Assessment of Nutrient and Organic Matter Sources to Oso Bay (Corpus Christi, Texas)

Final Report

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Table of Contents

Executive Summary

The goal of this study was to quantify flow rates from several small tributaries that drain into Oso Bay. This data was then used to construct nutrient and organic matter loading estimates from the tributaries, which were then compared to loadings from Oso Creek, the Oso Wastewater Plant, atmospheric deposition, and groundwater. Results suggest that the small tributaries are a minor contributor to water flow and nutrient/organic matter loadings to Oso Bay, with total dissolved nitrogen loading being dominated by discharge from the Oso Wastewater Plant and dissolved organic carbon loading dominated by Oso Creek. Accompanying field data indicates considerable impairment of the western Oso Bay region with regard to excessive chlorophyll levels and low dissolved oxygen, and further indicates that the excessive algal growth (chlorophyll) is largely controlled by nitrogen availability. Consequently, efforts to control these symptoms of water quality impairment must focus on reducing nitrogen inputs from the Oso Wastewater Plant.

List of Tables and Figures

Introduction

Oso Bay (Corpus Christi, TX) is a critically important habitat for numerous migratory bird species, as well as for fish and shellfish (Withers and Tunnell 1998), and is home to the Suter Wildlife Refuge. In the past several decades, significant urbanization and land use change has occurred in the Oso Bay watershed, a trend that is projected to continue for the foreseeable future. At present, three municipal wastewater treatment plants and numerous smaller entities contribute point source discharges to the Oso system, while agricultural lands and significant impervious surface contribute non-point source runoff.

In a synthesis of existing water quality data from Oso Bay, Montagna and Palmer (2012) documented a nearly 2-fold increase in chlorophyll *a* levels from the early 1980's through 2010. Since at least the early 2000's, Oso Bay has exhibited symptoms of eutrophication, including excessive pathogenic bacteria levels (for which a TMDL has been established), episodic low dissolved oxygen conditions, and high chlorophyll levels (Nicolau 2001; Wetz unpubl. data). These symptoms are ultimately related to the physical-chemical dynamics of the system. High water temperatures can contribute to low oxygen conditions, considering that as water temperature increases, saturation levels of dissolved oxygen decrease. However, data collected through a companion study suggests considerable departure from expected oxygen levels based on temperature alone, pointing to a strong effect of microbial respiration (Wetz unpubl. data). Microbial respiration is fueled by labile organic matter, which in the case of Oso Bay could derive from the excessive microalgal biomass and possibly terrestrial inputs. One logical scenario is that significant nutrient loading triggers microalgal blooms, which upon reaching senescence are decomposed by bacteria, drawing down oxygen levels in Oso Bay. These symptoms also suggest that Oso Bay may be reaching a tipping point where it can no longer absorb and process nutrient and organic matter inputs from the various sources without harm to the ecosystem. As such, it is necessary to now consider that these inputs may need to be curtailed to lessen future impacts on Oso Bay.

Although the Oso Wastewater Plant (OWP) is an obvious source of nutrients to Oso Bay, there are several other potential sources that have not been well quantified. In short, lack of data on nutrient and organic matter loading sources to Oso Bay presents a challenge in terms of potential future efforts to manage nutrient inputs. For example, there are several tributaries that drain into Oso Bay from which flows and/or loadings have never been quantified, despite the fact that these tributaries drain land use types (golf course, corn field, impervious surface) that are known to contribute to nutrient enrichment in other systems (Mallin and Wheeler 2000; Rothenberger et al. 2009). The goal of this study was to quantify flow rates from these smaller tributaries. This data was used to construct nutrient and organic matter loading estimates from the tributaries, which were then compared to loadings from Oso Creek, the OWP, atmospheric deposition, and groundwater.

Methods

Study location – Oso Bay (Corpus Christi, Texas) is a shallow (≤ 1 m depth) coastal embayment that drains into Corpus Christi Bay. Circulation in Oso Bay is primarily driven by winds (Schroer 2014). Water inputs to Oso Bay include: 1) Oso Creek at the head of the bay, which receives runoff from the watershed as well as inputs from numerous small permitted discharges, the Robstown and Greenwood Wastewater Plants, and the Barney Davis Plant cooling ponds, 2) OWP, 3) several small tributaries, primarily in the western ("Blind Oso") region of the bay, and 4) precipitation.

Nutrient & organic matter concentrations – Surface water samples have been collected on a biweekly (March through October) to monthly (November through February) basis since August 2011 from six sites in Oso Bay (Figure 1). These sites include: 1) Yorktown Bridge, which

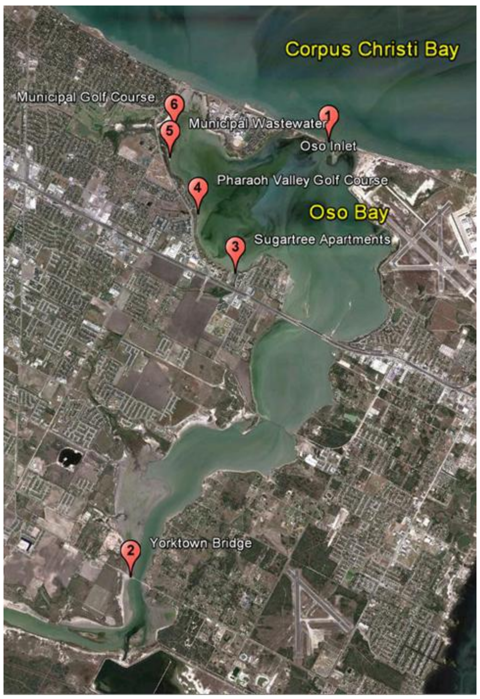

Figure 1. Map and description of Oso Bay sampling locations.

Study Site	Description
Oso Inlet	Mouth of Oso Bay
Yorktown Bridge	Entrance from Oso Creek
Sugartree Apartments	Tributary draining agricultural land
Pharaoh's Valley Golf Course	Tributary draining defunct golf course
Wastewater Treatment Plant	Tributary draining from treated municipal wastewater outfall
Municipal Golf Course	Tributary draining active golf course

integrates water chemistry from the various inputs to Oso Creek, 2) Oso Inlet, which integrates the net effect of water chemistry changes as water passes through Oso Bay, 3) OWP tributary, and 4) three additional tributaries in the Blind Oso. Of these, the "Sugartree Apartments" tributary drains a corn field as well as impervious surface, the "Municipal Golf Course" tributary drains a public golf course that is irrigated with reclaimed wastewater, and the "Pharaoh Valley Golf Course" drains a defunct golf course. Conductivity (salinity), dissolved oxygen (DO), pH and temperature were measured at each site using a YSI sonde. Discrete water samples from each site were analyzed for a suite of analytes. For purposes of loading calculations, we report here results from total dissolved nitrogen (TDN) and dissolved organic carbon (DOC) analyses.

A complete description of analytical methods for these analytes is available upon request from the P.I.

Flow measurements & loading calculations – Water flow measurements were obtained from various sources, including historical records and direct measurements (Table 1).

Table 1. Sources of data for loading estimates.

Data Type	**Source**
Rainfall	Naval Air Station Corpus Christi, available from: National Climatic Data Center
TDN & DOC	This study
Flow	1. Upper Oso Creek, available from: USGS (site 08211520) 2. Barney Davis Plant, Greenwood Wastewater Plant, OWP, available from: U.S. EPA 3. Sugartree, Pharaoh Valley Golf Course, Oso Municipal Golf Course tributaries (This study)
Atmospheric deposition	Site TX03, Beeville, TX, available from: National Atmospheric Deposition Program
Groundwater input	Hay (2011)

To estimate flow from Oso Creek into Oso Bay, information was drawn from three separate sources. First, daily volumetric flow rates during the study period (1 January 2013-1 May 2014) were obtained from the USGS gauging station located at FM-763 (site 08211520). These daily data were subsequently binned to get a monthly average flow. Unfortunately, no direct flow measurements are available downstream of this location, despite significant inputs from the Greenwood Wastewater Plant and Barney Davis Plant cooling ponds. However, each entity is required to report discharges to the U.S. EPA. Monthly volumetric flow from Greenwood (facility I.D. TX0047074) was estimated from data reported during the timeframe of January 2009-December 2011 (the newest data available), while monthly volumetric flow from Barney Davis (facility I.D. TX0008826) was estimated from data reported during the timeframe of January 2009-May 2011 (the newest data available). These monthly averages were subsequently added to monthly average volumetric flow from USGS site 08211520 to obtain a *total* monthly average volumetric flow out of Oso Creek into Oso Bay. Monthly volumetric flow from the OWP (facility I.D. TX0047058) into Oso Bay was estimated from data reported during the timeframe of January 2009-January 2011 (the newest data available).

To determine flow velocity from the three ungauged tributaries in the Blind Oso, we performed direct measurements using Acoustic Doppler Velocimeters (ADV, NortekUSA™ Vector Model). We placed one ADV near the mouth of each site at 0.035 m above the bottom on a stable metal frame. Flow velocity was sampled at 2 Hz in two minute bursts every 15 minutes for up to ten days. Each ADV was programed to best match the salinity of the sampling location. ADV's were subsequently retrieved to download data and recharge batteries, after which they were redeployed to the same site. Velocity (U) was analyzed by measuring individual velocity components in three dimensions: x or east, y or north and z or up. Net velocity (cm/s) was calculated as: $U = \sqrt{(u^2+v^2+w^2)}$. We determined the net velocity for each two minute measurement period and then averaged all of the measurement periods to determine the mean daily flow velocity. On numerous occasions, low water levels in the tributaries led to exposure of the ADV's, and consequently data from these instances had to be discarded. However, loadings would have been minimal on these dates anyway due to the extremely low water levels. All data were rigorously quality controlled by removing samples when beam correlations were < 70 and when the signal to noise ratio was <5, as per Nortek specifications. Because of data gaps imposed by instrument failure and/or quality control removal of data, it was necessary to build a model to determine flow velocity on days where we did not have data. Measured daily average flow velocities were plotted against daily rainfall, obtained from the Naval Air Station-Corpus Christi. From this data, it appears that flow velocities from these tributaries do not begin to exceed "base flow" velocities until rainfall reaches ca. 40 mm (~1.5 inches). It was determined that a 2nd order polynomial equation provided the best statistical relationship (Figure 2), and thus the following equation was applied to daily mean rainfall from 2013-2014 to estimate daily tributary flow velocity:

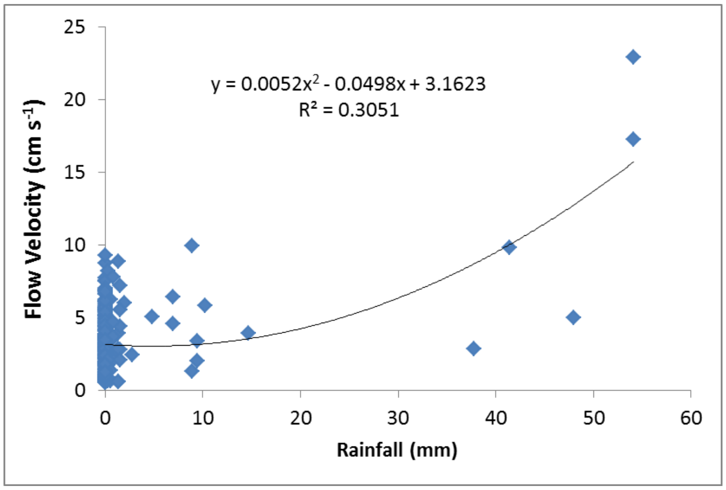

Figure 2. Modeled relationship between rainfall and tributary flow velocity.

Flow velocity $(cm\ s^{-1}) = 0.0052 \times rainfall^2 - 0.0498 \times rainfall = 3.1623.$

Results of modeled versus measured flows show reasonable agreement between the two data sources (Figures 3,4,5).

ADV's also included a pressure sensor (i.e., height of water above sensor). Water depth was determined by taking the average of the pressure data for each two minute burst and then adding 0.035m (ADV depth above the sediment). Recorded water depths during the study were used to guide an effort to estimate the cross-sectional area of each tributary at various water levels. In short, the distance across each tributary was measured at several water depths. This data was then used to calculate volumetric flow from each tributary by multiplying the flow velocity by the average cross-sectional area during the course of the study.

Monthly loading of TDN and DOC from each input source to Oso Bay was estimated by multiplying the volumetric flow from each by the monthly concentration of each of these

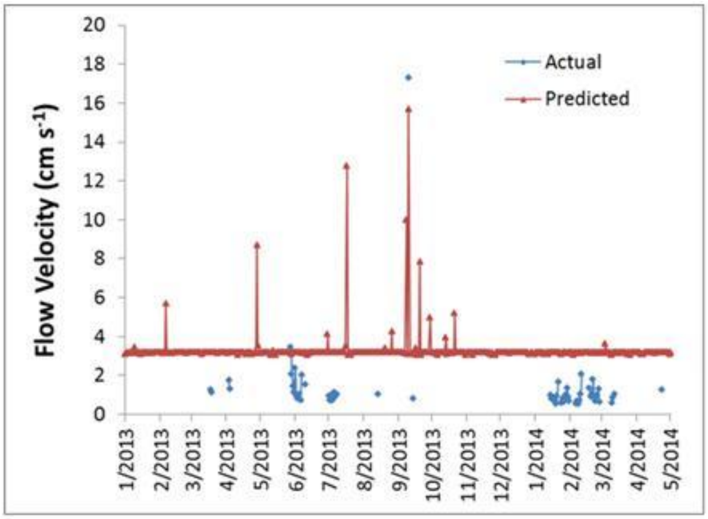

Figure 3. Modeled versus measured flow velocity at the Municipal Golf Course tributary.

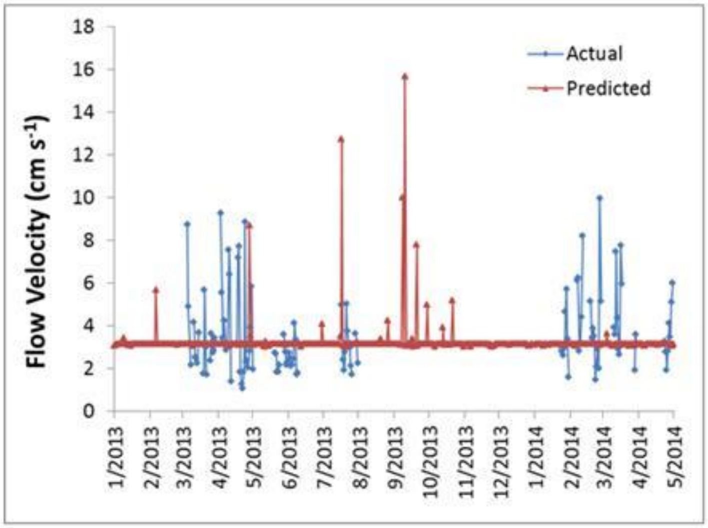

Figure 4. Modeled versus measured flow velocity at the Sugartree tributary.

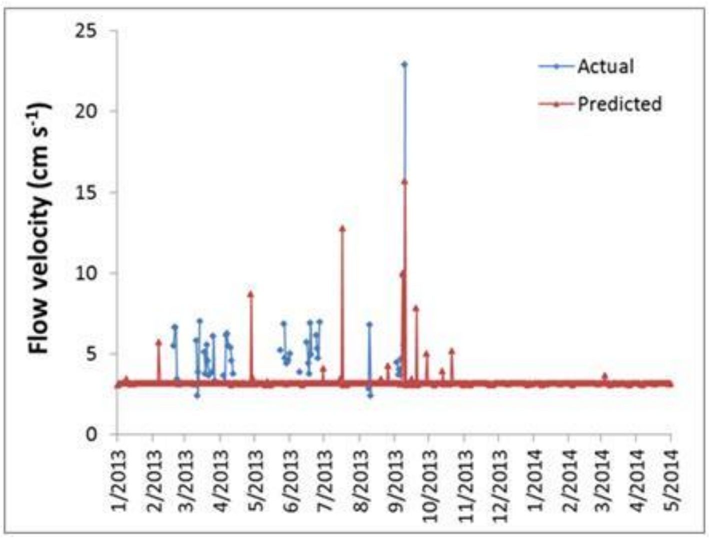

Figure 5. Modeled versus measured flow velocity at the Pharaoh Valley Golf Course tributary.

constituents. In the case of Oso Creek, the chemical concentration at Yorktown Bridge was used. Loading from additional sources, including atmospheric deposition and groundwater, was estimated from historical information. Atmospheric deposition estimates of inorganic nitrogen were obtained from the National Atmospheric Deposition Program (NADP), site TX03 located in Beeville, Texas. Annual average atmospheric deposition was estimated using data collected from 2011-2013. Data from NADP are reported in kg per square kilometer, thus to estimate total deposition to Oso Bay, this study assumed a surface area of 16 square kilometers for the bay. It is important to note that the NADP only reports deposition rates of inorganic nitrogen, but prior studies have shown that organic nitrogen may account for up to 40% of the nitrogen in atmospheric deposition (e.g., Paerl 1997). Thus the actual quantity of nitrogen deposited into Oso Bay from the atmosphere may be underestimated by a similar amount. It is also important to note that nitrogenous atmospheric deposition rates obtained from the Beeville NADP location are similar to those observed by Wade and Sweet (2008), who relied on samplers placed adjacent to Oso Bay. Groundwater input estimates to Oso Bay are thus far limited to data provided by Hay (2011), though a GLO-CMP funded study by Dorina Murgulet (TAMU-CC) and Wetz is underway to provide more robust estimates of groundwater nitrogen inputs to Oso Bay.

Results

TDN & DOC concentrations – In general, highest TDN concentrations (>300 µM) were found in the Oso wastewater tributary, except for a brief period in early-mid fall 2013 when concentrations were much lower at that site (Figure 6). This observation of low TDN values in

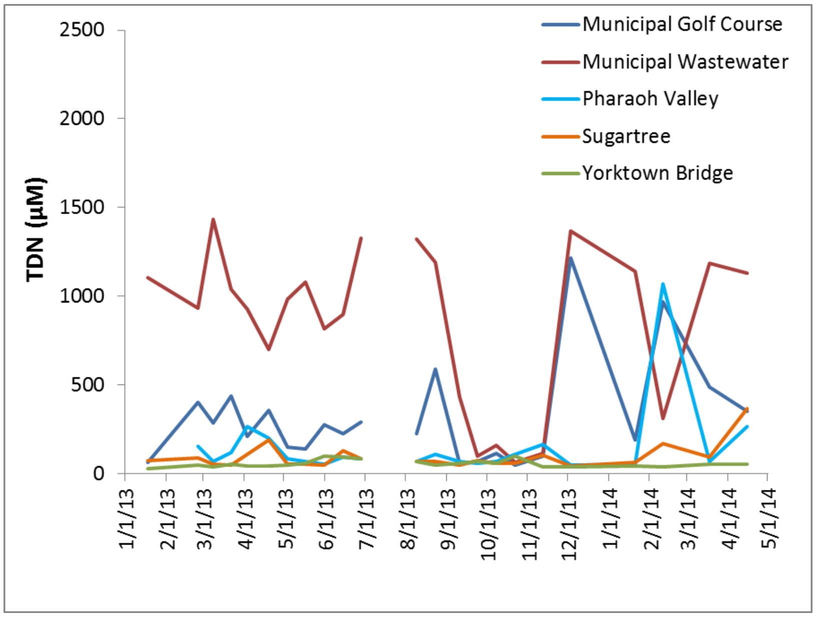

Figure 6. TDN concentrations over the course of the study.

fall was not noted in 2011 or 2012 however and may be anomalous. TDN concentrations were also relatively high (>100 µM) in the Municipal Golf Course tributary except for a similar drop in concentrations during fall 2013 (Figure 6). On average, TDN concentrations tended to be relatively low at the Sugartree and Pharaoh Valley tributaries, and lowest overall at Yorktown

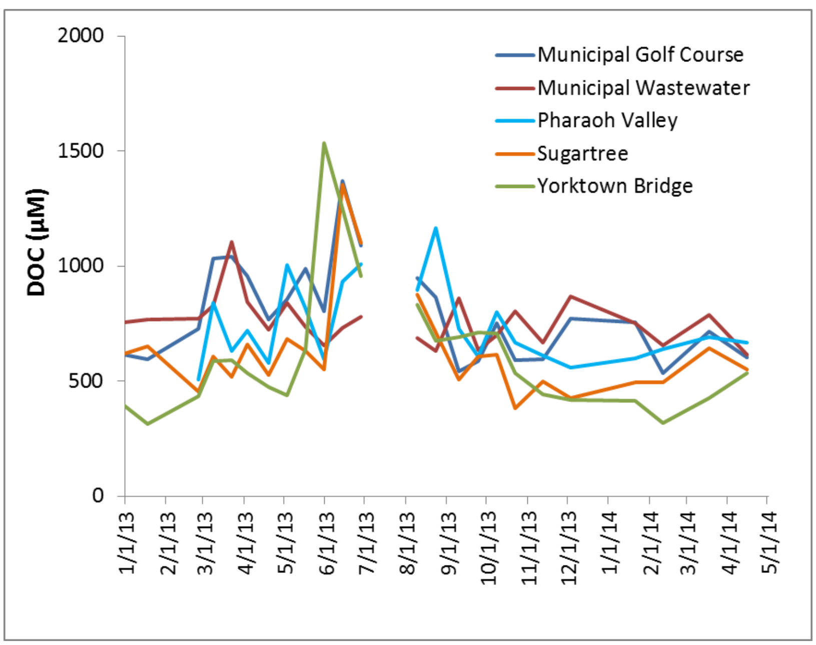

Figure 7. DOC concentrations over the course of the study.

Bridge (Figure 6). DOC concentrations were highly variable during the study period and no clear differences were observed between sites (Figure 7). In this and the longer-term dataset dating back to 2011, a seasonal pattern of higher DOC levels during summer is apparent (Figure 7).

Precipitation & Flow – During the 2013-2014 study period, rainfall was episodic. September to late October 2013 was relatively wet and included two days of 40+ mm rainfall and several smaller rain events (Figure 8). Overall, the largest contributor of water to upper Oso Bay is the

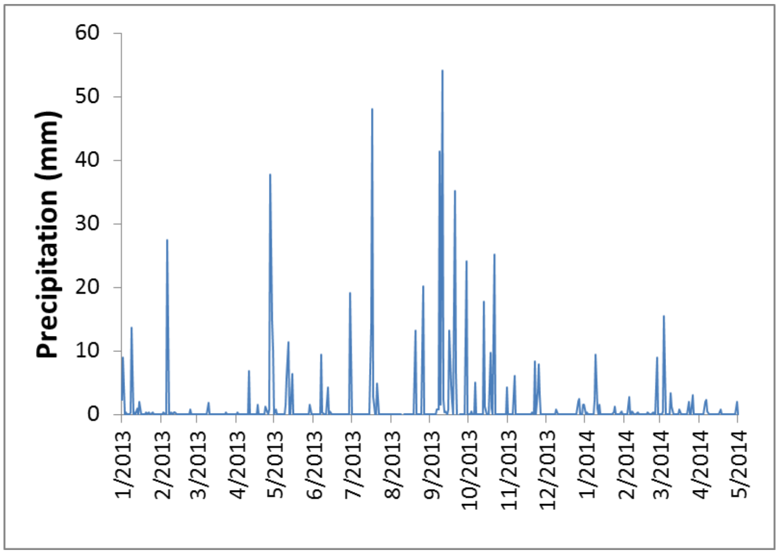

Figure 8. Daily rainfall as measured at the Naval Air Station Corpus Christi.

Barney Davis Plant (Figure 9), with flows routinely exceeding 400,000 m^3 d^{-1}. In contrast, flows from upper Oso Creek and Greenwood Wastewater Plant are typically <50,000-100,000 m^3 d^{-1} (Figure 9). In the Blind Oso region, the OWP is the largest contributor to water inputs, with

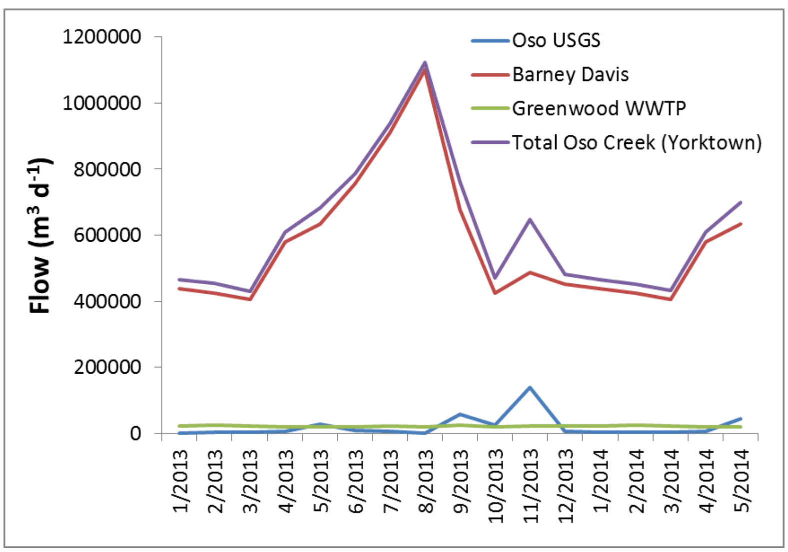

Figure 9. Average monthly volumetric flow for upper Oso Creek, Barney Davis Plant, and Greenwood Wastewater Plant. Also shown is the estimated total monthly flow into Oso Bay from Oso Creek.

flows on the order of 40,000-49,000 $m^3 d^{-1}$ (Figure 10). Flows ranged from 32,000-41,000 $m^3 d^{-1}$ at the Municipal Golf Course tributary, from 26,000-34,000 $m^3 d^{-1}$ at the Sugartree tributary, and from 10,000-13,000 $m^3 d^{-1}$ at the Pharaoh Valley Golf Course tributary.

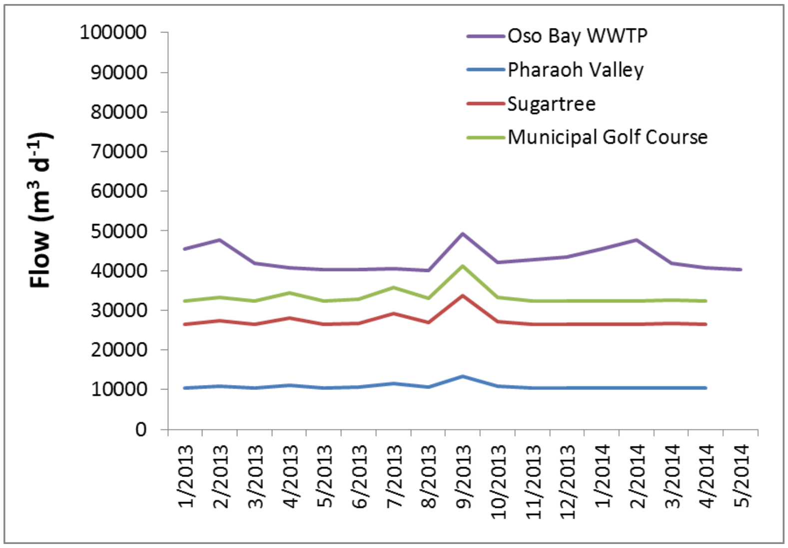

Figure 10. Average monthly volumetric flow for OWP, Pharaoh Valley Golf Course, Sugartree and Municipal Golf Course tributaries.

Loadings – The very high TDN concentrations found in the OWP tributary led to it being the dominant TDN loading source to Oso Bay, despite having much lower volumetric flow than the total flow out of Oso Creek (Table 2). On average, annual loading from the OWP tributary equates to 195,000 kg of nitrogen. Annual loading from Oso Creek was slightly lower, averaging 148,000 kg but with significant interannual variability (Table 2). Loadings from the Blind Oso tributaries were individually on the order of 65% (Municipal Golf Course tributary) to 90% lower (Sugartree, Pharaoh Valley Golf Course tributaries) than from the OWP tributary. Atmospheric deposition contributed roughly 1,300-4,300 kg of inorganic nitrogen per year, and if this is doubled to account for organic nitrogen, maximum nitrogen load from the atmosphere would be roughly 8,600 kg per year, about 4% of the contribution from the OWP. Loading from groundwater, as determined by Hay (2011), is roughly 2,800 kg per year, or 1% of that from the OWP.

The general equivalence of DOC concentrations between sites led to loading differences between sites that primarily reflected differences in volumetric flows. In other words, Oso Creek had the highest volumetric flows and consequently was the largest contributor to DOC loads, averaging 1.37 million kg per year (Table 2). The OWP tributary contributed an average of 140,000 kg per year, while the Municipal Golf Course tributary contributed an average of 104,000 kg per year. Loading from the Sugartree tributary averaged 71,000 kg per year, followed by the Pharaoh Valley Golf Course tributary which averaged 33,000 kg per year.

Table 2. Annual loading estimates (kg) to Oso Bay from watershed sources.

	Source	2013 Loading	2014 Loading
TDN	OWP tributary	183601	207200
	Oso Creek	179950	116727
	Municipal Golf Course tributary	51002	87203
	Sugartree tributary	10652	31927
	Pharaoh Valley Golf Course tributary	11774	27216
	Atmospheric deposition	1280-4320 (inorganic N only)	
	Groundwater	2830	
	Birds	Unknown, but seasonality of bird populations argues against significant contribution	
	Benthic nitrogen fixation	Unknown	
DOC	Oso Creek	1802734	928023
	OWP tributary	145541	135277
	Municipal Golf Course tributary	118035	90918
	Sugartree tributary	74250	67612
	Pharaoh Valley Golf Course tributary		

Discussion

Results from the companion GLO-funded Oso Bay water quality study, which will be reported upon completion of the study in late 2014, show clear impairment of Oso Bay in regards to chlorophyll that exceeds state criteria and episodic low dissolved oxygen levels. For example, water samples have exceeded the TCEQ chlorophyll criteria (11.6 µg/l) in >70% of samples collected from the Municipal Golf Course, Pharaoh Valley Golf Course and Sugartree tributaries over the nearly three years of this study. A recent study by Schroer (2014) showed that these high chlorophyll levels extend into central Oso Bay. Inorganic nutrient ratios, as well as experimental nutrient addition bioassays conducted by the P.I.'s laboratory strongly suggest that nitrogen enrichment is the primary causative agent of the excessive algal growth in this region (M.S. Wetz, unpubl. data). In addition to the high chlorophyll levels, hypoxia is routinely encountered during warmer months in the Blind Oso region (Wetz unpubl. data).

For this particular study, the overall goal was to assess the main sources of total dissolved nitrogen and dissolved organic carbon to Oso Bay. The smaller tributaries in the Blind Oso were found to be a relatively minor source of nitrogen to Oso Bay. However it must be noted that the region was in moderate to severe drought during the study period, thus it is possible that loadings from these tributaries may be higher during more "average" climate conditions. By far, the dominant quantifiable source of nitrogen is the Oso Wastewater Plant. Thus, it could be argued that efforts are necessary to lessen the excessive algal growth and decrease the frequency of low dissolved oxygen episodes seen in the Blind Oso region, and these efforts must focus on reducing nitrogen inputs from the Oso Wastewater Plant. Two other potential sources of nitrogen that were not quantifiable here are bird excretion and benthic nitrogen fixation. Nonetheless, several studies have shown that bird populations are seasonally variable in the Blind Oso (e.g., Withers and Tunnell 1998), with highest populations of shorebirds occurring in November through April and wading birds in fall. In contrast, over the course of this study from 2011-2014, TDN levels were typically highest from late winter/spring through early fall at the Municipal Golf Course site that is located in the vicinity of where maximum bird abundances are found (this report; Wetz unpubl. data). With the summertime TDN maxima being out of phase with maximum bird abundances, this would argue against significant nitrogen input from birds. Little can be said about benthic nitrogen sources, though previous studies have shown benthic microbial activity to be both important sources and sinks for nitrogen in shallow estuaries of the Texas coast (e.g., Gardner et al. 2006).

As for the organic matter fueling hypoxia in the Blind Oso, there is likely a significant influence of decomposition of algal biomass, as well as the possibility of labile organic matter inputs from the local tributaries. Input and breakdown of DOC from Oso Creek may also contribute to oxygen utilization, though the lack of a concentration gradient from Oso Creek to the Blind Oso suggests that local organic matter sources may be more important in terms of hypoxia formation in Blind Oso. A newly funded (by Sea Grant) study is about to commence, led by the P.I., will definitively quantify sources of organic matter fueling hypoxia in Oso Bay, including both algae and runoff sources. Nonetheless, it must be reiterated that current excessive algal biomass and low dissolve oxygen levels present clear evidence of an impaired environment.

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