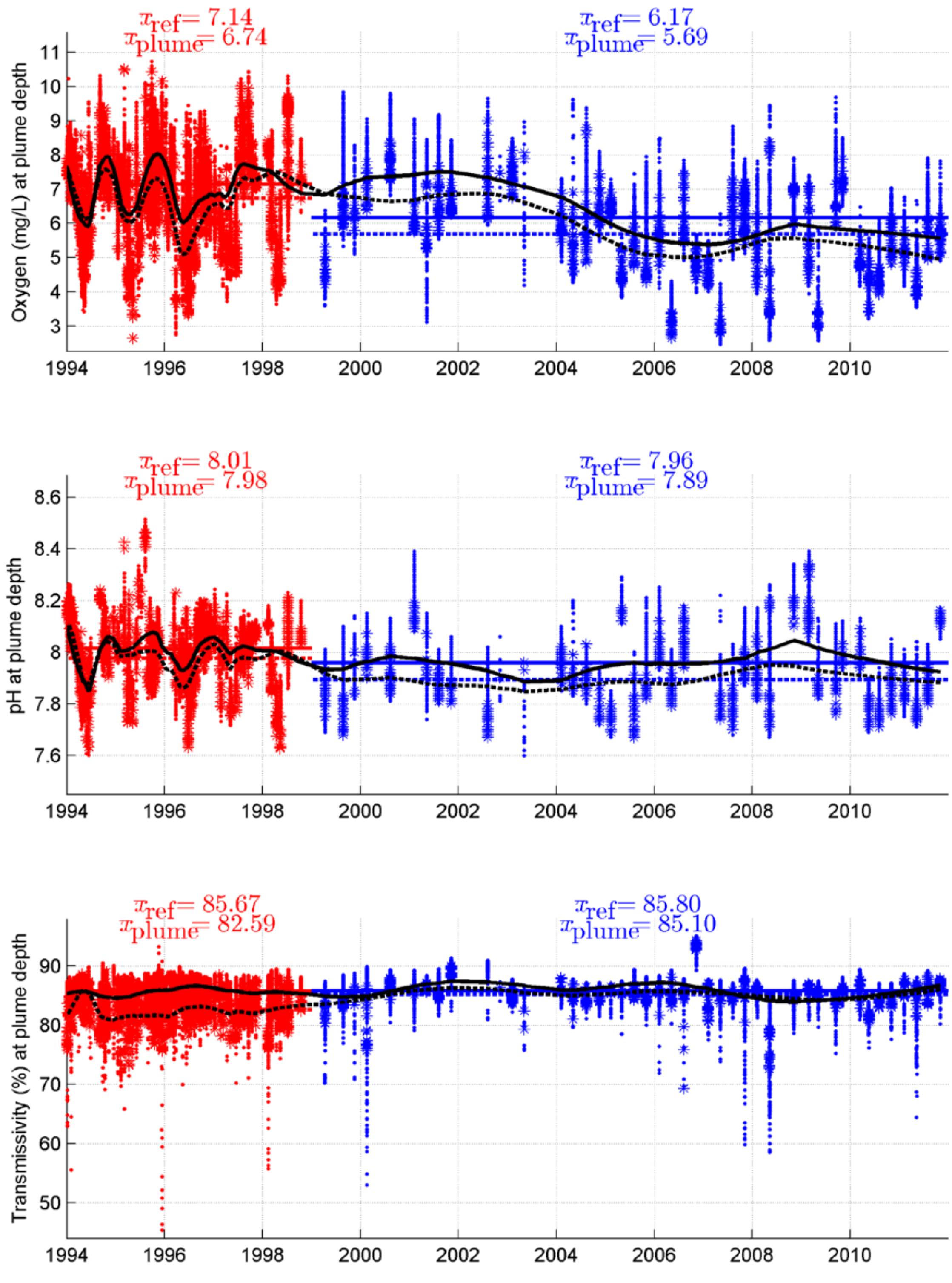


Figure 14 HTP Receiving Water Time Series

Reference and Plume levels of DO (mg/L), pH, and Transmissivity (%) for PS (red) and FS (blue) treatment periods. Points show all values at plume depth at all Reference and Plume sites from all surveys in each period. Moving average reference (black, solid) and plume (black dashed) lines are overlaid. Mean values of Reference (solid line) and Plume (dashed line) at plume depth are shown on each graph for PS (red) and FS (blue) treatment periods. Mean values are also labelled above each graph.

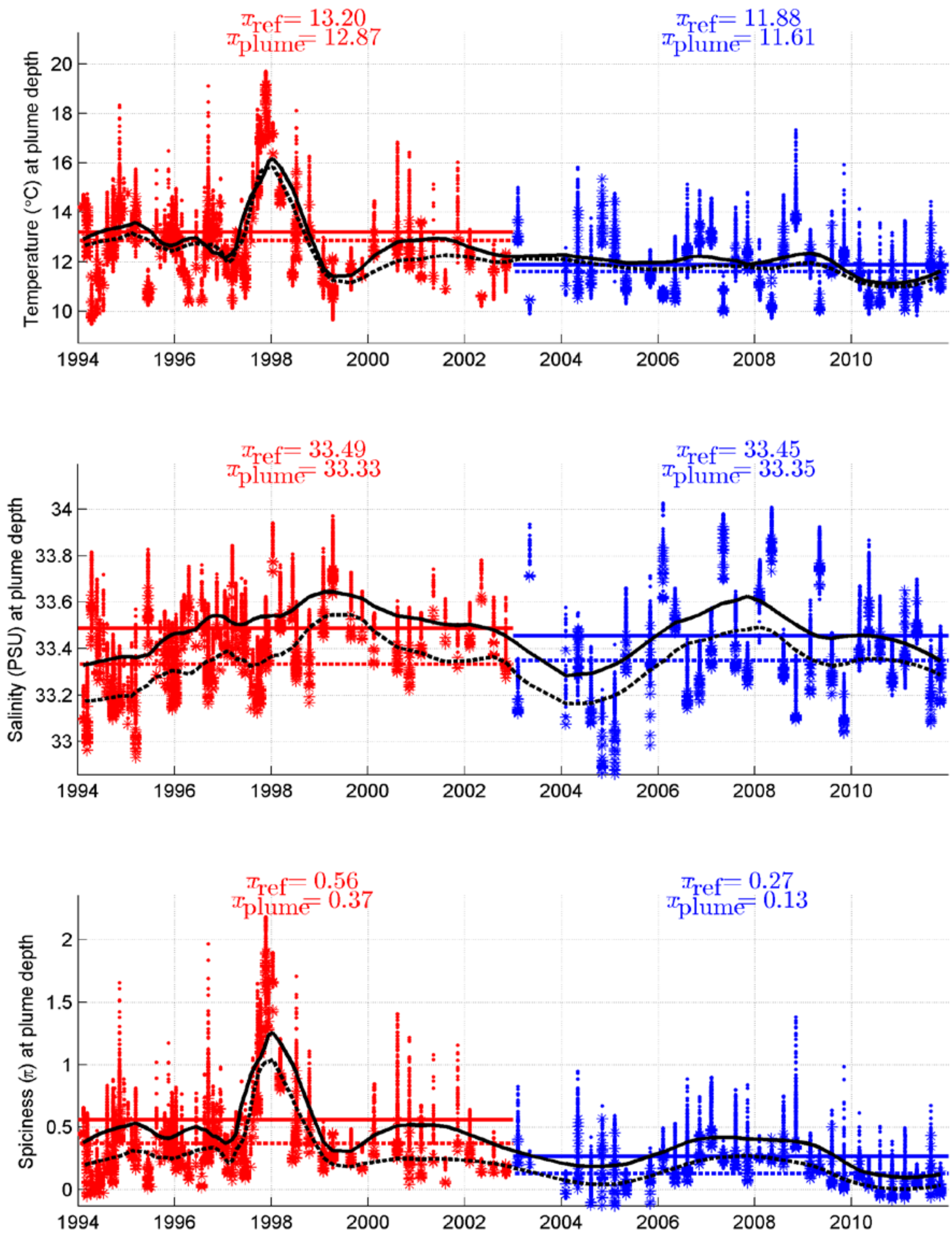


Figure 15 JWPCP Receiving Water Time Series

Reference and Plume levels of Temperature (deg C), Salinity (ppt), and Spiciness for PS (red) and FS (blue) treatment periods. Points show all values at plume depth at all Reference and Plume sites from all surveys in each period. Moving average reference (black, solid) and plume (black dashed) lines are overlaid. Mean values of Reference (solid line) and Plume (dashed line) at plume depth are shown on each graph for PS (red) and FS (blue) treatment periods. Mean values are also labelled above each graph.

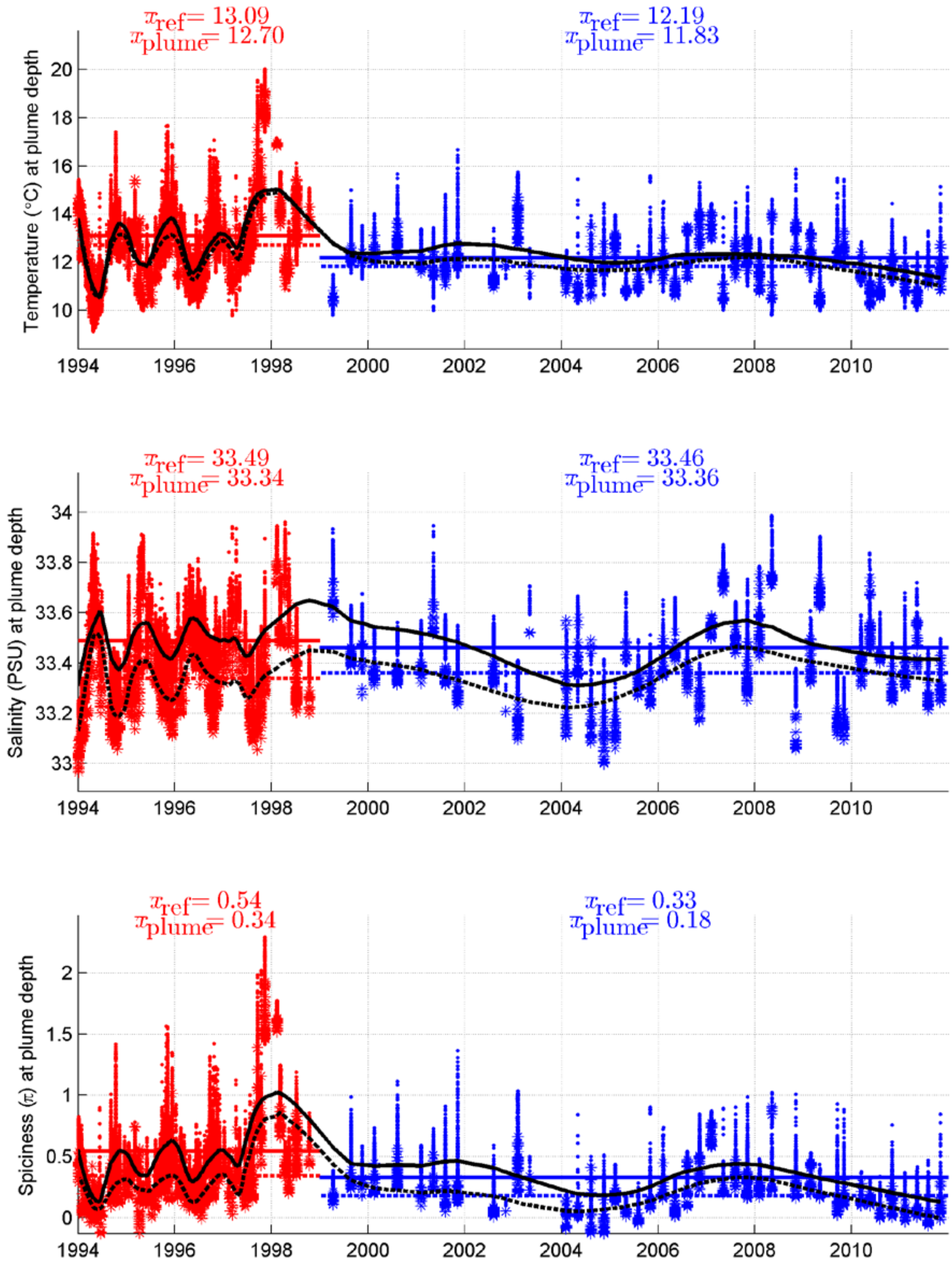


Figure 16 HTP Receiving Water Time Series

Reference and Plume levels of Temperature (deg C), Salinity (ppt), and Spiciness for PS (red) and FS (blue) treatment periods. Points show all values at plume depth at all Reference and Plume sites from all surveys in each period. Moving average reference (black, solid) and plume (black dashed) lines are overlaid. Mean values of Reference (solid line) and Plume (dashed line) at plume depth are shown on each graph for PS (red) and FS (blue) treatment periods. Mean values are also labelled above each graph.

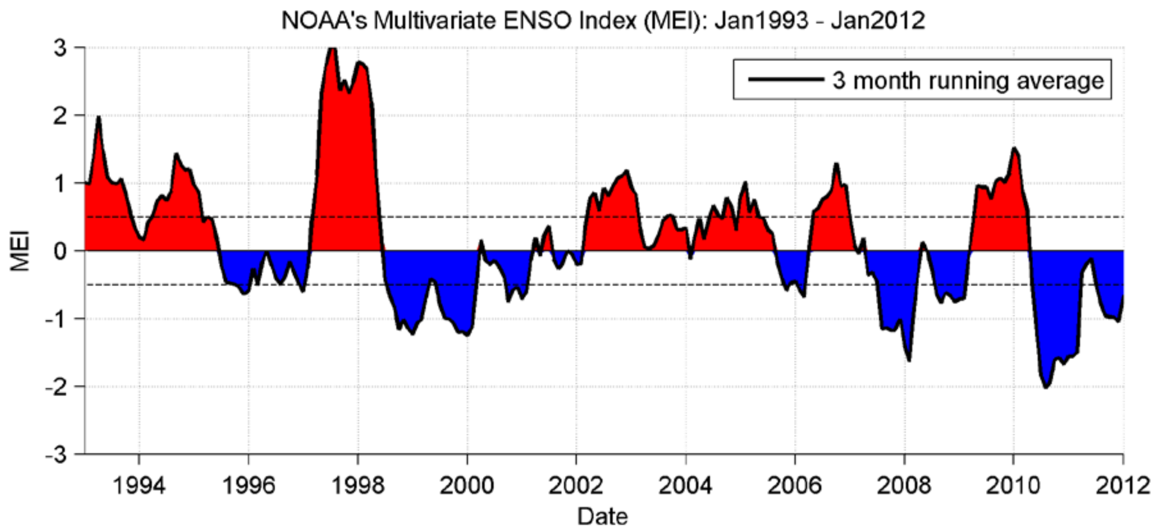


Figure 17 NOAA Multivariate ENSO Index

Three month running average of the NOAA multivariate El Niño/Southern Oscillation (ENSO) Index for the period 1993 to 2012. Negative values of the MEI (blue) represent the cold ENSO phase, a.k.a.La Niña, while positive MEI values (red) represent the warm ENSO phase (El Niño).

Table 13 JWPCP Receiving Water Statistics

Reference, plume, and ZID parameter averages for each treatment period

	PS (1994-2002)			FS (2003-2011)		
	Reference	Plume	ZID	Reference	Plume	ZID
Temperature (C)	13.20	12.87	12.83	11.88	11.61	11.74
Salinity (ppm)	33.49	33.33	33.41	33.45	33.35	33.37
DO (mg/L)	7.14	6.63	6.66	5.57	5.15	5.20
pH	8.06	8.00	8.01	7.91	7.86	7.87
LT (%T)	85.49	80.16	82.20	87.12	85.41	84.91

Table 14 HTP Receiving Water Statistics

Reference, plume and ZID parameter averages for each treatment period

	PS (1994-1998)			FS (1999-2011)		
	Reference	Plume	ZID	Reference	Plume	ZID
Temperature (C)	13.09	12.70	12.75	12.19	11.83	11.91
Salinity (ppm)	33.49	33.34	33.40	33.46	33.36	33.39
DO (mg/L)	7.14	6.74	6.64	6.17	5.69	5.79
pH	8.01	7.98	7.98	7.96	7.89	7.90
LT (%T)	85.67	82.59	83.32	85.80	85.10	85.33

Reference levels of pH were comparable between JWPCP and HTP during PS. Plume and ZID pH levels were also slightly lower than Reference. During the PS period, the reference levels of pH were lower, and in fact were lower than even the plume and ZID levels during the PS period.

Reference LT values rose between PS and FS periods at JWPCP, and the plume and ZID levels rose both in absolute terms, and also relative to the reference. At HTP, reference levels stayed constant between the PS and FS period, however the plume and ZID levels rose in the FS period. The changes in receiving water LT may reflect the reductions in effluent TSS following FS treatment at these plants.

Generally, the differences in DO and pH between the plume and reference were comparable between the PS and FS treatment periods in both JWPCP and HTP receiving waters. The implication is that the changes in treatment at JWPCP and HTP, although they had a dramatic effect on effluent DO, and a lesser effect on effluent pH, did not have a measurable effect in the receiving water. On the other hand, small changes in the amount of difference between reference and plume receiving water LT may reflect that receiving water monitoring did detect a small response due to the reduced TSS from increased treatment.

Estimates of Entrainment

The chemical effects. A similar effect would be found even if the discharge was nutrient free, potable water with no oxygen demand, and a pH equivalent to the receiving water. The effect is due to the buoyant nature of fresh water released into denser saline waters. As described below, the average entrainment contribution is estimated by looking at the temperature to DO and pH relationship of the reference receiving water between the discharge depth and the plume depth.

The reference water data in the depth range between the plume depth (variable with a mean: ~40m) and outfall discharge depth (~60m) was isolated and the average temperature difference and relationship of temperature to DO and pH were calculated. Gathering the average difference in DO and pH between water at those different depths at the reference stations allowed for an estimate of changes in those parameters associated with the chemical properties of the plume rather than physical entrainment of cooler, deeper water. For JWPCP, during 2003-2011, average DO of the plume water is 0.42 mg/L lower than the reference (5.57 - 5.15 mg/L) and the temperature is 0.27°C lower (11.88 – 11.61°C). The reference (at plume depth) to pipe depth differences in DO and temperature are 0.59 mg/L and 0.65°C, respectively. The average entrainment contribution is estimated to be 0.27 * (0.59/0.65) = 0.24 mg/L, which equates to 0.24/0.42 or 57% of the average plume DO reduction and leaves on average 0.18 mg/L or 43% unexplained DO reduction.

For HTP, 2003-2011, average DO of the plume water is 0.49 mg/L lower than the reference (6.17 - 5.69 mg/L). The temperature is 0.35 °C lower (12.19 – 11.83°C). The reference (at plume depth) to pipe depth differences in DO and temperature are 1.25 mg/L and 1.17°C, respectively. The average entrainment contribution is estimated to be 0.35 * (1.25/1.17) = 0.38 mg/L, which equates to 0.38/0.49 or 78% of the average plume DO reduction and leaves on average 0.11 mg/L or 22% unexplained DO reduction.

For JWPCP, pH average entrainment 0.27 * (0.06/0.65) = 0.025 pH units, equating to 0.025/0.06 = 42% of average plume pH reduction, and leaves on average 0.035 pH units or 58% of the reduction unexplained. For HTP, pH average entrainment 0.35 * (0.12/1.17) = 0.035 pH units, equating to 0.035/0.07 = 50% of average plume pH reduction, and leaves on average 0.035 pH units or 50% of the reduction unexplained.

The COP includes a standard that DO should not be reduced by more than 10%. The residual unexplained DO reductions after entrainment are 0.18 mg/L at JWPCP and 0.11 mg/L at HTP, and equate to 3% and 2% reductions, respectively relative to the reference DO. The COP standard for pH states that pH should not be altered more than 0.2 units. The residual unexplained change in pH at JWPCP and HTP is only 0.035 pH units. Methods to estimate entrainment are currently being refined by the Water Quality Compliance Committee for wastewater discharges in the Southern California Bight.

Spatial Patterns of Plume after FS

To look for potential effects of the discharge on the receiving water, the complete offshore data set of receiving water data collected during the period 2003-2011, when both JWPCP and HTP had FS treatment, were averaged for all 1-m depth intervals at every sampling site (Figure 1 upper map and Figure 2 upper map). These data were then plotted as depth versus distance transects to show the spatial patterns. To look more closely for a discharge effect, an overall average profile, built by averaging the same depths from all the averaged sites was

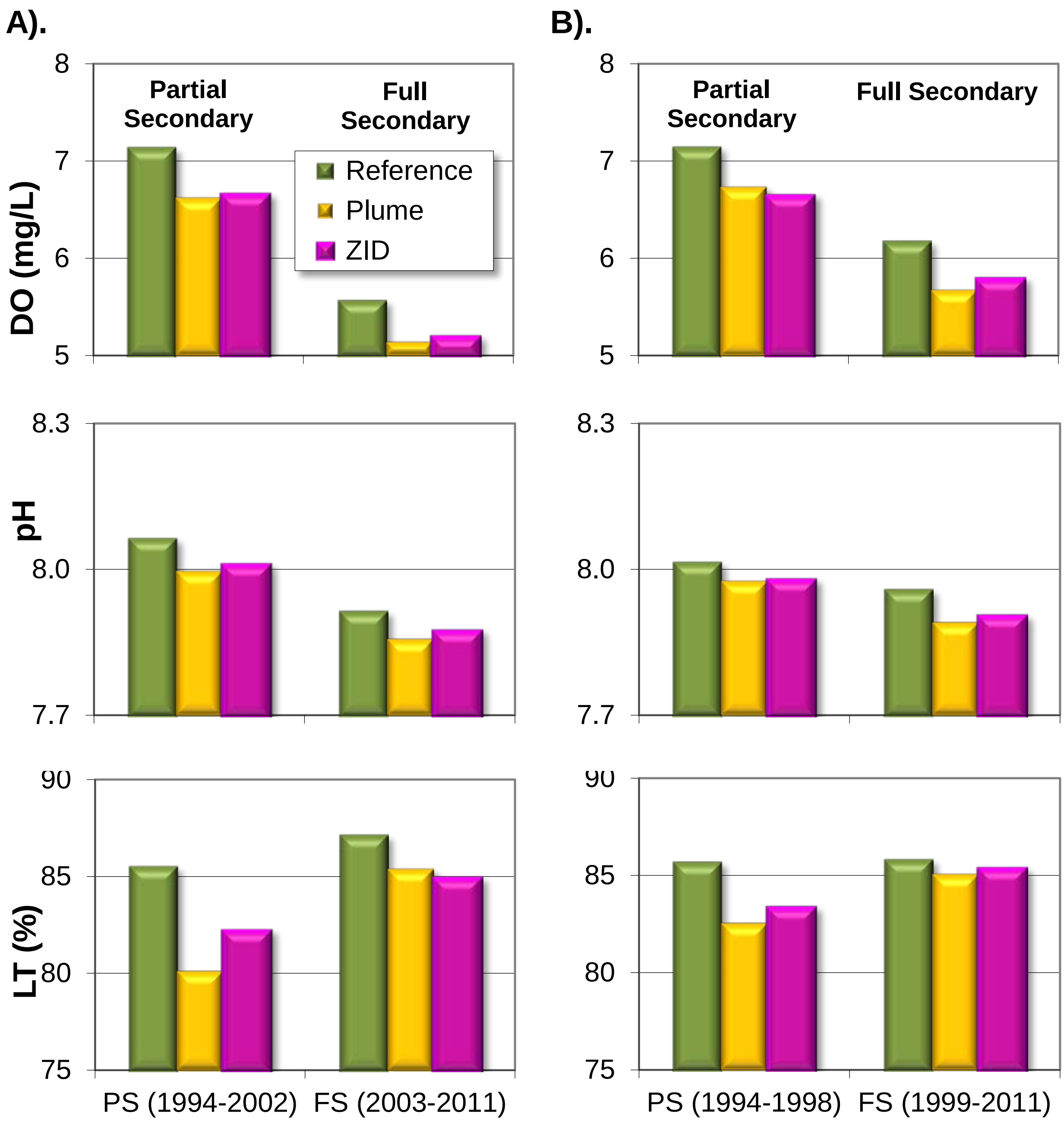


Figure 18 JWPCP and HTP receiving water properties by Treatment Period
Reference, Plume, and ZID levels of DO (mg/L), pH and LT (%) for PS and FS time periods in JWPCP (A) and HTP (B) receiving waters. Plotted using numeric data in Table 13 and Table 14.

subtracted from the mean in order to calculate local anomalies and features. The data distributions, absolute anomaly, and percent anomaly of each parameter are plotted on an alongshelf and two cross-shelf transects using sites that include the ZID site nearest the outfall diffuser. Typically, the plots of the average data distribution for DO, pH and LT do not show any plume associated feature. However, the anomaly plots may show a plume feature, usually located over the ZID. The anomaly data are plotted using the same units as the original data, but at a tighter scale intended to enhance the anomaly features. For example, the DO data distribution is plotted on a scale from 3 mg/L to 9 mg/L to show the range of values in the stratified water column, while the DO anomaly is plotted on a narrower scale from -1 mg/L to +1 mg/L to emphasize the anomaly features.

Reductions in levels of DO and pH in the plume water are often the result of entrainment of naturally stratified receiving water by the buoyant effluent. In these cases, the differences in the DO and pH between the plume and reference are an indirect effect of the discharge, an impact due to upward displacement of naturally stratified receiving water by the buoyant effluent.

The average distribution patterns of DO, pH and LT are also influenced by proximity to the coast and the seafloor (in the case of the cross-shelf plots), and by natural gradients along the coastline (in the case of the alongshore plots), and by features that arise due to the circulation patterns of the ambient currents around the highly variable subsurface topography of the region.

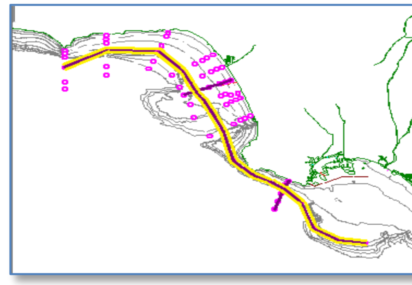
Figure 19 plots average surface to 60m distribution patterns of salinity, CDOM, and ammonia; all tracers for the effluent plume, on an 84-km alongshore transect that as shown in the inset map, links 17 receiving water sites. The receiving water sites are labeled at the top of each graph. Two sites highlighted in red, represent the ZID (outfall) sampling points for HTP (Site 3505) and JWPCP (Site 2903). While the salinity and CDOM distribution patterns are generated from 1-meter vertical interval data from the surface to the bottom, the ammonia distribution patterns are generated from four discrete samples collected between the surface and a maximum depth of 45m, and therefore the ammonia distribution patterns only extend to 45m. All three tracer variables clearly identify a core feature of each effluent plume directly over each ZID site. This feature is generally restricted to the mid-depths between 20 and 40 meters below the surface. Both plume features also extend several kilometers horizontally to sites up and downcoast. Cross-shelf patterns of the same three tracer variables, plotted using the same scales, are shown in **Figure 20**. These transects are perpendicular to the coast, with one crossing the HTP ZID site, and the second crossing the JWPCP ZID site. Sites are labeled at the top of each transect, and the ZID sites are highlighted in red. The inset map shows the locations of each cross-shelf transect. Ammonia data are limited to a maximum depth of 45m, and these transects are limited because ammonia samples are not collected at the most inshore or furthest offshore sites. In the cross-shelf transects, a plume feature is clearly apparent, centered over each ZID site. The cross-shelf transects extend much shorter distances, about 10 kilometers and 8 kilometers for the HTP and JWPCP transects, respectively. When the actual distances are factored, it is apparent that the average plume is roughly ten-fold or more elongated parallel to the coast versus across the shelf.

Figure 21 plots the distribution of DO, the DO absolute anomaly, and the percent DO anomaly along the same alongshore transect, using the 2003-2011 average data. The color scale maps the concentration of DO in milligrams per liter (mg/L). Lower DO levels are redder and higher DO levels are blue. On the second row, the calculated absolute anomaly is plotted, also using mg/L units. On the anomaly plots, red colors show the areas where the anomaly is below the average, and blue colors show where the anomaly is higher than average. Note that the anomaly scale was intentionally plotted over a narrow range of -1 to +1 mg/L to emphasize the patterns. On the third row the percent anomaly is plotted, also using red to show areas with a percent reduction compared to the mean, and blue to identify areas above the mean. **Figure 22** uses the same color scales and ranges to show the cross-shelf distributions of the DO, the DO absolute anomaly and the percent DO anomaly.

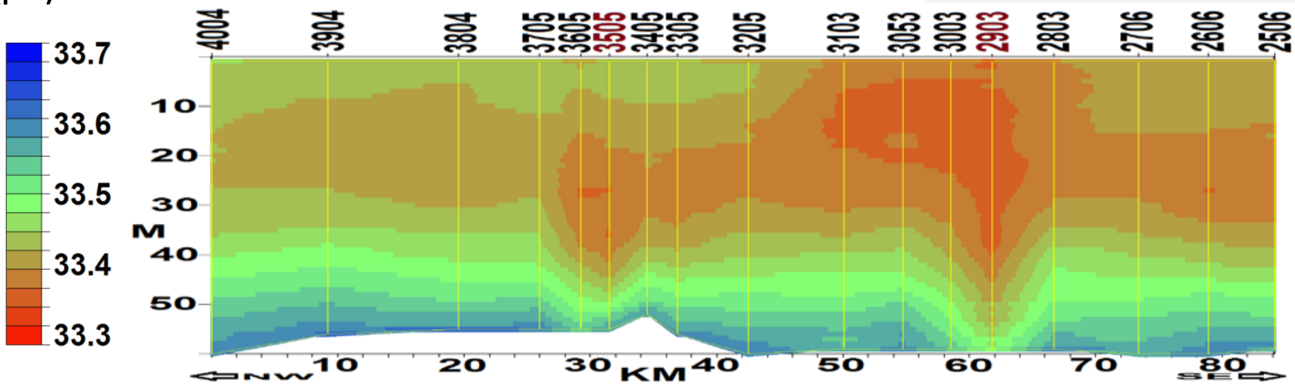
Figure 23 plots the distribution of pH, the pH absolute anomaly, and the percent pH anomaly. The color scale maps the level of pH. Lower pH levels are redder and higher pH levels are blue. On the second row, the calculated absolute anomaly is plotted, also using pH units. On the anomaly plots, red colors show the areas where the anomaly is below the average, and blue colors show where the anomaly is higher than average. The anomaly scale was intentionally plotted over a narrow range of -0.2 to 0.2 pH units to emphasize the patterns. On the third row, the percent anomaly is plotted, also using red to show areas with a percent reduction compared to the mean, and blue to identify areas above the mean. **Figure 24** uses the same color scales and ranges to show the cross-shelf distributions of the pH, the pH absolute anomaly, and the percent pH anomaly.

Figure 25 plots the distribution of LT, the LT absolute anomaly, and the percent LT anomaly. The color scale maps the level of LT. Lower LT levels are redder and higher LT levels are blue. On the second row, the calculated absolute anomaly is plotted, also using LT (%) units. On the anomaly plots, red colors show the areas where the anomaly is below the average, and blue colors show where the anomaly is higher than average. The anomaly scale was intentionally plotted over a narrow range of -8 to 8 LT (%) units to emphasize the patterns. On the third row, the percent anomaly is plotted, also using red to show areas with a percent reduction compared to the mean, and blue to identify areas above the mean. **Figure 26** uses the same color scales and ranges to show the cross-shelf distributions of the LT, the LT absolute anomaly, and the percent LT anomaly.

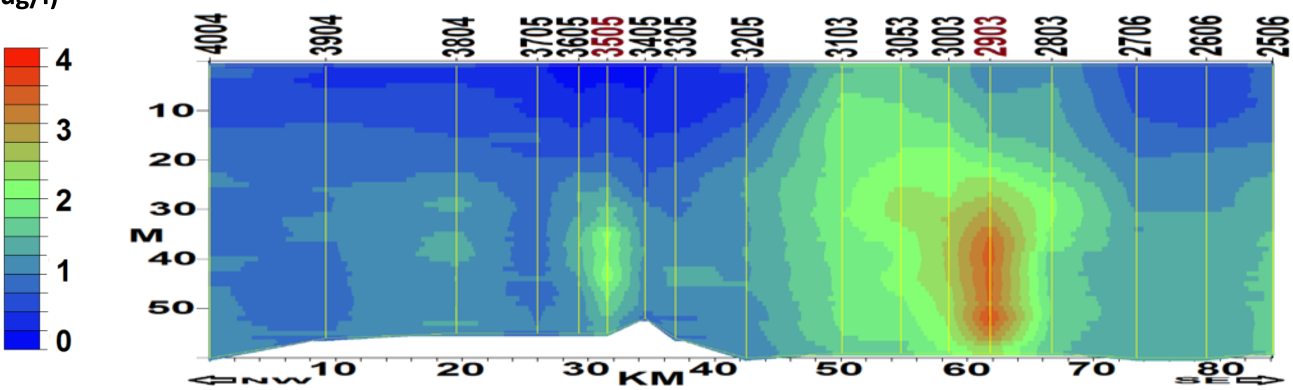
Effluent Plume Tracers– Alongshelf Patterns



Salinity
(psu)



CDOM
(ug/l)



Ammonia
(mg/L)

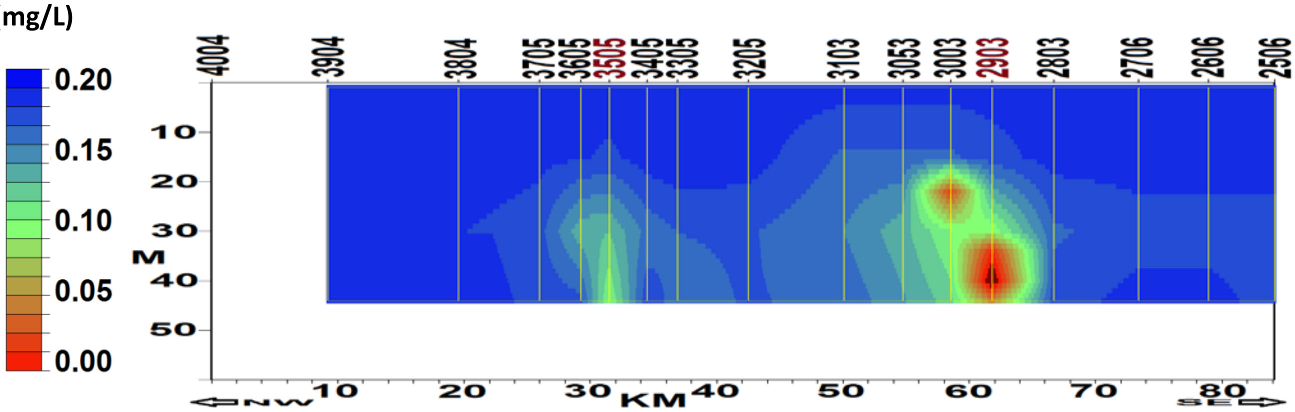
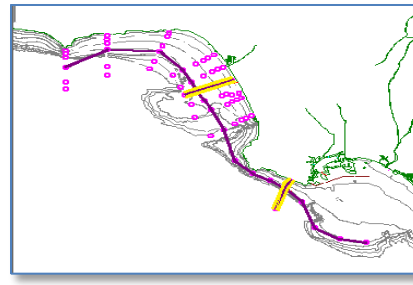


Figure 19 Alongshelf Transects of Salinity, CDOM, and Ammonia
Average 2003-2011 Salinity (psu), CDOM (ug/L), and ammonia (mg/L) receiving water data plotted on a coast paralleling transect connecting 17 sites including ZID sites over the HTP (3505) and JWPCP (2903) outfalls.

Effluent Plume Tracers – Cross-Shelf Patterns



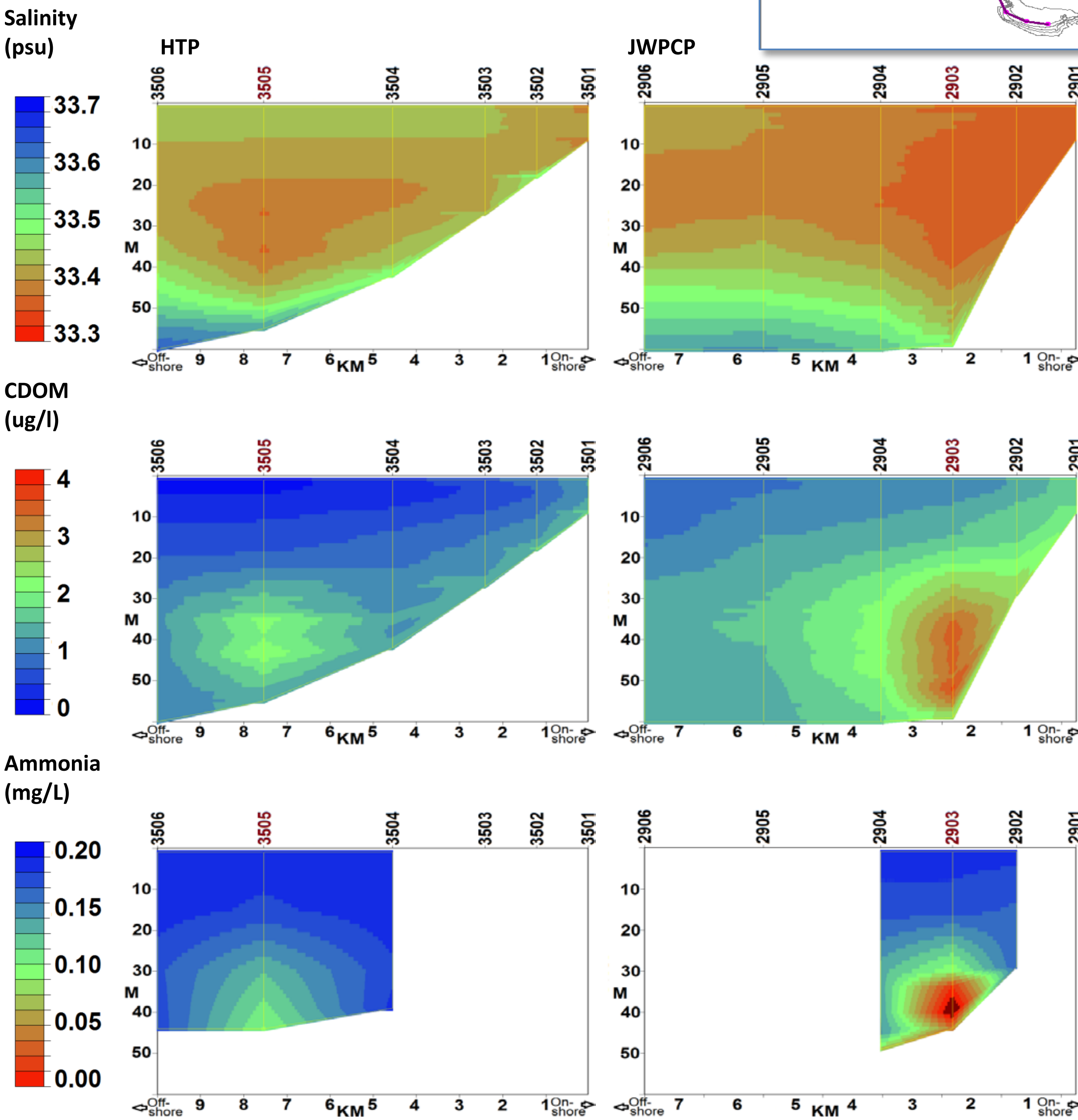
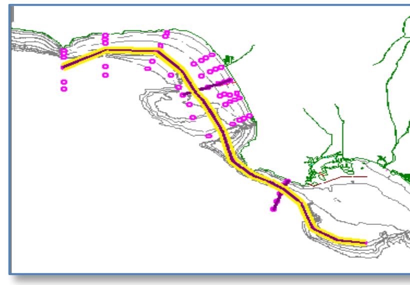


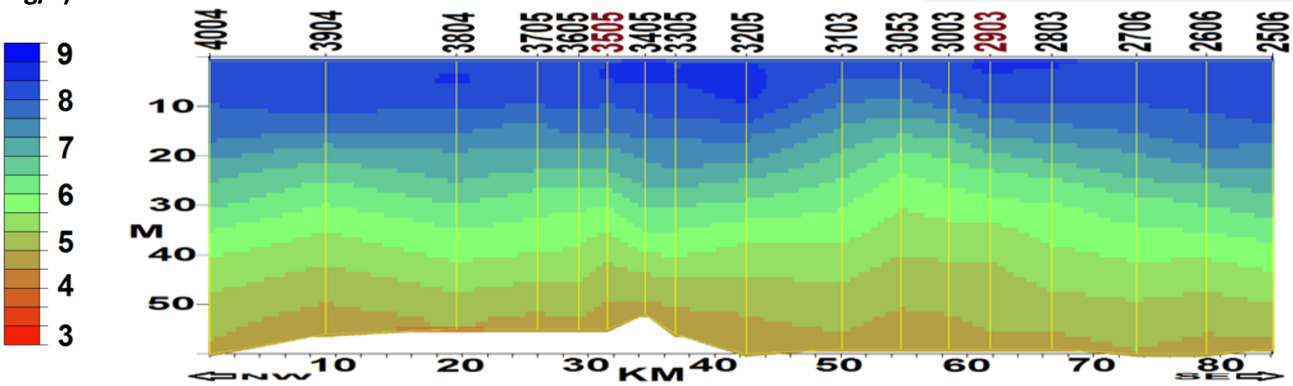
Figure 20 Cross-shelf Transects of Salinity, CDOM, and Ammonia

Average 2003-2011 Salinity (psu), CDOM (ug/L), and ammonia (mg/L) receiving water data plotted on cross-shelf transects perpendicular to the coast, that include ZID sites over the HTP (3505) and JWPCP (2903) outfalls.

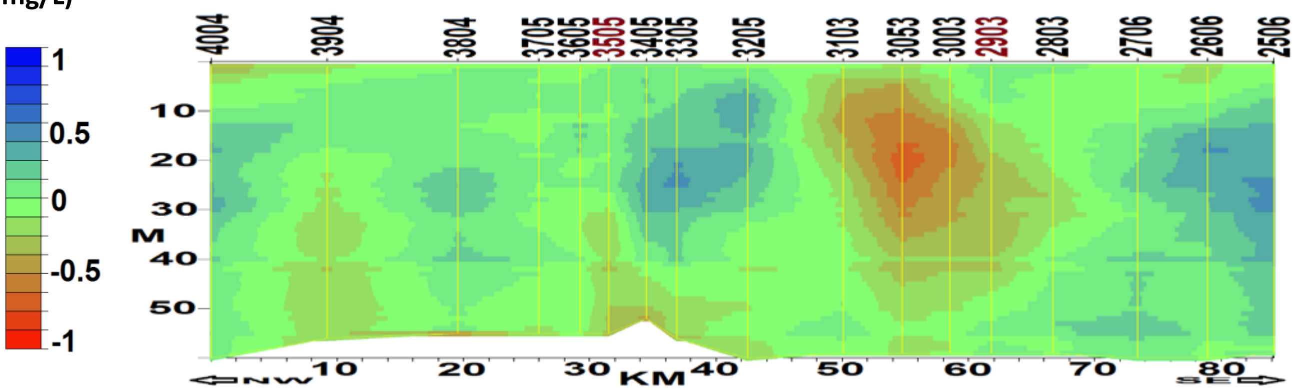
Dissolved Oxygen – Alongshelf Patterns



Distribution (mg/L)



Absolute Anomaly (mg/L)



Percent Anomaly (%)

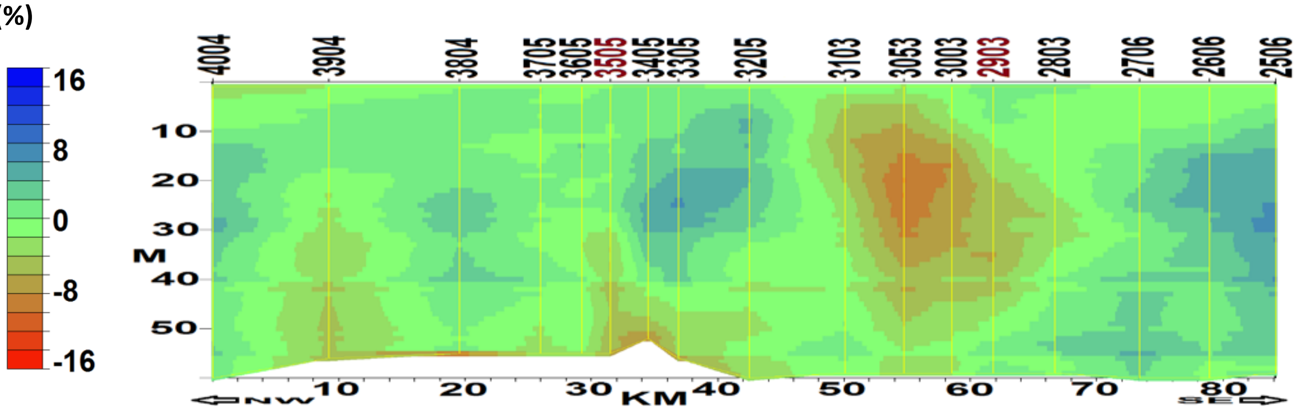
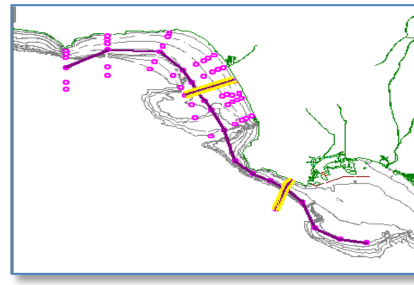


Figure 21 Alongshelf Transects of DO, Absolute Anomaly, and % Anomaly

Average 2003-2011 DO, absolute anomaly, and % anomaly receiving water data plotted on a coast paralleling transect connecting 17 sites including ZID sites over the HTP (3505) and JWPCP (2903) outfalls.

Dissolved Oxygen – Cross-shelf Patterns



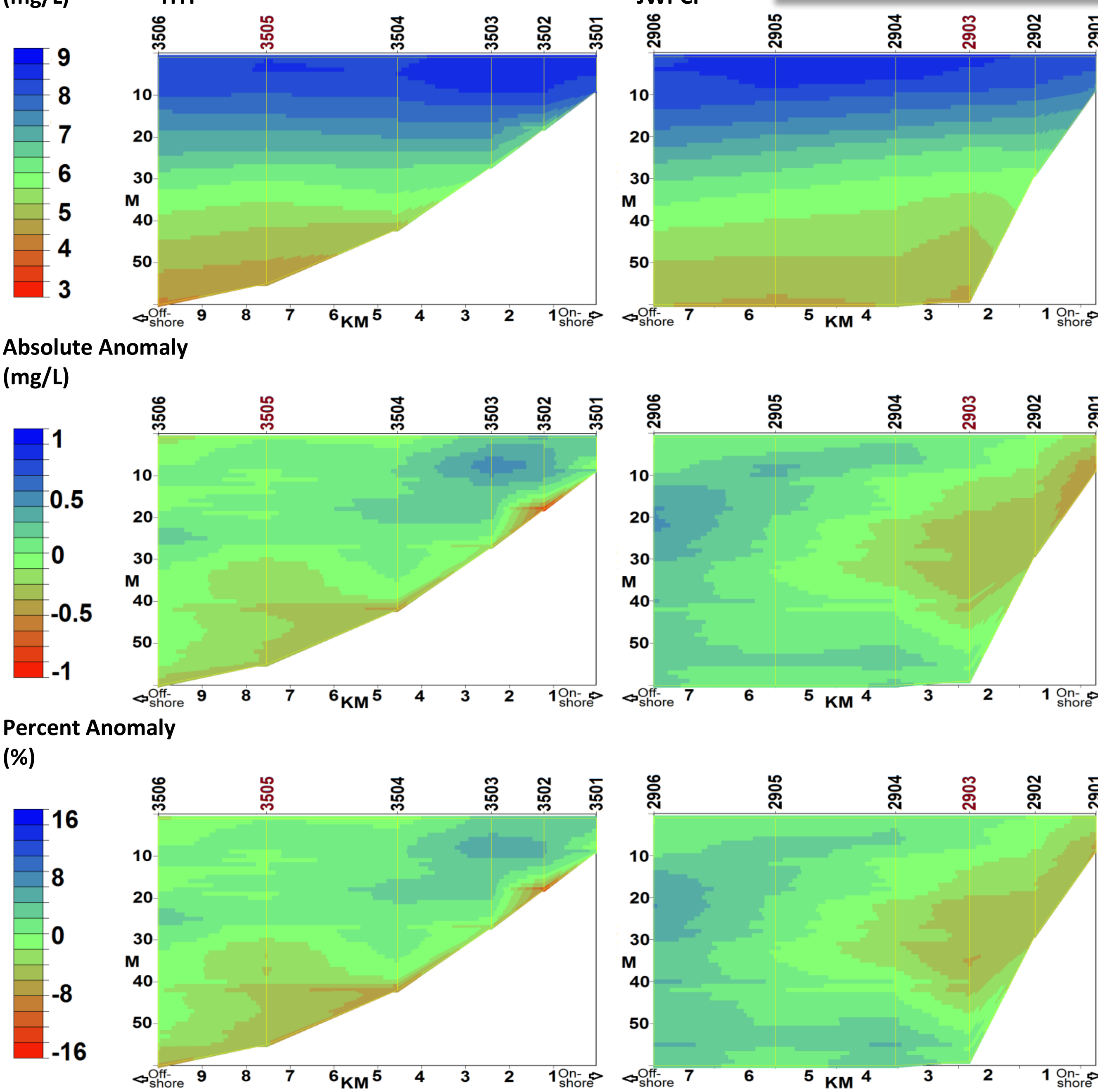
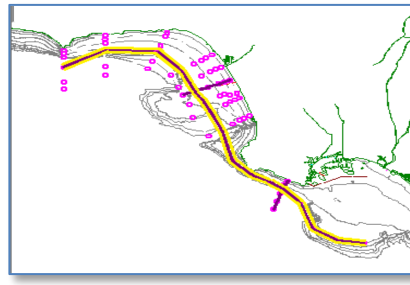


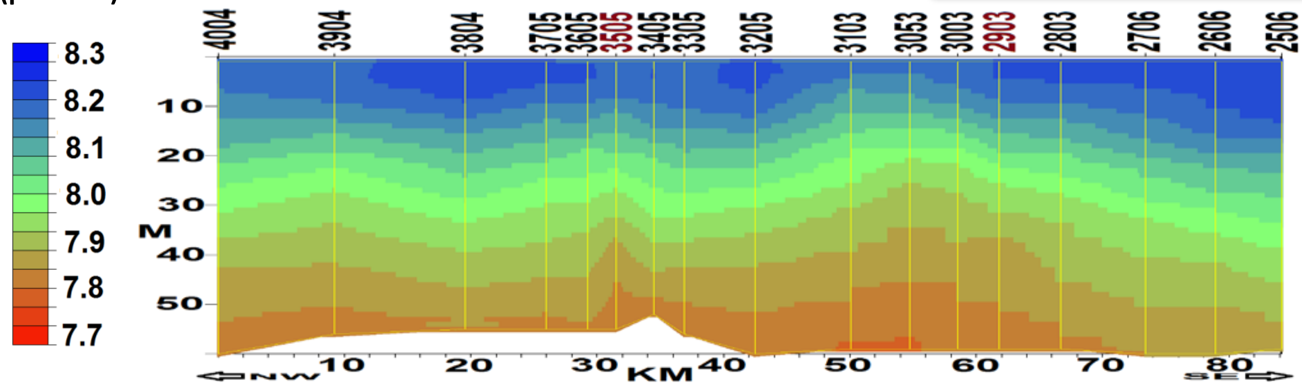
Figure 22 Cross-shelf Transects of DO, Absolute Anomaly, and % Anomaly

Average 2003-2011 DO, absolute anomaly, and % anomaly receiving water data plotted on cross-shelf transects perpendicular to the coast, that include ZID sites over the HTP (3505) and JWPCP (2903) outfalls.

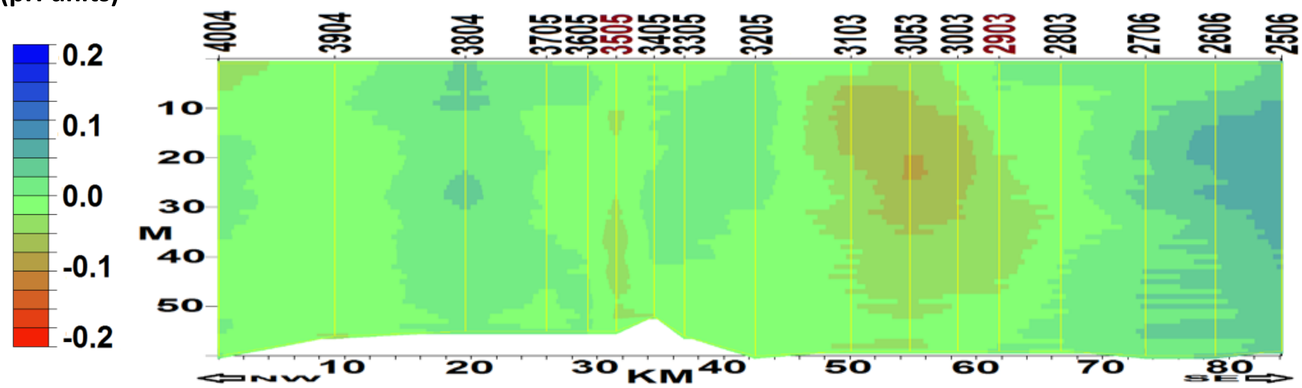
pH – Alongshelf Patterns



Distribution
(pH units)



Absolute Anomaly
(pH units)



Percent Anomaly
(%)

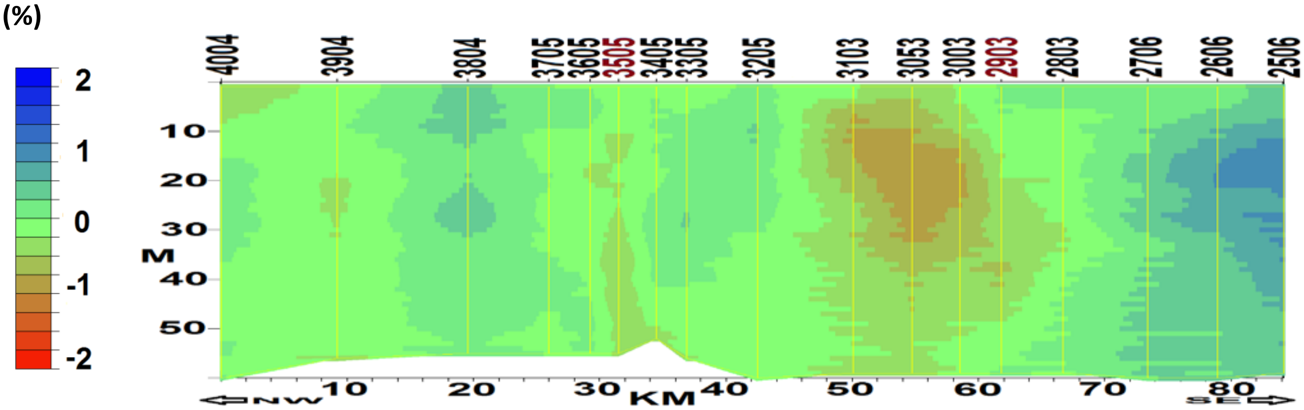
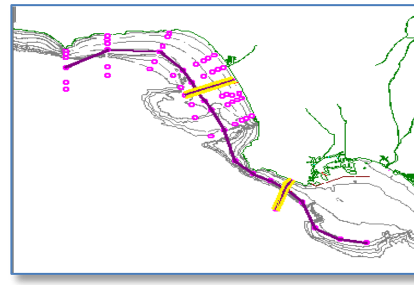


Figure 23 Alongshelf Transects of pH, anomaly, and % Anomaly

Average 2003-2011 pH, anomaly, and % Anomaly receiving water data plotted on a coast paralleling transect connecting 17 sites including ZID sites over the HTP (3505) and JWPCP (2903) outfalls.

pH – Cross-shelf Patterns



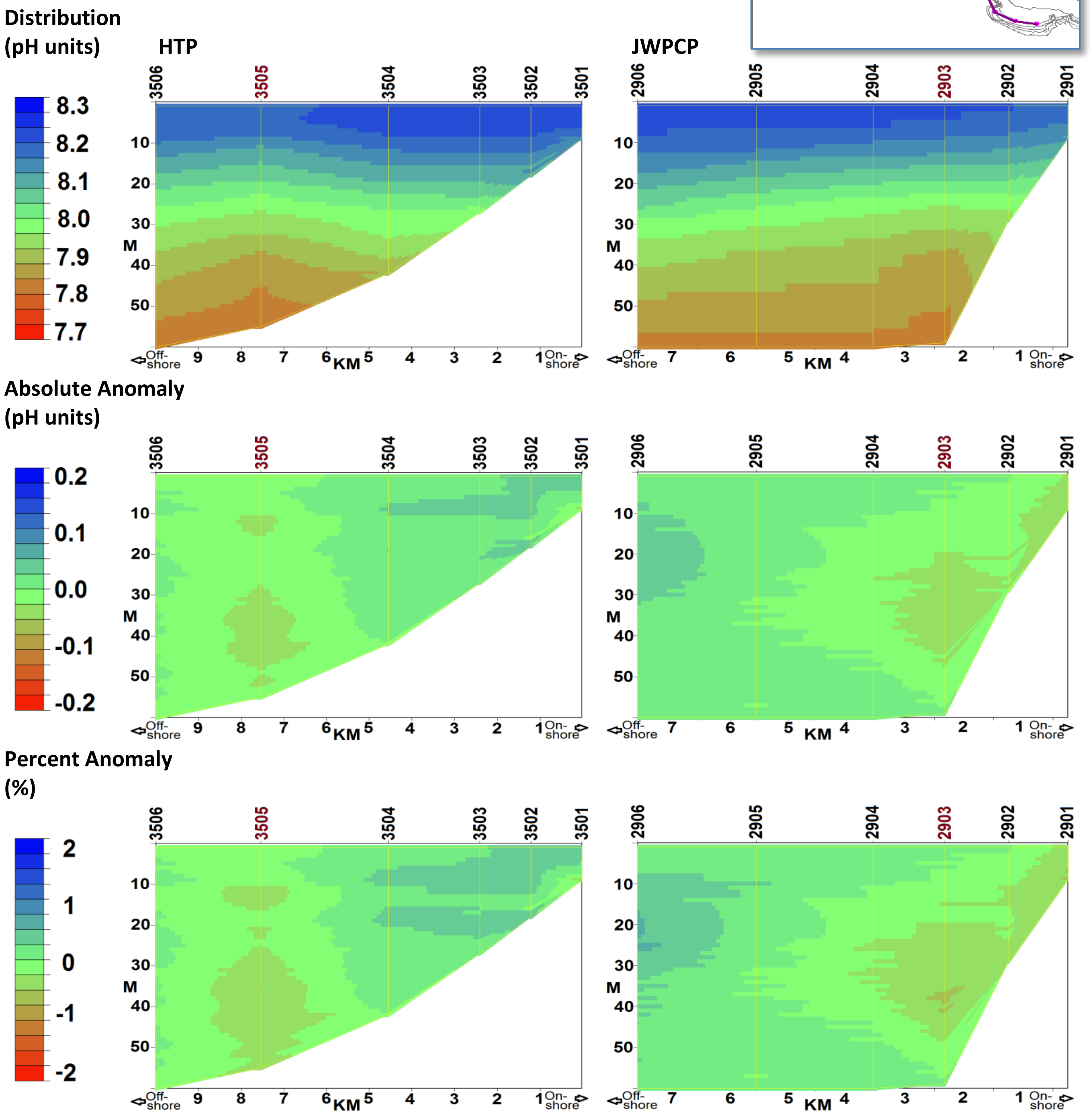
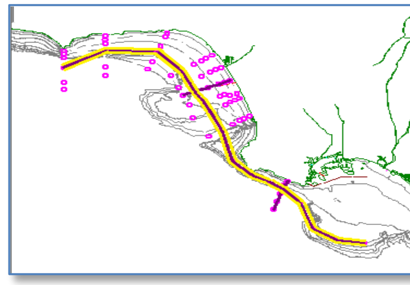


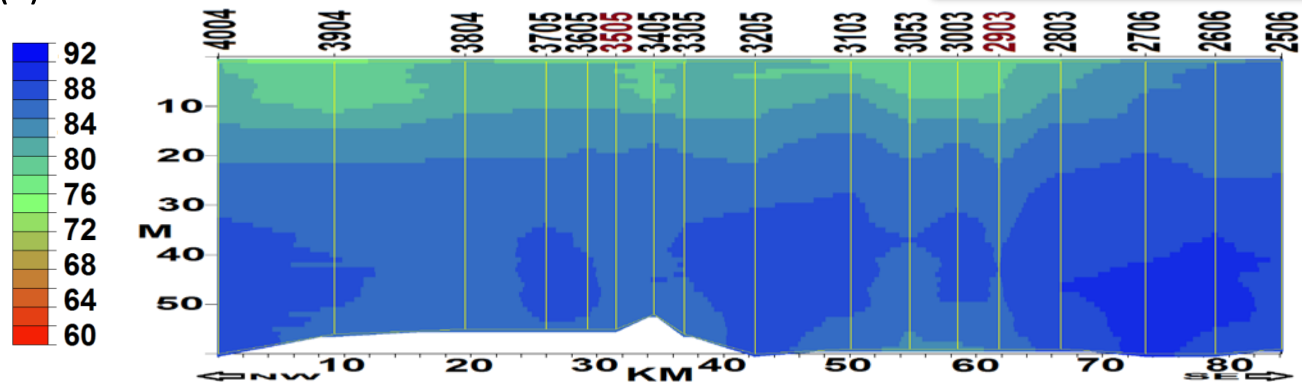
Figure 24 Cross-shelf Transects of pH, anomaly, and % Anomaly

Average 2003-2011 pH, anomaly, and % Anomaly receiving water data plotted on cross-shelf transects perpendicular to the coast, that include ZID sites over the HTP (3505) and JWPCP (2903) outfalls.

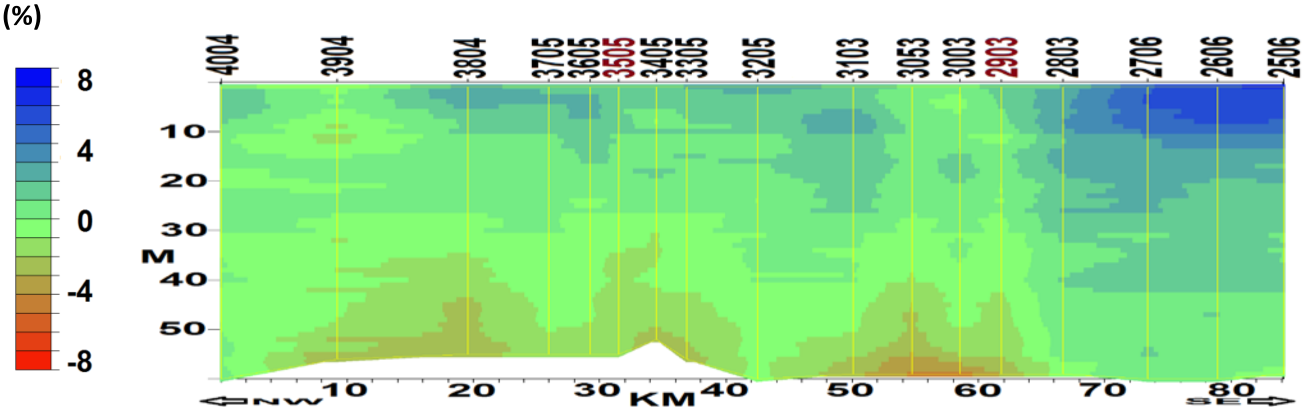
Light Transmissivity – Alongshelf Patterns



Distribution
(%)



Absolute Anomaly
(%)



Percent Anomaly
(%)

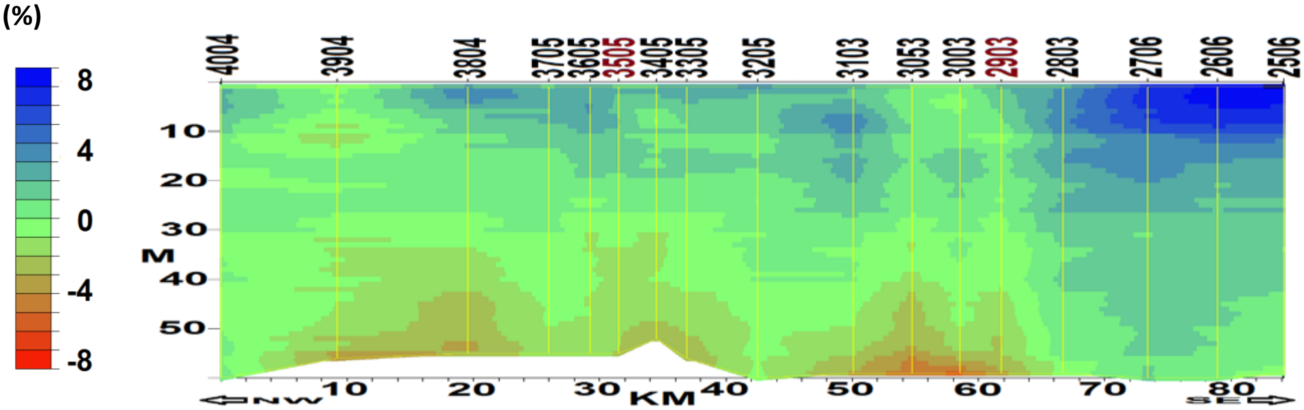
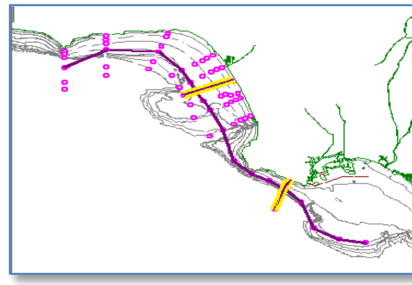


Figure 25 Alongshelf Transects of LT, Absolute Anomaly, and % Anomaly
Average 2003-2011 LT, Absolute Anomaly, and % Anomaly receiving water data plotted on a coast paralleling transect connecting 17 sites including ZID sites over the HTP (3505) and JWPCP (2903) outfalls.

Light Transmissivity – Cross-shelf Patterns



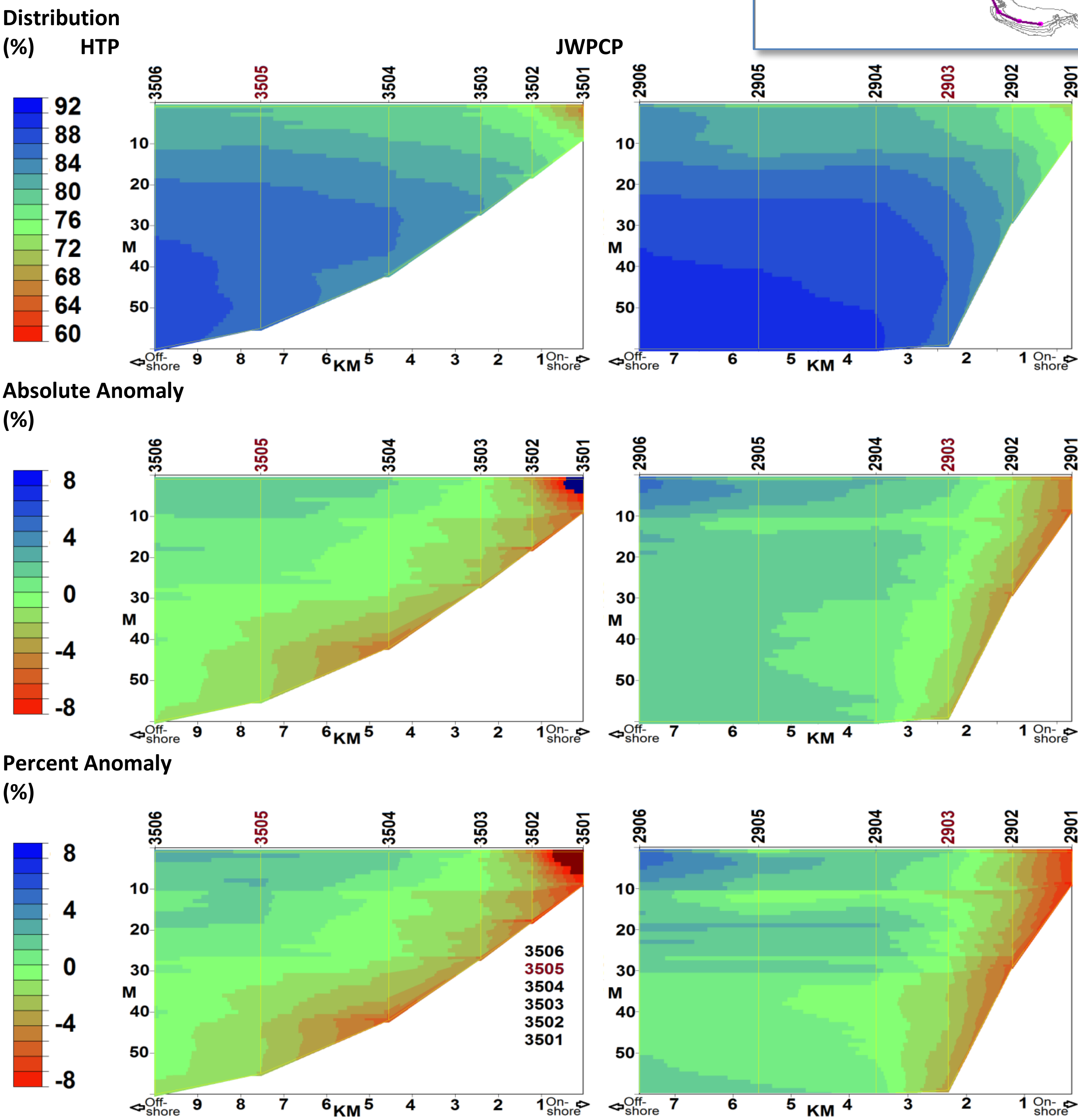


Figure 26 Cross-shelf Transects of LT, Absolute Anomaly, and % Anomaly

Average 2003-2011 LT, Absolute Anomaly, and % Anomaly receiving water data plotted on cross-shelf transects perpendicular to the coast, that include ZID sites over the HTP (3505) and JWPCP (2903) outfalls.

DISCUSSION

History of SCB Nutrient Discharges from POTWs

Both the HTP and JWPCP plants have discharged through the same deep water ocean outfall diffusers since 1959 and the late 1960s, respectively, and due to dramatic improvements in water conservation, effluent flow volumes, after peaking in the late 1980s, are currently at the same levels as they were over 50 years ago, despite a growing population. The earliest accurate and detailed records of the effluent properties of SCB POTWs (SCCWRP, 1974) document effluent properties, including nutrient MERs from 1971. Between 1971 and 2011, the combined JWPCP and HTP flow has declined from 703 mgd to 540 mgd, a 23% reduction. Over the same 40-year period, combined JWPCP and HTP effluent quality improved significantly; with TSS reduced from a flow-weighted average of 222 mg/L to 16 mg/L, a 93% reduction, and BOD reduced from 191 to 10 mg/L, a 95% reduction.

Nutrient discharges are also significantly lower than they were 40 years ago. In 1971, the HTP discharged sludge through a 7-mile line – and nutrients in this stream were not characterized. So, for this comparison, the 1971 values were estimated by first calculating a total discharge flow and TSS, and then estimating nutrient values by substituting JWPCP effluent values with adjustments for the flow and for the "strength" of the HTP effluent based on the ratio of TSS.

Between 1971 and 2011, the total nitrogen MER for JWPCP and HTP declined 65%, from 92,663 mtons/yr to 32,151 mtons/yr, and the total phosphate MER for JWPCP and HTP declined 89%, from 38,314 mtons/yr to 4,107 mtons/yr. In fact, nutrient discharges from these plants are lower today than they were at the advent of the use of deep offshore diffusers in the 1950s and 1960s. In 1971, the JWPCP and HTP flow accounted for the majority (73%) of the 967 mgd combined total ocean discharge of the five large SCB POTWs (SCCWRP, 1974).

As described above, major reductions in nutrient MERs occurred prior to the 1994 to 2011 period addressed in this Report. Those historical changes are associated with the introduction of the CWA, the establishment of industrial pre-treatment programs, the introduction of advanced primary, and then partial secondary treatment, and by growing efforts to conserve, and where possible, reuse water. During the years 1994 to 2011, as both plants further increased treatment from PS to FS, average effluent MERs of nutrients in each treatment period were compared. The JWPCP had a small reduction in total nitrogen MER between PS and FS, of 9%, which is consistent with long term declining trends in both flow and nitrogen. The HTP saw a 9% increase in total nitrogen, and an 18% increase in ammonia nitrogen. Further investigation suggests that in-plant process changes to enhance biosolids quality to meet "Class A" standards, probably explain these increases in nitrogen at HTP. The initiation of FS reduced the MER of phosphate in JWPCP and HTP effluent by 78% and 33%, respectively. In 2011, 92% of JOS and 64% of CLA total phosphate was diverted to biosolids.

Distribution and Fate of Nutrients

In the process of FS treatment, roughly 98% of the solids are removed from the JWPCP influent. These solids are anaerobically digested and dewatered before being trucked offsite for disposal by landfilling, land-application, or composting. The Sanitation Districts measures the levels of nutrients in the biosolids. In 2011, the JWPCP produced 114,455 dry metric tons of biosolids. By comparing the tonnage of nutrients in the biosolids with the MER of nutrients in the JWPCP effluent and the WRP effluent, it was determined that 68% of total nitrogen went to the ocean, 27% went to various biosolids disposal end points, and 5% was discharged under NPDES permits to recycling uses and in NPDES-permitted discharges to inland waterways. By contrast, 92% of total phosphate went to biosolids, with only 7% sent to the ocean, and 1% to inland waterways. In 2011, the HTP produced 63,159 dry metric tons of biosolids. Overall, 82% of total nitrogen went to the ocean, 15% went to various biosolids disposal end points, and 2% was discharged under NPDES permits to inland waterways. By comparison, 64% of total phosphate went to biosolids, with 35% sent to the ocean, and 1% to inland waterways.

Water Recycling

Approximately one third of the wastewater collected in the JOS is distributed among six inland WRPs, where the water is tertiary treated and also, since circa 2000, subject to NDN treatment, which reduces nitrogen levels. Subsequently, this water is either beneficially reused – primarily for irrigation or groundwater replenishment, or is discharged to inland waterways. Thus, a fraction of the total nutrient load is removed by NDN, or is land applied by irrigation, or is percolated back to groundwater. Comparing between the years 1994 and 2011, the annual average flow treated at the JOS inland WRPs declined from 151 mgd to 127 mgd, while the amount beneficially reused was 49 mgd in both years. However, in 2011, as a result of NDN, the average concentration of ammonia nitrogen and total nitrogen in the WRP effluent was reduced to approximately 15% and 50%, respectively, of concentrations in 1994. The mass of ammonia nitrogen in water sent from the WRPs for beneficial reuse or discharged to inland waters under NPDES permits has dropped from 1,000 mtons/yr to 122 mtons/yr, and total nitrogen from 2,108 mtons/yr to 844 mtons/yr. When compared with JWPCP nutrient MERs to the ocean, in 2011 only about 1% of all ammonia nitrogen and 5% of total nitrogen was discharged to inland waterways.

The NDN Process at CLA's DCT & LAG WRPs was initiated in 2007. Approximately 15% of wastewater collected by the HTP service area population is from the two inland WRPs, the LAG and DCT WRPs, where the water is tertiary treated and also subject to NDN treatment, which reduces nitrogen levels. About 65% of the tertiary-treated water is beneficially reused for irrigation, lakes replenishment, power plant cooling, and in-plant use. At CLA's two inland WRPs, between 1994 to 2011 the annual average flow treated reduced from 74 mgd to 51 mgd, while the amount beneficially reused remained approximately 30 mgd in both years. When compared to 2011, the average concentration of ammonia nitrogen and total nitrogen in the WRP effluent was reduced to about 3% and 22%, respectively, of concentrations in 1994. The amount of ammonia nitrogen in water sent from the CLA WRPs for beneficial reuse, or discharged to inland waters under NPDES permits has dropped from 1901 mtons/yr to 64 mtons/yr, and total nitrogen from 2,243 mtons/yr to 489 mtons/yr. When compared with HTP nutrient MERs to the ocean in 2011, only about 0.4% of all ammonia nitrogen and 2.5% of total nitrogen is discharged to inland waterways.

Per Capita Flow and Nutrient Data

Total flows in the JOS and CLA systems declined by 9% and 13%, respectively between the averaged periods of PS and FS treatment, primarily due to water conservation. Between the PS and FS period, per capita flow to the ocean declined from 72 to 63 gpcd at JWPCP and from 93 to 78 gpcd at HTP. Between PS and FS periods, tertiary treated effluent for recycling was reduced from 34 to 29 gpcd in the JOS, but increased from 12 to 18 gpcd in the CLA. By 2011, combined flows to ocean and to recycled uses totaled 84 gpcd and 85 gpcd at the JOS and CLA, respectively. Also, in 2011, recycled water was 32% of JOS and 21% of CLA per capita flow.

The annual average per capita rates of nutrient discharge (kg/yr) to the ocean from the JWPCP and HTP were calculated for each year 1994 to 2011. At the JWPCP the average per capita MER of total nitrogen was reduced by 13%, from 3.83 to 3.34 kg/yr and total phosphate was reduced 79%, from 0.98 to 0.21 kg/yr between the PS and FS treatment periods. At the HTP the average per capita MER of total nitrogen increased by 3%, from 4.05 to 4.19 kg/yr, and total phosphate was reduced 37%, from 1.53 to 0.97 kg/yr.

Receiving Water Nutrient Data

Both CLA and the Sanitation Districts sample for ammonia nitrogen in the receiving waters. Sampling is conducted at the surface, and at 15, 30, and where deep enough, 45 meters, at approximately half of the sites where quarterly CTD casts are made. Many years of sampling have determined that the HTP and JWPCP effluent are by far the dominant source of ammonia nitrogen in the receiving water near the outfalls. When plotted, the average survey data show a very clear feature centered at the ZID sites directly adjacent to the outfalls, with concentrations dropping to below detection levels at sites furthest from the outfalls. Peak and average levels of ammonia in the receiving waters are expected to vary between surveys, as the currents that dilute and advect the effluent plume are different from survey to survey. To reduce this variability, the average and upper 95th % ammonia levels were calculated for each year, effectively integrating discrete results sampled during four different times of the year.

Comparing between periods of PS and FS treatment at JWPCP, final effluent ammonia MER remained almost unchanged. During the same time periods, the average and upper 95th % ammonia concentrations measured in the receiving waters were also nearly unchanged. However, at HTP, while the average effluent MER of ammonia increased by 18% after implementation of FS, the average receiving water ammonia level declined by 20%, while the upper 95th % receiving water ammonia data increased by 4%. This is probably due to the expansion of the HTP receiving water survey area that occurred coincident with the improved treatment in 1998.

Receiving Water DO, pH and LT

POTW effluent discharges and associated nutrient loading to the coastal ocean have limited direct effects on DO, pH, and water clarity in local receiving waters. Through the methods employed in this special study, it has been demonstrated that plume dispersal dynamics, and particularly entrainment resulting from a buoyant plume may explain a large amount of any observed changes in these parameters.

Indirect effects could not be assessed given the limitations of the dataset and may be significant. Indirect, secondary effects on DO, pH, and LT include the nitrification of ammonia to nitrate (an oxygen consuming process), increased primary production sparked by nutrient introduction into the system, and bacterial respiration as primary productivity stimulated by effluent nutrients is subsequently broken down (reducing DO and pH). Results of the Bight '08 Offshore Water Quality Study provided evidence that on small scales, relevant to the development of algal blooms, anthropogenic nitrogen loads were equivalent to upwelled nitrogen loads in the coastal area adjacent to heavily urbanized regions of the SCB (Howard et al. 2012). POTW effluent was the main source of anthropogenic nitrogen loads, whereas riverine runoff and atmospheric deposition were determined to be 1-3 orders of magnitude smaller (Howard et al. 2012). POTW effluent was also shown to alter the natural composition of the nitrogen pool, which could have implications for algal community composition. Additionally, an analysis of satellite data found the extent of surface algal blooms has increased over the last decade, with chronic blooms documented in areas of the SCB co-located with major inputs of anthropogenic nutrients as well as longer residence times of coastal waters. However, since the density stratification of the receiving water typically traps POTW effluent 20 meters or deeper below the surface, and the POTW discharges occur at some distance from the coastline, at 60 m water depth, it is not clear whether there is any association between these satellite observations of the near-surface waters and the POTW discharges. Other remaining questions, that also part of the Bight 2013 Regional Monitoring Program include measuring rates at which anthropogenic ammonium is converted to nitrate in the receiving waters, as well as indirect effects of nutrients into the system, which is the basis for the Bight 2013 Regional Monitoring Program and long-term coastal modeling efforts with government and academic collaborators.

Changes in DO and pH of coastal ocean receiving waters, particularly those changes documented during the last decade, are unlikely to be associated with POTW effluent nutrient loading to the coastal ocean. Reductions in effluent turbidity due to FS treatment may have led to small increases in the water clarity of water in the plume, relative to reference levels.

Future Research

Full secondary treatment, introduced at HTP in late 1998 and at JWPCP in late 2002, uses biological processes to improve the quality of effluent. The greatest benefits of secondary treatment are reductions in effluent BOD and TSS levels. However, neither secondary nor tertiary treatment directly removes nitrogen, (although total phosphate is closely bound to solids and thus is generally reduced by treatment that extracts solids). In order to reduce nitrogen, expensive treatment plant modifications are required. NDN has been installed at upstream WRPs to meet applicable receiving water targets – specifically nitrate levels for groundwater recharge, and ammonia levels for potential toxicity to sensitive freshwater biota. Neither of these is an issue in the ocean receiving waters where JWPCP and HTP effluent are discharged. Furthermore, during dry periods, the inland waters are often effluent dominated, while the initial dilution of the JWPCP and HTP effluents, achieved within minutes of the effluent entering the ocean, are conservatively calculated to be greater than 100:1.

Because ammonia can be biologically transformed into other nitrogen forms, future studies are planned to look at chemical conversion and biological response rates in the receiving waters. In particular to determine the rates at which effluent ammonia is transformed into nitrate, as well as the rates at which ammonia and nitrate are taken up by phytoplankton.

Changes in effluent properties resulting from the switch to FS treatment are expected to significantly reduce any direct effects of the effluent on receiving water levels of DO, pH, and water clarity by dramatically lowering the effluent levels of BOD, TSS, and turbidity, while slightly raising the effluent pH. Addition of FS treatment at the JWPCP reduced average effluent BOD concentrations from 90 mg/L to 6 mg/L, a reduction of 93%. TSS was reduced from 62 mg/L to 15 mg/L, a reduction of 77%, and turbidity was reduced from 47 NTUs to 5 NTUs, a reduction of 88%. Average final effluent pH increased from 6.8 to 7.1. At the HTP, FS reduced BOD from 73 mg/L to 19 mg/L, a reduction of 74%. TSS was reduced from 30 mg/L to 20 mg/L, a reduction of 34%, and turbidity was reduced from 26 NTUs to 9 NTUs, a reduction of 65%. At the HTP, final effluent pH was reduced from 7.1 to 7.0 after FS treatment.

2011 daily effluent measurements of BOD and pH were analyzed using the State Water Board application RPcalc II, which is designed to find whether reasonable potential exists for a receiving water standard to be exceeded. The inputs to the program are a representative population of final effluent measurements, a conservative minimum initial dilution, and a specified confidence level (usually 95%). The results determined no reasonable potential for either the JWPCP or HTP FS effluent to cause an exceedence of either the DO or pH COP standards.

The receiving waters for the JWPCP and HTP discharges are the open coastal waters of the Eastern Pacific Ocean. These waters are documented to undergo considerable variability at annual to decadal and longer time scales. California Current waters are increasingly experiencing oxygen depletion and acidification (Chan et al., 2008; Feely et al., 2008), concomitant with an expanding Eastern Pacific oxygen minimum zone (Keeling & Garcia, 2002; Bograd et al., 2008; Stramma et al., 2008; 2010; Pierce et al., 2012) and shoaling aragonite saturation horizon (Hauri et al., 2013). Some variability is attributable to natural climate fluctuations, such as Pacific Decadal Oscillation (PDO) and El Niño Southern Oscillation (ENSO) cycle influences on the California Undercurrent (Connolly et al., 2010; Nam et al., 2011). Additionally, there is evidence of non-cyclical changes attributed to climate variability impacting the DO content of ocean waters across the Eastern Pacific (Deutsch et al., 2005, 2011; Brewer & Peltzer 2009). Since the mid-1990's, DO concentrations within the coastal region of the Southern California Bight have decreased dramatically and faster than during the previous four decades and in comparison to offshore data sets (Booth et al., 2014). The exact cause of the observed declines in Southern California DO appear to be a complex integration of large-scale trends caused by natural climate variability that account for ~30% of the observed change, possibly combined with local increases in productivity due to yet unknown causes. Future studies are planned to deploy moored sensors that will provide continuous long term measurements of DO, pH and chlorophyll fluorescence at multiple sites in the SCB, including adjacent to POTW outfalls.

Between 1994 and 2011, receiving water DO and pH variability was dominated by these large-scale oceanographic phenomena; however, subtle localized differences were detected around the effluent pipe. Graphical assessments of the average patterns of DO, pH, and LT in the receiving waters, using data for the period 2003-2011, when both JWPCP and HTP were at FS, show that effects of the effluent discharge are far lower than the natural variability. When anomaly patterns are calculated and plotted over narrow ranges, they reveal that the effluent discharges cause small localized effects on the distribution of DO and pH in the water column. These effects are predominantly due to entrainment of stratified waters rather than to any direct effect, and the unaccounted for differences are on average far less than those stipulated by the NPDES Permits. The State Water Quality Control Board, working with SCCWRP and the SCB POTWs, has been guiding the development of a consistent approach that in future will allow POTWs to fully assess data from discrete surveys for compliance with the COP standards for DO, pH and LT.

Secondary effects on local coastal ocean properties as a result of POTW nutrients are an active area of research. However, as pointed out above, POTW nutrient discharges are much lower now than they have been for most of the last 60 years. Given that typical ocean currents flowing over the outfalls will rapidly dilute and advect the effluent plumes, by 4 to 12 kilometers per day, any secondary effects are likely to occur at considerable distance from the original discharge point. This also makes it possible that secondary effects may occur nearer to an adjacent POTW outfall than at the original discharge site. Therefore, future investigation of secondary effects will need to recognize the merged contributions of multiple discharges into the shared receiving water. Typical residence times for water in the SCB are estimated in the 30-to 90-day range, although near-coastal circulation in the SMB is likely slower than more open sections of the coast (Oram, 2004; Uchiyama et al., 2014). Given these realities, there is a significant challenge of how to design a far-field monitoring program that can track the effluent far enough in space and time to measure secondary effects. The Southern California Bight 2013 Regional Monitoring Program encompasses many of the areas of expanded or additional monitoring that will be needed to address the question of secondary effects in coming years. These include, continuous moored measurements of DO, pH and chlorophyll at multiple sites in the SCB, measurements of DO and other parameters at selected sites to depths greater than 100 meters, incorporation of higher precision pH probes, collection of discrete samples for accurate pH and carbonate chemistry analyses, measurements of key biological rates such as the rates of conversion of effluent ammonia to nitrate, and continued review and assessment of historical monitoring data. Continued studies of natural variability in the SCB are also important, as is the development of improved and even more comprehensive modeling of the SCB coastal ocean physical, biological and chemical system, so that relative effects of anthropogenic inputs as well as natural variability can be assessed with improved certainty.

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