

Spatial Evaluation of the Proximity of Outfalls and Eelgrass (*Zostera marina* L.) in Greater Puget Sound

February 2015



WASHINGTON STATE DEPARTMENT OF
Natural Resources
Peter Goldmark - Commissioner of Public Lands

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EXECUTIVE SUMMARY

The Washington State Department of Natural Resources (DNR) is steward of 2.6 million acres of state-owned aquatic land. DNR manages these aquatic lands for the benefit of current and future citizens of Washington State. DNR's stewardship responsibilities include protection of eelgrass (*Zostera marina* L.), an ecologically important nearshore habitat in greater Puget Sound. DNR has been the monitoring lead for the Puget Sound eelgrass ecosystem indicator since the current indicators were selected in 2010 and contributes to efforts to achieve the goals set by the Puget Sound Partnership to conserve and restore eelgrass.

An understanding of key eelgrass stressors is needed to drive management actions that will support the growth of eelgrass in greater Puget Sound. Globally, nutrient loading has been demonstrated to have detrimental effects on eelgrass in field, mesocosm and in situ studies. The effects of sediments organic matter content, grain size and pore water sulfide concentrations have also been investigated extensively, but the effects of other contaminants and pollutants are less known. Greater Puget Sound presents unique environmental conditions, and little information is available on the effects of these types of loading on eelgrass locally. The objective of the report is to characterize previously published loading sources and assess their proximity to known eelgrass beds in an effort to identify areas where anthropogenic inputs may affect eelgrass in Puget Sound.

The greater Puget Sound is subject to loading from diverse sources, from atmospheric deposition to thousands of outfalls that range from small manmade or natural drainages to the largest permitted facilities in the country. Outfalls are ubiquitous along the shoreline. Outfall densities, the sum of NPDES permitted outfalls and all other types of human made conduits that convey water into Puget Sound are highest in Central Puget Sound (4.3 outfalls km⁻¹) and lowest in the South Puget Sound (1 outfall km⁻¹). Permitted outfalls that service areas of highest human population density, or urban growth, range in density from one for every 80 km of shoreline in South Puget Sound to one for every three km of shoreline in Central Puget Sound. Eelgrass commonly grows along the shorelines where outfalls discharge in all basins except the Southern Inlets basin where eelgrass does not occur.

Along the eastern side of the Sound eelgrass grows in the marine nearshore, adjacent to the highest population density, the greatest number of outfall discharge points, and the greatest total magnitude of loading. The Saratoga-Whidbey and Central Puget Sound basins have the highest concentration of outfalls in shallow waters within 100 m of shore. These basins also have the highest density of combined sewer overflows, which discharge untreated

sewage and surface runoff directly into the nearshore during high flow events. In addition to spatial proximity to loading, other environmental factors (e.g., geomorphology, depth, circulation) throughout Puget Sound influence the effects of loading on eelgrass.

Altered river deltas that channelize and increase the peak rate of discharge may also pose a risk to eelgrass in the Sound. Although there are major rivers in most of the basins, the Saratoga-Whidbey and Central Puget Sound basins have the highest riverine inputs compared to other basins. The riverine inputs in these basins carry anthropogenic sources of nutrients, metals, organic contaminants and sediments from the watershed that may affect eelgrass condition at the deltas.

Globally, seagrass meadows are under threat from a suite of anthropogenic stressors, notably nutrient and sediment loading associated with coastal development and population growth. With human population in the Puget Sound region expected to increase by 1.5 million by 2025, resource managers face a challenge to protect and conserve eelgrass to maintain a healthy and functioning ecosystem.

1 Introduction

The Washington State Department of Natural Resources (DNR) stewards 2.6 million acres of state-owned aquatic land for the benefit of current and future citizens of Washington State. Eelgrass (*Zostera marina* L.), the dominant seagrass in the Pacific Northwest region, is an important component of both public and private nearshore aquatic lands in greater Puget Sound.

Puget Sound has an estimated 23,000 hectares (57,000 acres) of eelgrass (*Zostera marina* L.) (NHP 2015, Gaeckle et al. 2011). Eelgrass and other seagrasses are considered indicators of estuarine health (Dennison et al. 1993, Krause-Jensen et al. 2005, Orth et al. 2006) and provide extensive ecosystem services worldwide (Constanza 1997, Green and Short 2003, Larkum et al. 2006). In Puget Sound, eelgrass provides spawning grounds for Pacific herring (*Clupea harengus pallasii*), out-migrating corridors for juvenile salmon (*Oncorhynchus* spp.) (Phillips 1984, Simenstad 1994), and important feeding and foraging habitats for water birds such as the black brant (*Branta bernicla*) (Wilson & Atkinson 1995) and great blue heron (*Ardea herodias*) (Butler 1995). Due to its ecological importance and its rapid response to environmental degradation, eelgrass has been identified as a Vital Sign of ecosystem health and a 2020 eelgrass recovery target was adopted by the Puget Sound Partnership (<http://www.psp.wa.gov/vitalsigns/>).

Seagrass decline has been observed globally and is primarily attributed to anthropogenic activities such as nutrient and sediment loading and shoreline development (Duarte 2002, Freeman et al. 2008, Orth et al. 2006, Short and Burdick 1996, Thom and Hallum 1990, Waycott et al. 2009). In Puget Sound, it is likely that eelgrass is less abundant than it was historically (Dowty et al. 2010). Human-induced disturbances, assumed to have caused most of the loss and threats to critical nearshore habitats, are expected to increase with population growth and coastal development. However, there are critical uncertainties about the intensity, extent, and reversibility of stressors affecting eelgrass in Puget Sound (Thom et al. 2011).

An improved understanding of key eelgrass stressors is needed to drive management actions that will slow and possibly even reverse eelgrass declines in Puget Sound. One area where a significant data gap exists is the effects nutrient, metals, contaminants, sediments and other types of loading have on eelgrass in Puget Sound.

1.1 Sources of loading to Puget Sound

Loading is the amount of a substance added to a system through conduits or sources that are human made (e.g., pipe, channelized drainage, septic seepage) or through natural means (e.g., atmospheric deposition, rivers or natural drainage channels, groundwater seepage, surface water flow). The amount of loading of each substance depends on the rate of discharge (e.g., flow) and the concentration of the substance in the discharge. Puget Sound receives a suite of compounds from sources of natural and anthropogenic origin (EnviroVision et al. 2008a, 2008b, Mohamedali et al. 2011, Norton et al. 2011). Natural input sources include atmospheric deposition, oceanic upwelling and discharge from natural, un-manipulated streams, rivers and groundwater. Human constructed conduits include channelized drainages, stormwater pipes, slope drains or tightlines, residential sewage and industrial treatment facilities, septic systems and other urban sources. Puget Sound is strongly impacted by the upwelling of deep ocean water of the Washington coast (Cope and Roberts 2013). The impact of terrestrial loading on nearshore ecosystems in Puget Sound is less documented, but there is evidence that even small septic systems can add a significant amount of nutrient and other contaminants to the nearshore (De Sieyes 2011). For the purpose of this report, we focus on loading from terrestrial sources, and assess the potential impact on intertidal and subtidal submerged aquatic vegetation in Puget Sound.

1.2 Effects of Loading on the Marine System

There are a number of ways in which outfalls can affect the physical, biological, and chemical processes of an ecosystem. The two main drivers include the physical infrastructure of the loading source and the characteristics of the discharge. This is best illustrated by large municipal and industrial wastewater outfalls. Both the construction of the infrastructure and the structure itself can affect species, habitats, and processes (e.g., circulation) within the nearshore environment. The effect of the effluent from these outfalls is more diffuse and difficult to track, but efforts exist to monitor cumulative effects on indicator species, sediments and the receiving waters (e.g., Moore et al. 2014, Partridge et al. 2005, Lanksbury et al. 2014).

One method to evaluate water quality is to measure Total Maximum Daily Loads (TMDL) as required by law and used to implement the Clean Water Act. Data from water quality monitoring are analyzed relative to water quality criteria and water bodies that do not meet certain standards are identified as impaired waters. In 2012, a number of impaired waters were identified throughout Puget Sound based on Washington State's Water Quality Standards for dissolved oxygen (Figure 1).

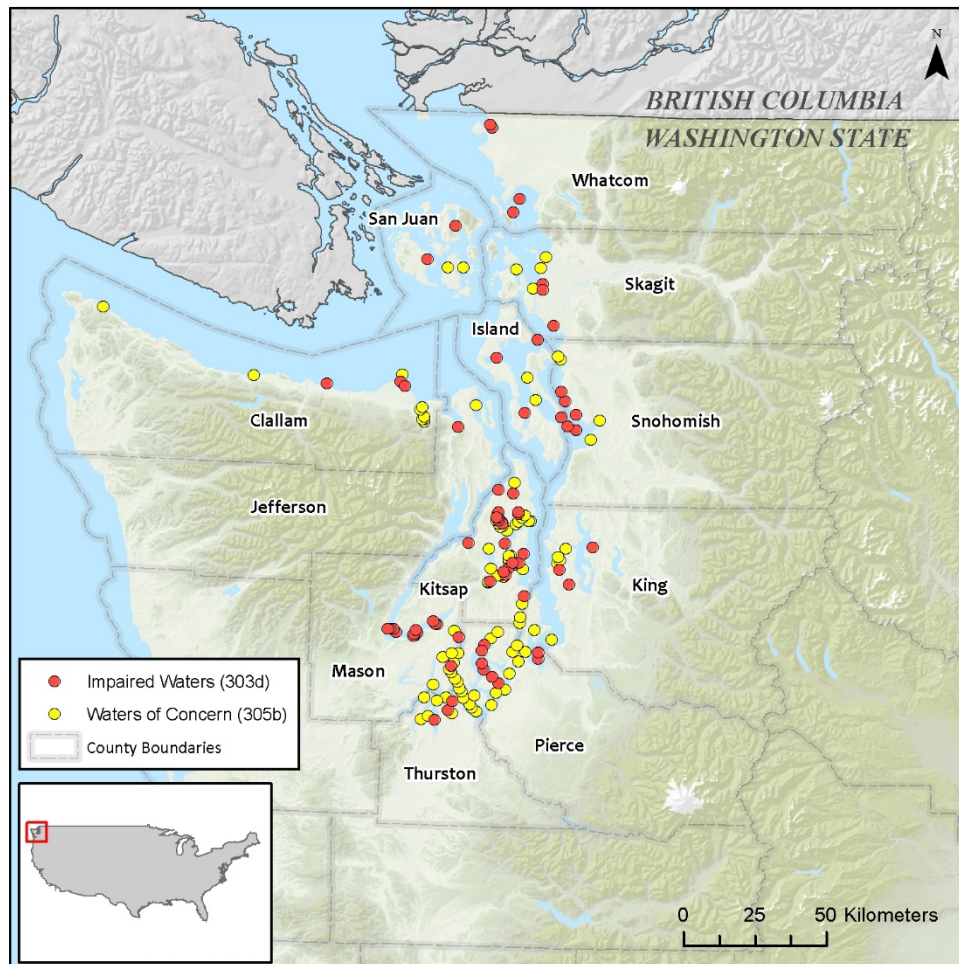


Figure 1. Assessment of water quality as categorized by dissolved oxygen levels in Puget Sound, Washington, USA, measured within 150 m of shore (Water Quality Assessment Program 2012).

Recent model-based assessments of dissolved oxygen concentrations have identified that human nitrogen contributions have the greatest impacts on dissolved oxygen in portions of South and Central Puget Sound (Ahmed et al. 2014).

There is some evidence that loading sources and effluent alter physical processes associated with seagrass beds such as hydrology (Neverauskas 1985), or characteristics of receiving waters such as salinity (Short 2008), and temperature (Robinson 1987, Thorhaug 1978). Prolific growth of macroalgae, epiphytes, and phytoplankton in response to nutrient loading has been demonstrated to have detrimental effects on eelgrass in numerous field and mesocosm studies (Harlin and Thorne-Miller 1981, Short et al. 1991, 1995, Short and Burdick 1996, Silberstein et al. 1986, Neckles et al. 1993, Williams and Ruckelshaus 1993, Hauxwell et al. 2001, 2003) and in the in situ assessments of outfalls (Vaudrey et al. 2010).

Eutrophication eventually leads to a reduction in the available light necessary for seagrasses to photosynthesize (Ralph et al. 2006, Short et al. 1995) and can create conditions of low dissolved oxygen (Simonds et al. 2008) that affect seagrass (Bricker et al. 2008).

Nutrient-related impacts have been associated with major losses of seagrass world-wide (Orth et al. 2006, Short and Wyllie-Echeverria 1996), yet there are surprisingly few data documenting the extent of nutrient-related impacts on eelgrass in Puget Sound. This is partly due to the unique nature of the Puget Sound ecosystem. The upwelling off the Washington coast creates a high background level of naturally occurring DIN (dissolved inorganic nitrogen, the sum of ammonium, nitrate and nitrite), which makes it difficult to distinguish the effect of comparatively small sources of nitrogen pollution. However, this does not imply that these sources cannot have an effect on local eelgrass beds, especially if loading sources are in close proximity to vegetated areas. Dissolved inorganic nitrogen (DIN) loading from anthropogenic sources is known to have deleterious effects on seagrass (Moore and Wetzel 2000). In Puget Sound, it is estimated that 59% of the anthropogenic DIN load is from wastewater treatment plants and 14% is from anthropogenic sources carried by rivers from the surrounding watersheds (Mohamedali et al. 2011). However, current efforts to monitor and manage DIN loads in Puget Sound to meet regulatory thresholds in dissolved oxygen do not consider thresholds for effects on primary producers such as eelgrass.

In addition to nutrients, research has observed effects of metals and organic contaminants on seagrass physiology (see review by Lewis and Devereux 2009), but there are limited data specific to eelgrass and Puget Sound (USFWS 1994). Contaminants such as heavy metals (Brackup and Capone 1985, Hamoutene et al. 1996, Lewis and Devereux 2009, Pergent-Martini and Pergent 2000, Prange and Dennison 2000), pesticides and herbicides (Bester 2000, Lewis et al. 2002), and organic substances (e.g., naphthalene) (Brackup and Capone 1985) have been shown to have detrimental effects on seagrass physiology. Yet, there is also limited information on the physical impacts to eelgrass habitat and the trophic transfer of nutrients, metals and contaminants in eelgrass from loading sources in Puget Sound.

While sources of loading have major impacts to marine ecosystems (Clark 1997, Gorman 1993), it is difficult to describe and monitor the effects on seagrass systems. First, it is difficult to adequately capture the broad nature of the direct and indirect physical, biological and chemical effects. Additionally, it is difficult to identify the effects of individual outfalls due to the cumulative impacts of wastewater treatment plants and other loading sources in Puget Sound (Carmichael et al. 2009, Mohamedali et al. 2011).

The objective of this report is to characterize the loading sources into Puget Sound and to conduct a spatial analysis of these sources to identify potential hotspots for risk to eelgrass in Puget Sound. In order to accomplish this, a synthesis of spatial information and analyses of loading sources and eelgrass distribution in Puget Sound was performed. This report characterizes loading sources and evaluates the spatial proximity of sources to known eelgrass beds in an effort to identify areas of greatest concern to eelgrass in Puget Sound.

This study considered only spatial proximity of eelgrass to outfalls at the basin scale. It does not consider the influence of water circulation on loading. To consider this aspect of water quality to the greatest degree possible, work by the Washington State Department of Ecology are included in the discussion: 1) the current 303(d) list, which identifies Impaired Waters and Waters of Concern based on dissolved oxygen concentration criteria; and 2) recent model-based assessments of dissolved oxygen (Ahmed et al. 2014, Roberts et al. 2014).

2 Methods

The project entailed an extensive data mining effort to identify existing loading sources and presence of eelgrass (Appendix A – Data sources). The existing data included loading sources (natural or human made), type or description of loading (freshwater, sediment, nutrients, metals and contaminants, flow and concentration), and the proximity of eelgrass to these sources throughout greater Puget Sound. Data were synthesized and manipulated into useful formats to identify the potential impacts of loading on eelgrass in greater Puget Sound using geospatial analyses. The contribution of oceanic sources to total nitrogen load in Puget Sound falls outside the scope of this report, as we focus on loading from terrestrial sources (rivers and outfalls).

2.1 Geographic Study Area

The geographic study area for this report is greater Puget Sound, which is part of the larger Salish Sea watershed. Greater Puget Sound includes the U.S. portions of the Strait of Juan de Fuca, Strait of Georgia, and all marine waters to the south (Figure 2).

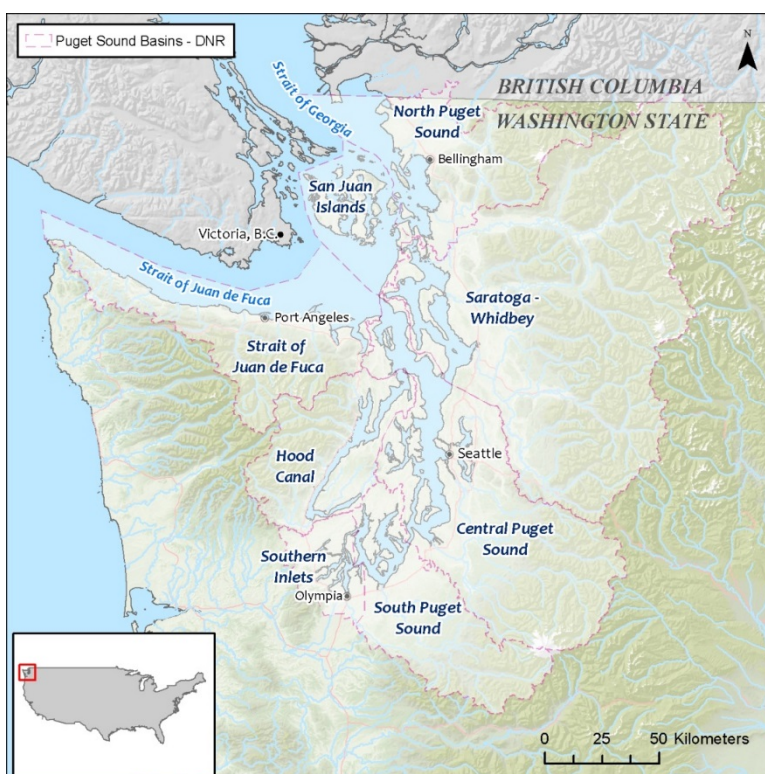


Figure 2. Map of the greater Puget Sound study area, Washington, USA. The study area was separated into eight basins. The basin boundaries were derived from the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) and the Submerged Vegetation Monitoring Program (SVMP).

Compiled datasets were further summarized by Puget Sound drainage basins to improve the analysis of loading on eelgrass (Figure 2). Basins were derived from a combination of sources including the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) and the Submerged Vegetation Monitoring Program (SVMP; Berry et al. 2003).

Basins were chosen for analysis since eelgrass is a nearshore species and will be most influenced by nearshore water quality conditions. Nearshore water quality will be affected by development along a shoreline, including loading from outfalls, groundwater inputs, and other non-point sources, and the riverine discharge that captures watershed scale loading. The vulnerability of the nearshore to the effects of loading depends on water circulation and residence time, loading type and quantity, and shoreline development within an area (Mackas and Harrison 1997). However, water circulation is not considered in the report due to limited understanding of fine scale patterns in the Puget Sound nearshore.

2.2 Description of Loading Sources

Loading enters Puget Sound through a range of natural and human made conduits. The report focuses sources for loading as potential factors that influence eelgrass in Puget

Sound. Data on human population, loading sources, and marine vegetation were compiled from multiple pre-existing resources (Appendix A). Data exist in a wide range of formats. Therefore the best available and most recent data were re-organized and formatted to meet the analysis needs of the report (Table 1). Most of these data were available online through reports, excel files, and when available, ArcGIS shapefiles. For other information, data requests were made to the source agency (Appendix A). Ultimately, all data were re-formatted into tabular and spatial datasets for analyses. No new data were used in the analyses and discussion of the report. Descriptions of each data source are available in Appendix A. The following datasets were used in this report:

- Population growth and urban change - These data were compared to current eelgrass data to track areas in Puget Sound that may be most likely impacted over time.
 - Human population (2010 Census)
 - Urban growth areas (2010 Census)
- Loading data sources
 - Human made outfalls – permitted (PARIS 2014, Mohamedali et al. 2011, EnviroVision et al. 2008a, Herrera 2011)
 - NPDES municipal waste outfalls
 - NPDES industrial waste outfalls
 - NPDES combined sewage overflow outfalls
 - Human made outfalls that convey stormwater through a range of structures (Carmichael et al. 2009, EnviroVision et al. 2008b)
 - Drainage pipes
 - Culverts
 - Ditches
 - Outfalls associated with transportation
 - Natural conduits can range from somewhat pristine to heavily impacted by humans (Carmichael et al. 2009) such as rivers, streams, or creeks.
 - 14 major rivers discharge into Puget Sound (Cedar, Deschutes, Dosewallips, Dungeness, Elwha, Green/Duwamish, Nisqually, Nooksack, Puyallup, Samish, Skagit, Skokomish, Snohomish, and Stillaguamish).
 - Flow/DIN from Washington State Department of Ecology (Mohamedali et al. 2011)
 - Sediment loading (USGS, Czuba et al. 2011)
- Eelgrass data
 - ShoreZone data – primary data source used because of its comprehensive spatial coverage of eelgrass in Puget Sound (ShoreZone 2001)

There were a number of loading sources that were not incorporated into the analysis for a variety of reasons. The most common reason for the omission of these sources was the inability to identify a specific load to Puget Sound and the lack of chemical analysis conducted to describe the concentration of substances. For example, there is uncertainty in the number and amount of loading each septic system contributes to Puget Sound. Furthermore, there is no understanding of the condition and efficacy of each septic system in a basin. Many septic systems were installed prior to maximum discharge standards adopted by WA State (Water Quality Program 2012). Therefore tracking the effects of loading from failing septic systems, poorly treated septic waste from old systems, and the addition of new systems as population increases in the area has its challenges (http://www.psparchives.com/our_work/waste/septics.htm).

Other sources of loading not incorporated into the analysis include vessel discharges, sloughing of contaminants from marine industry, commercial and recreational boaters (e.g., copper, zinc, and lead), and non-point source loading from various land use practices in the area (e.g., residential, commercial, industrial, agricultural, and forestry).

3 Results – Data Summary

3.1 Human Population in Puget Sound

Approximately 4.6 million people reside in towns and cities in the greater Puget Sound study area (Figure 2). Throughout Washington State human population is increasing. The population in the Puget Sound study area experienced a 15.6% change between 2000 and 2010 (Table 1). As of 2010, four of the 115 cities in the Puget Sound region had populations greater than 100,000 people. Seventeen cities with a population greater than 40,000 people account for approximately 40% of the population in the Puget Sound basin (Table 1; <http://www.ofm.wa.gov/pop/census2010/data.asp>). Recent evidence suggests Seattle is the fastest growing city in the U.S. (<http://blogs.seattletimes.com/fyiguy/2014/05/22/census-seattle-is-the-fastest-growing-big-city-in-the-u-s/>).

Table 1. Population of 17 cities in 2010 with more than 40,000 people in the greater Puget Sound study area (<http://www.ofm.wa.gov/pop/census2010/data.asp>).

CITY	POPULATION 2000	POPULATION 2010	PERCENT CHANGE
Seattle	563,375	608,660	8.0%
Tacoma	193,556	198,397	2.5%
Bellevue	109,569	122,363	11.7%
Everett	91,488	103,019	12.6%
Kent	79,524	92,411	16.2%
Renton	50,052	90,927	81.7%
Federal Way	83,259	89,306	7.3%
Bellingham	67,171	80,885	20.4%
Auburn	40,314	70,180	74.1%
Marysville	25,315	60,020	137.1%
Lakewood	58,211	58,163	-0.1%
Redmond	45,256	54,144	19.6%
Shoreline	53,025	53,007	0.0%
Kirkland	45,054	48,787	8.3%
Olympia	42,514	46,478	9.3%
Sammamish	34,104	45,780	34.2%
Lacey	31,226	42,393	35.8%
Total	1,613,013	1,864,920	15.6%
Total (greater Puget Sound area)		4,606,319	

Throughout the study area, there are 129 Urban Growth Areas (UGAs) designated as areas where urban growth is encouraged (RCW 36.70a.110). UGAs make up approximately 3% of the total Puget Sound study area but comprise roughly eighty-two percent (82%) of the population therein (Table 2). Urban Growth Areas have a high proportion of impervious surfaces (e.g., roads, parking lots, building roof tops) that direct rain water into storm drains which is often discharged untreated into Puget Sound. As population growth increases there is an inevitable change in the natural environment from forestlands, wetlands, and other open spaces that naturally absorb or treat runoff in the system to an increase of impervious surfaces. Ultimately, a change in land cover and subsequent increase of impervious surfaces leads to an increased pollutant load carried by stormwater runoff and degradation to ecosystems (Brabec et al. 2002).

Table 2. Area (km²) and estimated population of Urban Growth Areas (UGAs) relative to study area basins. Population estimates from the Office of Financial Management (<http://www.ofm.wa.gov/pop/estimates.asp>).

Basin	UGA Area	Total Basin Area	UGA % of Basin Area	2010 UGA Population	Total Population 2010	% Population within UGA
	(km ²)	(km ²)	(%)			(% UGA pop / Total pop)
Strait of Juan de Fuca	77	5,324	1.4	34,605	71,145	49
San Juan Islands	21	1,949	1.1	10,100	29,975	34
North Puget Sound	280	4,368	6.4	158,985	236,386	67
Saratoga-Whidbey	524	15,018	3.5	499,236	700,450	71
Central Puget Sound	217	7,631	2.8	2,505,216	2,733,236	92
South Puget Sound	12	3,750	0.3	322,255	472,591	68
Southern Inlets	177	1,168	15.2	123,789	172,439	72
Hood Canal	35	3,145	1.1	1,724	53,231	3
Total	1,342	42,353	3.2	3,655,910	4,469,453	82

The Central Puget Sound basin has the highest human population throughout UGAs and non-UGAs represented in metropolitan areas along the eastern shore of Puget Sound and including Snohomish, King and Pierce counties (Figure 3).

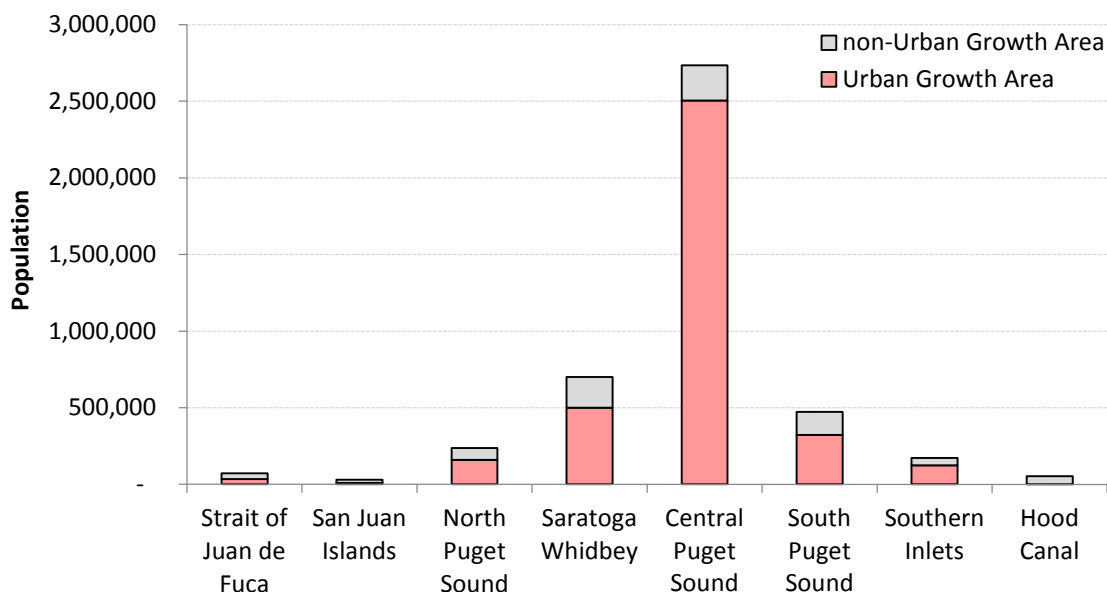


Figure 3. Human population in 2010 per Urban Growth Area (UGA) and non-Urban Growth Area in each of the eight Puget Sound basins (Population estimates from the Office of Financial Management (<http://www.ofm.wa.gov/pop/estimates.asp>)).

3.2 Loading Sources

Due to the availability of data, the major sources of loading presented in the report were from permitted outfalls (PARIS 2014) and rivers (Czuba et al. 2011, Mohamedali et al. 2011). Other loading data exists, such as atmospheric deposition, oceanic upwelling, septic leaching, groundwater seepage, and stormwater runoff but these data were limited, particularly at a basin scale. Loading from oceanic upwelling is well described in other documents (Cope and Roberts 2013) and is not explicitly presented here. Although not segregated out in the data sources, it is assumed that some contribution of atmospheric deposition, septic leaching, groundwater seepage, and stormwater runoff are largely integrated into riverine loading. However, the direct loading from these sources along the shoreline, although a small fraction of the total loading, may play an important role relative to nearshore vegetation.

This section describes the spatial distribution of outfalls and rivers throughout greater Puget Sound and the loading associated with each source to provide an understanding of how these factors may affect eelgrass.

3.2.1 Outfalls

A review of the Washington State Department of Ecology Permitting and Reporting website shows 331 permitted outfalls discharge into Puget Sound watersheds (PARIS 2014). These consist of 113 municipal outfalls, 49 industrial outfalls, and 169 combined sewer overflows (CSOs). Of the 331 permitted outfalls, 208 drain directly into Puget Sound. In addition to the permitted outfalls, there are 4,529 manmade surface and stormwater outfalls, and 2,121 natural outfalls that drain directly into greater Puget Sound (Figure 3; Carmichael et al. 2009). The inventory of manmade surface, stormwater and natural outfalls was a first attempt to quantify the magnitude of discharge delivery pathways into Puget Sound (Carmichael et al. 2009). Although the current number of non-permitted delivery pathways into Puget Sound is likely different than the 2009 estimate, these data provide the best available inventory of conduits that drain stormwater into Puget Sound (Carmichael et al. 2009). It is also possible that the 2009 estimate of discharge points into Puget Sound is low as development continues to increase in the region. The majority of manmade surface and stormwater outfalls often serve local, site specific needs, and there is no treatment or method to measure discharge volume from these outfalls, and therefore, no understanding of the net loading to Puget Sound. The National Pollution Discharge Elimination System (NPDES) permits make up 5% of the total estimated outfalls that discharge into greater Puget Sound (Figure 4) and represent the second largest source of anthropogenic loading into the Sound, slightly lower than riverine loads on an annual basis (Mohamedali et al. 2011). The reported total volume of wastewater discharged from permitted outfalls from 2006 to 2007 was approximately 174,000 millions of gallons per year (EnviroVision et al. 2008a).

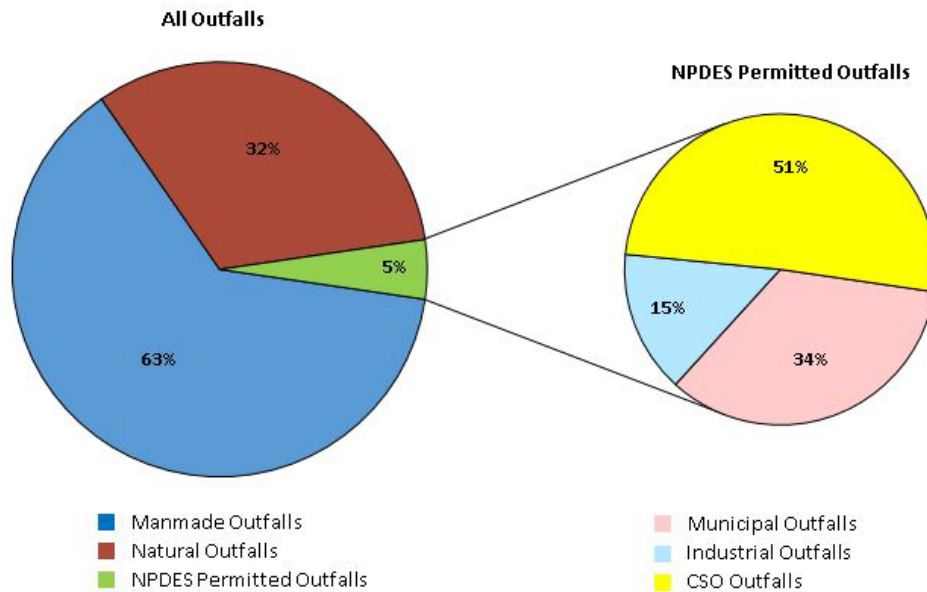


Figure 4. Proportion of NPDES, manmade, and naturally occurring outfalls that discharge into greater Puget Sound (Carmichael et al. 2009, PARIS 2014).

The Central Puget Sound basin has the largest number of both permitted and non-permitted outfalls (2,414) and the greatest proportion of outfalls per kilometer of shoreline (4.3 outfalls km^{-1}) (Figure 5). The Hood Canal basin has the second highest number of outfalls (1,230) and proportion of outfalls per kilometer of shoreline (3.1 outfalls km^{-1}) (Figure 5). In the Strait of Juan de Fuca, a basin with one of the lowest population densities (Figure 3), there are 269 known outfalls and 1.8 outfalls per kilometer of shoreline.

Only 43% of the CSOs discharge directly into Puget Sound (72 of 169). The 97 remaining CSOs discharge indirectly to the Sound via Lake Washington (42), Lake Washington Ship Canal (34), the Duwamish River (12), the Snohomish River (6), and the Skagit River (2). Six (6) of the CSOs that drain directly into Puget Sound discharge into waters deeper than where eelgrass grows (> -11 m, MLLW; NHP 2015).

The Central Puget Sound basin has the highest concentration of NPDES municipal outfall discharges (35 of 114, 31%) and the Saratoga-Whidbey basin has the second highest concentration (33 of 114, 29%) (Figure 5).

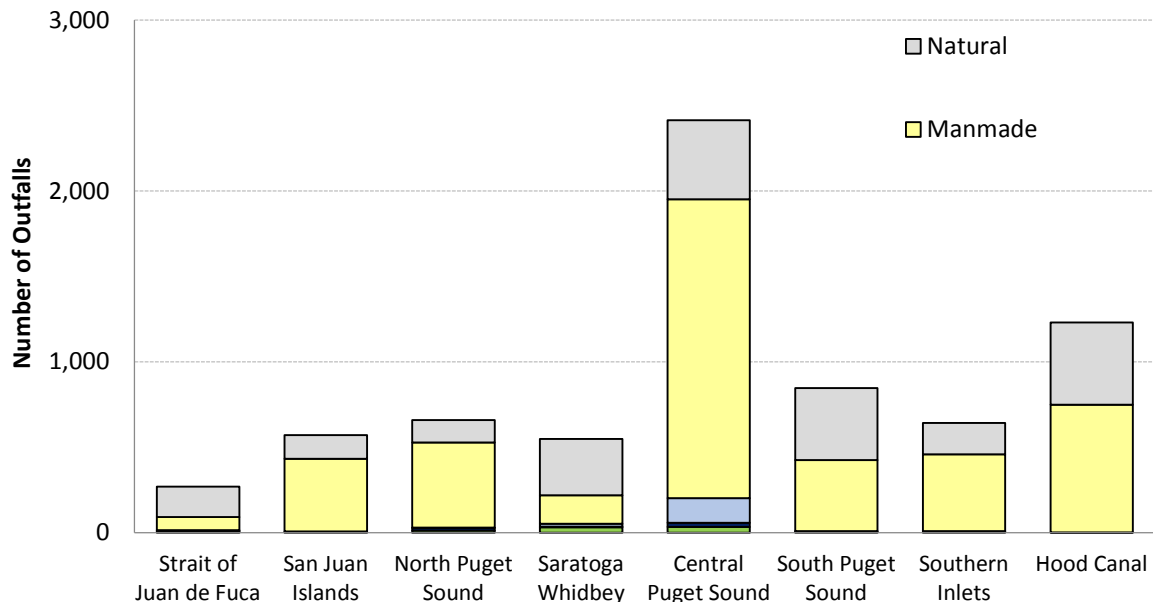


Figure 5. Counts of different types of outfalls in each of the eight Puget Sound basins (Carmichael et al. 2009, PARIS 2014).

3.2.1.1 Permitted Outfalls in Puget Sound

Washington State Department of Ecology is recognized by the US EPA as the state water pollution control agency, and regulates effluent discharge through the NPDES permit process. A wastewater discharge permit is required for disposal of treated wastewater into state waters; marine or freshwater. Outfalls regulated through the NPDES include industrial, municipal, and combined sewer overflow outfalls (CSOs).

Approximately 34% (113) and 15% (49) of the 331 NPDES permitted outfalls are municipal and industrial outfalls, respectively, and are closely associated with urban centers in the Central Puget Sound, Saratoga-Whidbey, and North Puget Sound basins (Figure 6, Figures 7a-c; PARIS 2014, Carmichael et al. 2009). As expected with development, there are many more CSOs (169) with a majority (145, 86%) that eventually discharge into the Central Puget Sound basin (Figure 6, Figure 7).

3.2.1.2 Distribution

Within the study area, the Central Puget Sound basin has the highest density of NPDES permitted outfalls, with approximately four outfalls per 10 km of shoreline. The Saratoga-Whidbey basin has approximately one NPDES permitted outfall for every 10 km of shoreline. The lowest density of NPDES permitted outfalls occurs in the Hood Canal basin with a total of three for the entire basin. There are 8 municipalities throughout Puget Sound with CSO systems that discharge a suite of pollutants through 169 CSO pipes into the Sound after heavy rain events. These municipalities include: Anacortes, Bellingham, Bremerton, Everett, Mount Vernon, Olympia, Port Angeles, and Seattle. (Hart Crowser et al. 2007). Due to overflow events, the toxic chemicals from the CSO effluent have caused

the sediment adjacent to some of the discharge points to be considered contaminated (Hart Crowser et al. 2007).

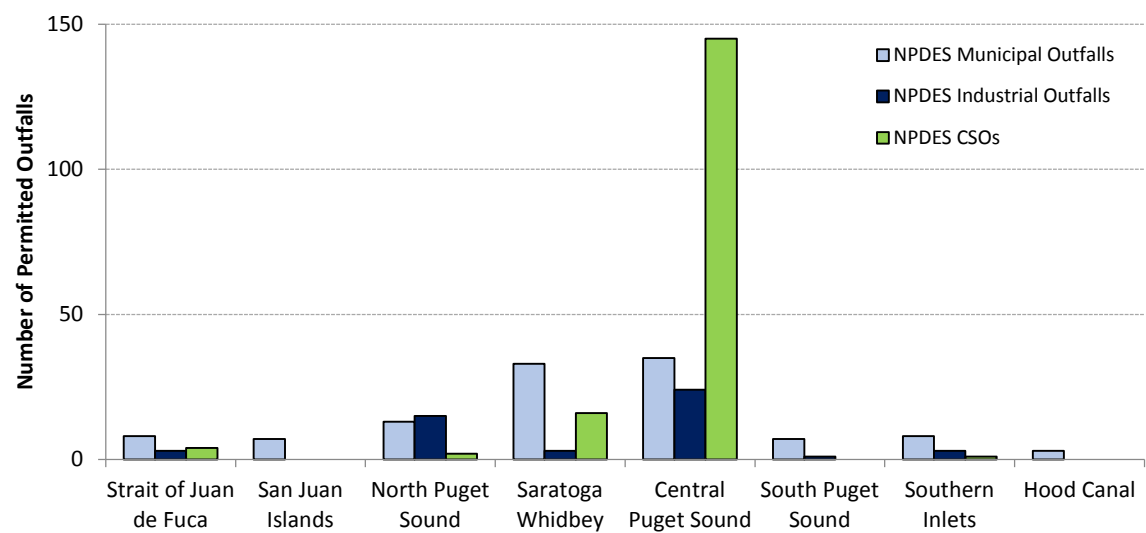


Figure 6. Distribution of NPDES outfalls throughout the Puget Sound study area (PARIS 2014).

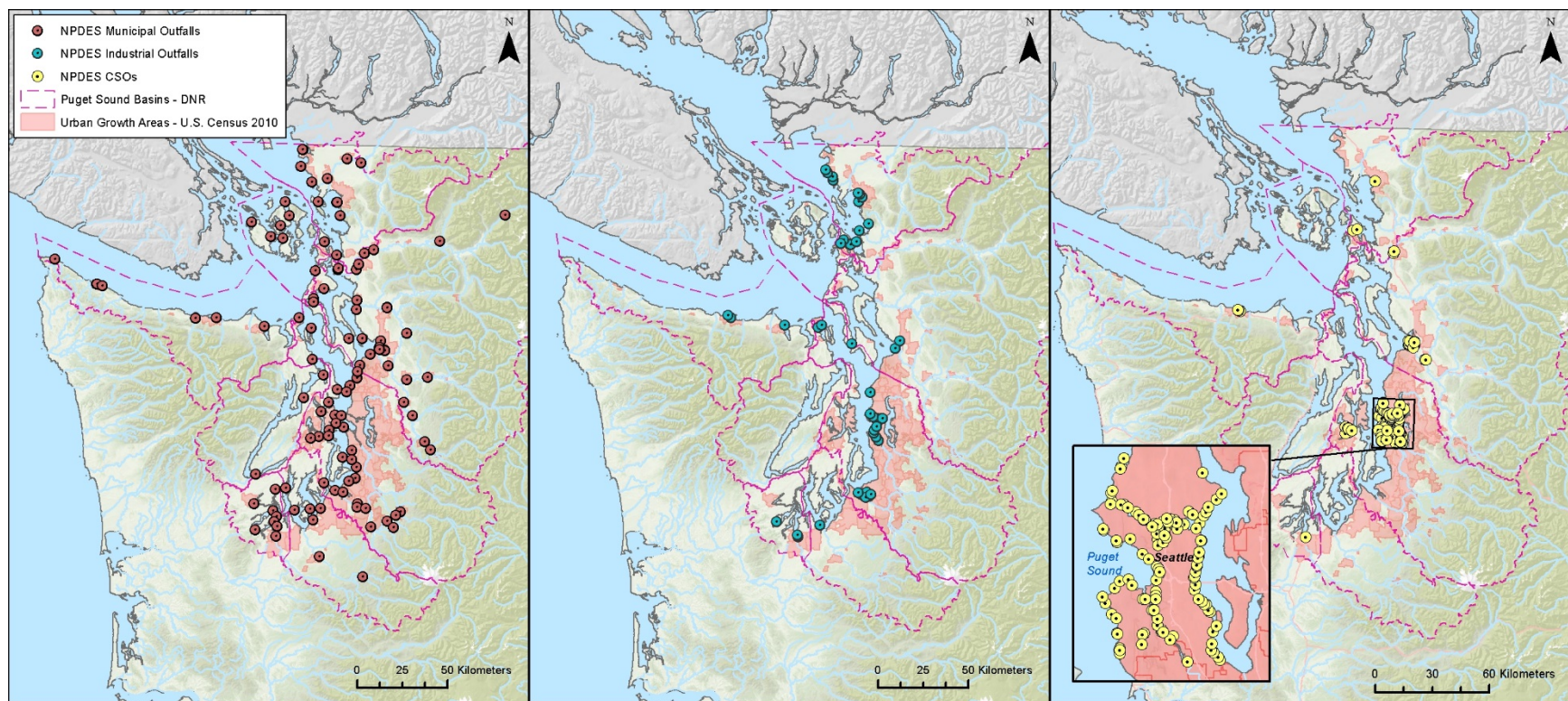


Figure 7. Distribution of NPDES permitted (a) municipal, (b) industrial, and (c) combined sewer overflows (CSOs) outfalls throughout the greater Puget Sound study area (PARIS 2014).

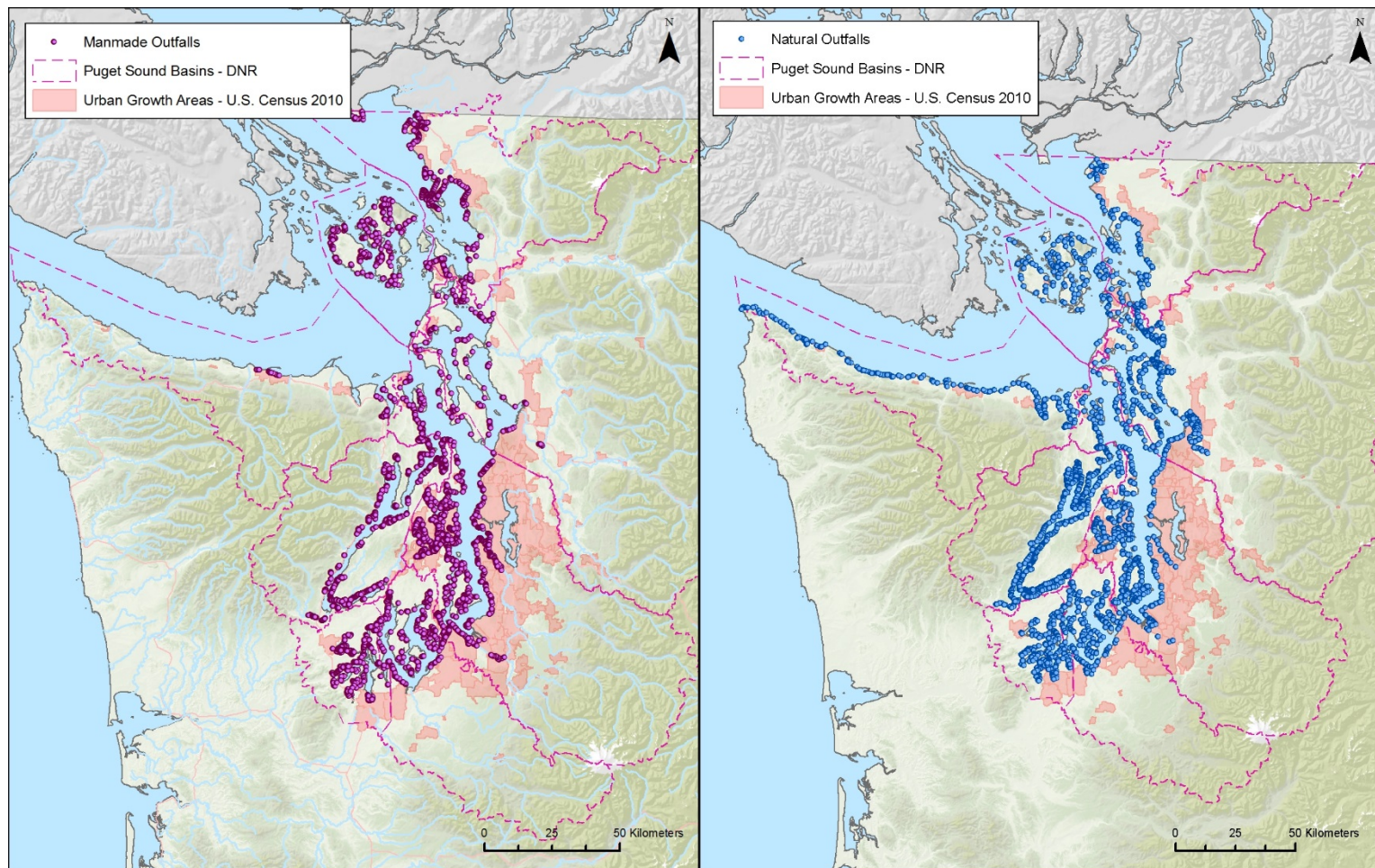


Figure 8. Distribution of (a) man-made (4,529) and (b) natural outfalls (2,123) within the greater Puget Sound basins (Carmichael et al. 2009)

3.2.1.3 Distance from Shore

The distance an NPDES permitted outfall discharges from shore varies throughout Puget Sound. For the permitted outfalls that discharge into Puget Sound, some discharge on the beach or bluff directly above the beach, while others discharge over 3,000 m (9,840 ft) from shore. Currently, there are 113 NPDES permitted outfalls, 34% of the total, that discharge within 100 m (328 ft) of the Puget Sound shoreline. Fifty-seven (63%) of these are located in Central Puget Sound basin (Table 3).

Table 3. Number of NPDES permitted outfalls (municipal, industrial, and CSO) that discharge directly into Puget Sound within 100 m from shore (PARIS 2014).

Basin	Municipal	CSO	Industrial	
	(<100 m from shore)			<i>subtotal</i>
Strait of Juan de Fuca	0	3	1	4
San Juan Islands	3	0	0	3
North Puget Sound	5	3	9	17
Saratoga-Whidbey	4	7	3	14
Central Puget Sound	3	56	12	71
South Puget Sound	0	0	0	0
Southern Inlets	0	1	3	4
Hood Canal	0	0	0	0
TOTALS	15	70	28	113

Twenty-four (21%) of the 113 NPDES outfalls within 100 m of shore discharge in areas where patchy or continuous seagrass has been observed (PARIS 2014, ShoreZone 2001; Figure 9). The basins with the highest concentration of permitted outfalls within a 100 m of shore that discharge near patchy or continuous seagrass beds include the Central Puget Sound, North Puget Sound, Saratoga-Whidbey, and San Juan Island basins (Figure 9). Permitted outfalls within 100 m of shore are present in the other four basins but eelgrass status is either absent within the adjacent ShoreZone segment or the status is unknown (ShoreZone 2001; Figure 9).

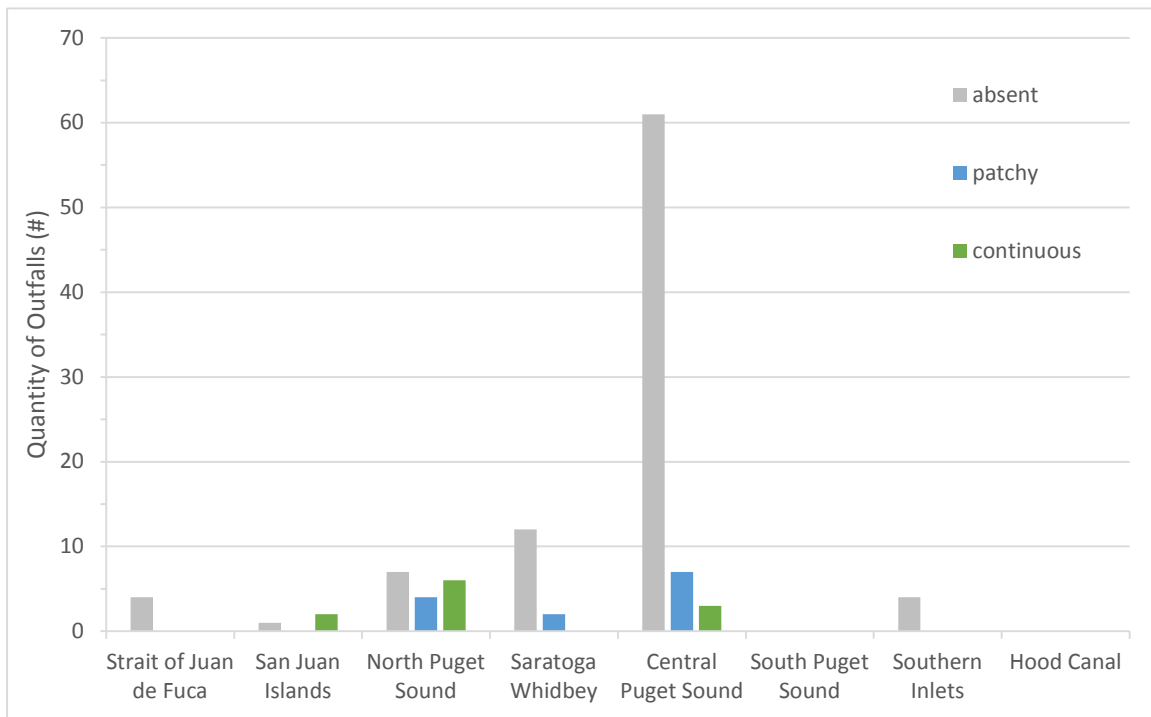


Figure 9. Number of NPDES permitted outfalls (sum of municipal, industrial, and CSOs) within 100 m of shore in each basin relative to the seagrass status (absent, patchy, continuous) in the nearest adjacent ShoreZone segment (PARIS 2014, ShoreZone 2001).

3.2.1.4 Discharge Depth

The discharge depth of outfalls is critical to understand the influence of effluent on the nearshore environment. Outfalls that discharge in shallow waters (< 10 m, MLLW) will likely have a greater effect on eelgrass than outfalls that discharge in deep water from the addition of nutrients and sediments. Of the thousands of outfalls that discharge into greater Puget Sound, municipal outfalls have the most complete discharge data available (e.g., descriptions of effluent, discharge depth, flow rates, capacity).

Municipal outfalls discharge at a wide range of depths throughout Puget Sound (Figure 10). The deepest municipal outfall depth is the King County South Waste Water Treatment Plant at -191 m (-625 ft) relative to Mean Lower Low Water (MLLW). The shallowest discharge depths for municipal outfalls are within intertidal zones of a beach, through creeks or rivers or subsurface flow that drain into the Puget Sound nearshore. For example, the NPDES permitted outfall for Fort Flagler State Park discharges effluent, after passing through a membrane bioreactor and ultraviolet disinfection, into an impounded lagoon which drains through subsurface flow into Puget Sound (Dougherty 2009).

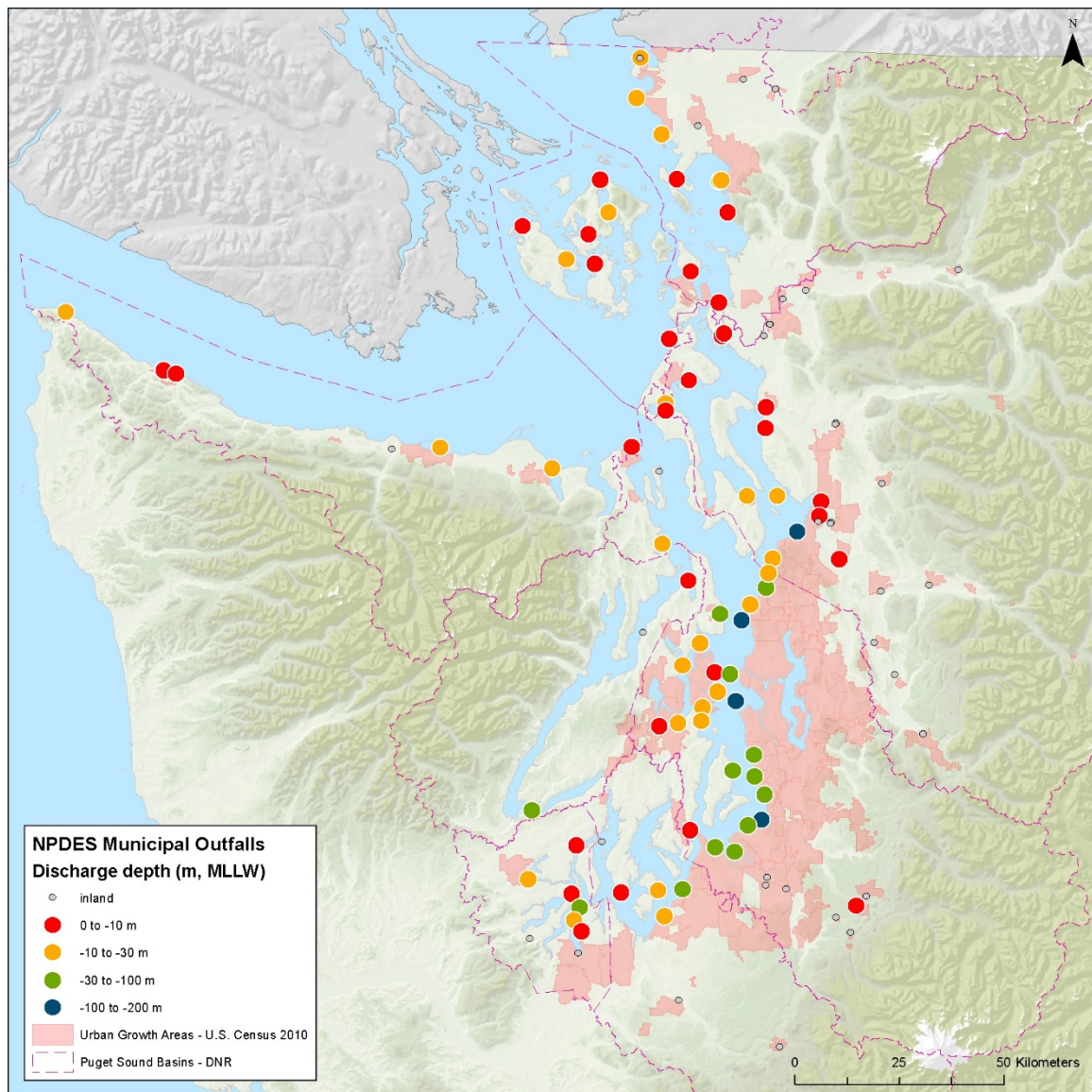


Figure 10. NPDES municipal outfall discharge depth (meters, MLLW). Municipal outfalls that discharge into rivers are indicated as gray points (inland) within the watershed. The effluent from these outfalls eventually enter greater Puget Sound through river discharge (PARIS 2014).

Of the 60 NPDES permitted outfalls that discharge into rivers that eventually drain into Puget Sound throughout the eight basins, 37 are NPDES municipal permitted. These rivers eventually drain into Puget Sound contributing municipal effluent from each watershed into the nearshore environment (Figure 10).

3.2.1.5 Outfall discharge volume

Discharge volume also varies widely by outfall. The 15 largest wastewater treatment facilities by discharge volume are responsible for 76% of the total volume of wastewater discharged to Puget Sound (EnviroVision et al. 2008). The reported total volume of wastewater discharged from permitted outfalls from data collected between 2006 and 2007, was approximately 174,000 millions of gallons per year (EnviroVision et al. 2008). The Central Puget Sound basin receives 65% of the effluent volume discharged from all permitted wastewater treatment plants that discharge into greater Puget Sound (Figure 11).

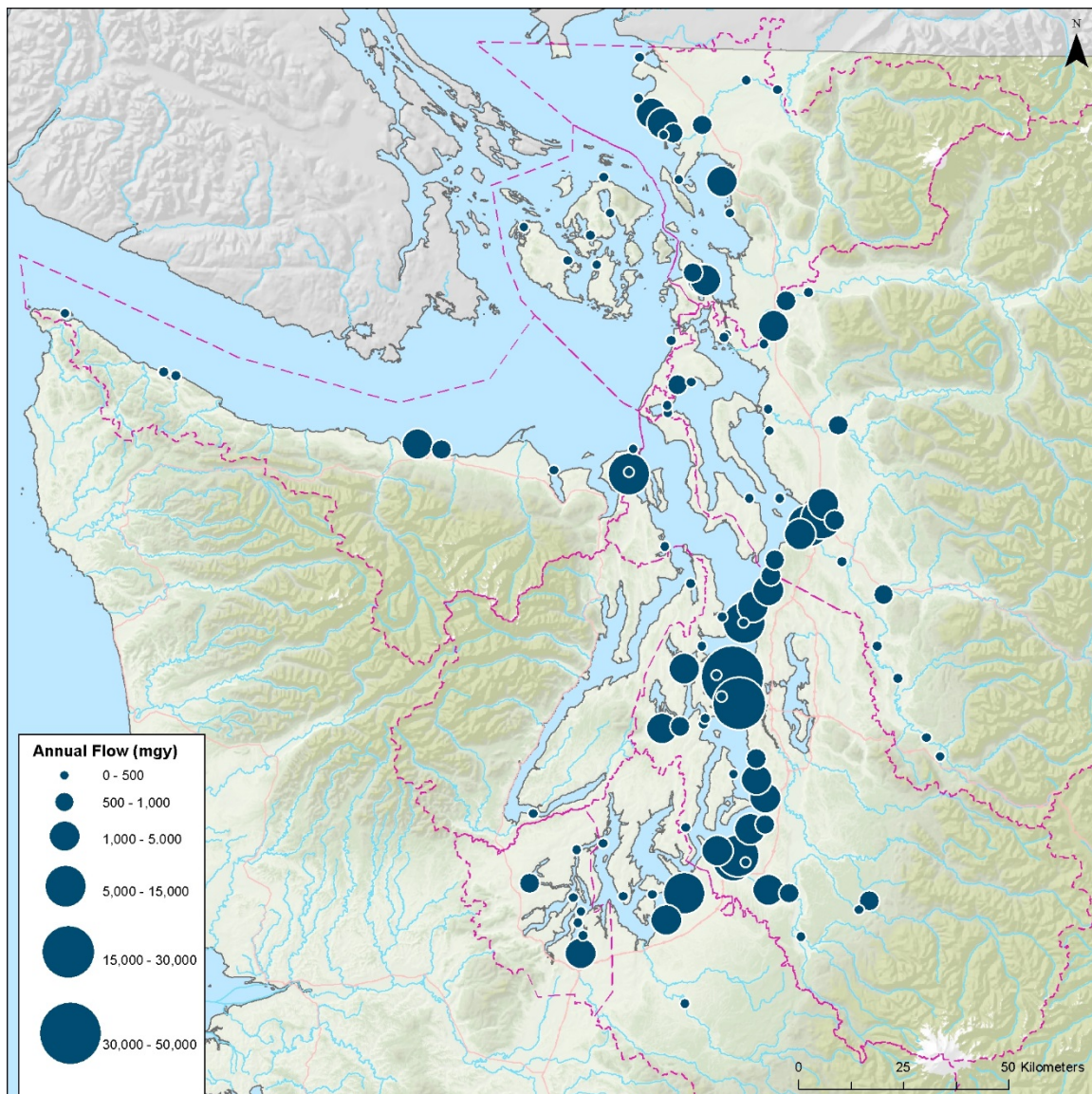


Figure 11. Annual effluent flow (million gallons per year) from NPDES permitted outfalls (municipal and industrial) that discharge into the greater Puget Sound study area (Mohamedali et al. 2011, PARIS 2014).

3.2.1.6 *Eelgrass distribution relative to NPDES permitted outfalls*

Of the 331 NPDES permitted outfalls within the study area, 208 discharge directly into Puget Sound (PARIS 2014). Seventy-six (76) of these discharge along a segment of the Puget Sound shoreline where patchy or continuous eelgrass has been observed (ShoreZone 2001). The remaining 132 NPDES permitted outfalls discharge along a segment of the shoreline where eelgrass was determined to be absent or the status is currently unknown (Figure 12, Table 4).

The one hundred thirteen (113) NPDES permitted outfalls that discharge into Puget Sound are located within 100 m of shore; an area with a high likelihood of potential eelgrass habitat. Of these 113 NPDES outfalls within 100 m of shore, 24 outfalls discharge along a segment of shoreline with patchy or continuous eelgrass has been observed, while the remaining 89 outfalls are located where eelgrass status is either absent within the adjacent shoreline segment or the seagrass status is unknown (Figure 12, Table 4; PARIS 2014, ShoreZone 2001). More than half (60%) of NPDES outfalls within 100 m of shore are in the Central Puget Sound basin, but only 10 out of the 70 (14%) were found to have eelgrass growing in the adjacent shoreline segment (Table 4) (ShoreZone 2001).

Greater than 50% of the municipal outfalls in each the San Juan Islands, North Puget Sound and Hood Canal basins have patchy or continuous eelgrass present in the adjacent shoreline segment (Figure 12, Figure 13 and Table 4). There is one outfall in the San Juan Island basin, the Eastsound Sewer and Water District discharge point, which diffuses treated wastewater between two eelgrass beds on the north end of Orcas Island (Gaeckle 2014).

The three (3) NPDES permitted outfalls in the Hood Canal basin have patchy or continuous eelgrass growing in the adjacent shoreline segment. There is eelgrass growing in the adjacent shoreline segment for approximately 15-40% of the NPDES outfalls in the remaining four basins; Strait of Juan de Fuca, Saratoga-Whidbey, Central Puget Sound, and South Puget Sound (Figure 13, Table 4). There is no eelgrass present in the adjacent shoreline segment for permitted outfalls in the Southern Inlets (ShoreZone 2001, PARIS 2014). However, much of the Southern Inlet basin is not considered suitable eelgrass habitat (Berry et al. 2003).

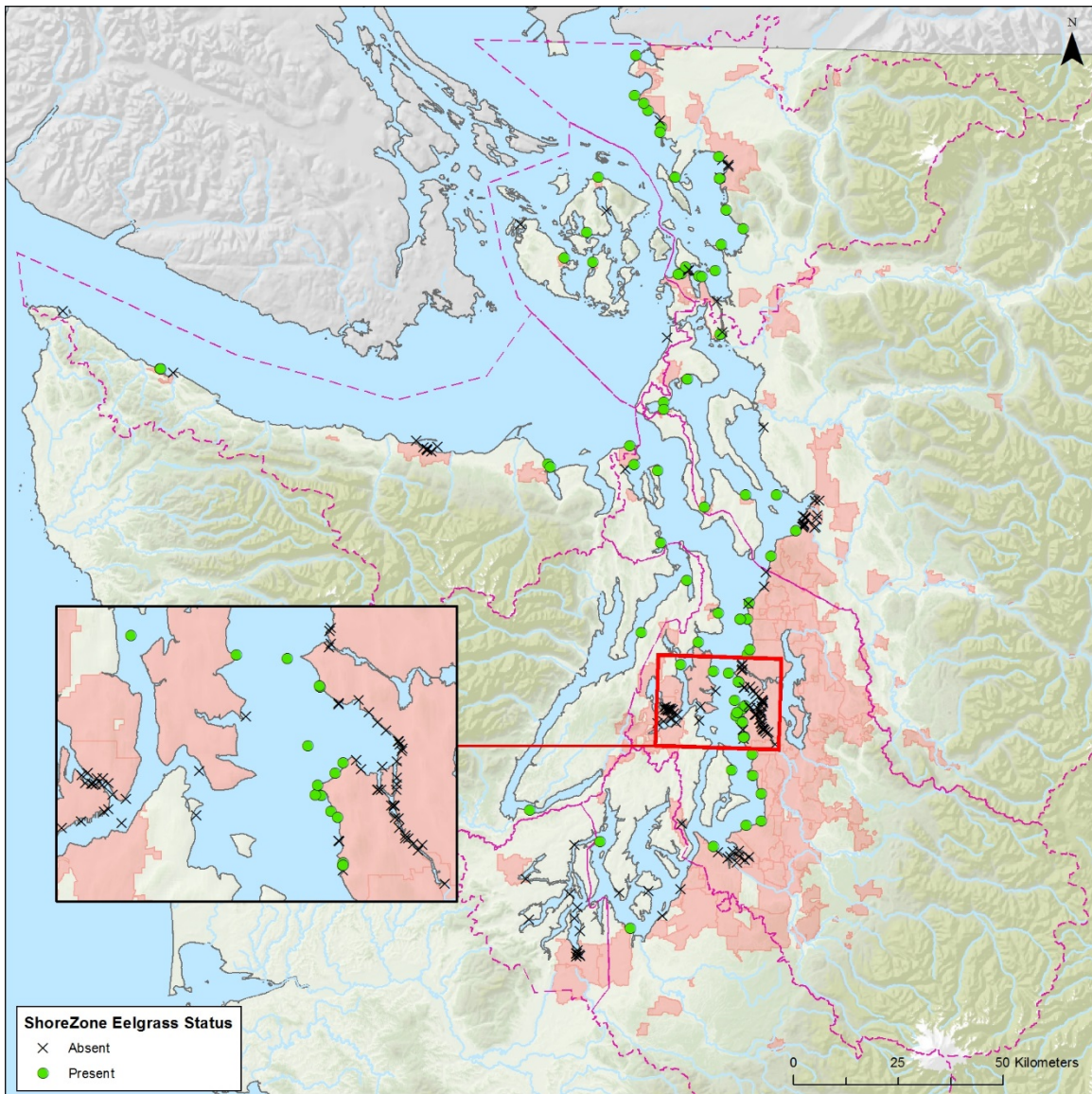


Figure 12. Eelgrass present in the adjacent shoreline segment relative to all NPDES permitted outfalls in the greater Puget Sound study area. Eelgrass data are from ShoreZone (ShoreZone 2001, PARIS 2014).

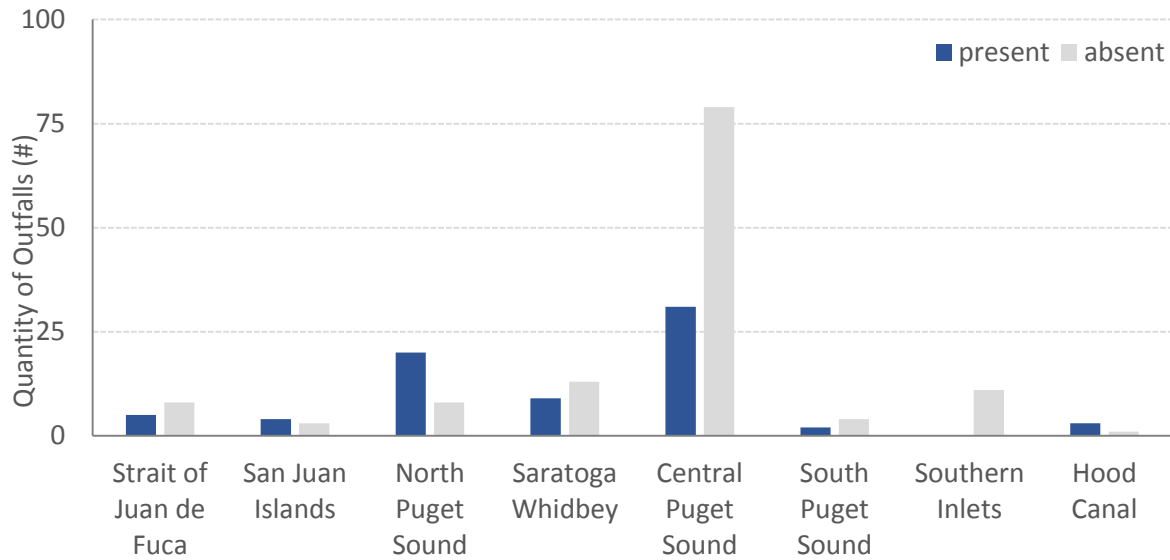


Figure 13. Quantity of NPDES outfalls with eelgrass presence by each greater Puget Sound basin (n=201) (ShoreZone 2001).

Table 4. Quantity of all NPDES outfalls and NPDES outfalls within 100 m of shore with eelgrass present or absent throughout greater Puget Sound (PARIS 2014, ShoreZone 2001).

	ALL OUTFALLS			OUTFALLS < 100 m SHORE		
	<i>Eelgrass Present</i>	<i>Eelgrass Absent</i>	<i>subtotal</i>	<i>Eelgrass Present</i>	<i>Eelgrass Absent</i>	<i>subtotal</i>
Strait of Juan de Fuca	5	8	13	1	4	5
San Juan Islands	4	3	7	0	0	0
North Puget Sound	20	8	28	10	7	17
Saratoga Whidbey	9	13	22	3	12	15
Central Puget Sound	31	79	110	10	60	70
South Puget Sound	2	4	6	0	2	2
Southern Inlets	0	11	11	0	6	6
Hood Canal	3	1	4	1	0	1
TOTALS	74	127	201	25	91	116

3.2.2 Rivers

There are 14 main rivers and over 10,000 streams that drain into Puget Sound (Czuba et al. 2011). The current river discharge rates vary across the study area with the largest originating from the Skagit River. It is estimated that 12 trillion gallons of freshwater

(Figure 14, Figure 15), and 6.5 million tons of sediment are transported by rivers into greater Puget Sound (Figure 16, Figure 17; Czuba et al. 2011). Although the Fraser River does not discharge directly into the greater Puget Sound study area, it surpasses all other river discharge in the area by an order of magnitude (Czuba et al. 2011, <http://www.thecanadianencyclopedia.ca/en/article/fraser-river/>). The discharge from the Fraser River likely influences sediment loads and water quality in the North Puget Sound and San Juan Islands basins, however, these impacts are not explored in detail.

In Washington State, the largest annual discharge of water comes from the Skagit River in the Saratoga-Whidbey basin ($510 \text{ m}^3 \text{ s}^{-1}$, $18,000 \text{ ft}^3 \text{ s}^{-1}$), and the Snohomish ($283 \text{ m}^3 \text{ s}^{-1}$, $10,000 \text{ ft}^3 \text{ s}^{-1}$) and the Puyallup Rivers ($102 \text{ m}^3 \text{ s}^{-1}$, $3,600 \text{ ft}^3 \text{ s}^{-1}$) in the Central Puget Sound basin (Figure 14, Figure 15). The three largest sediment loads from rivers comes from the Skagit River in the Saratoga-Whidbey basin (2.8 million tons per year), the Nooksack River in Northern Puget Sound basin (1.4 million tons per year), and the Puyallup River in Central Puget Sound basin (just under 1 million tons per year) (Figure 16, Figure 17; Czuba et al. 2011). In general, the Saratoga-Whidbey basin receives the largest loads of sediment from rivers annually (over 50% of the total discharged into Puget Sound) (Figure 17), whereas Central Puget Sound basin receives the largest discharge of freshwater in greater Puget Sound (nearly 60% of the total discharge into greater Puget Sound) (Figure 15). This riverine sediment load comparison is based on estimates for the Elwha River prior to dam removal, loads there increased substantially in 2011 in response to restoration.

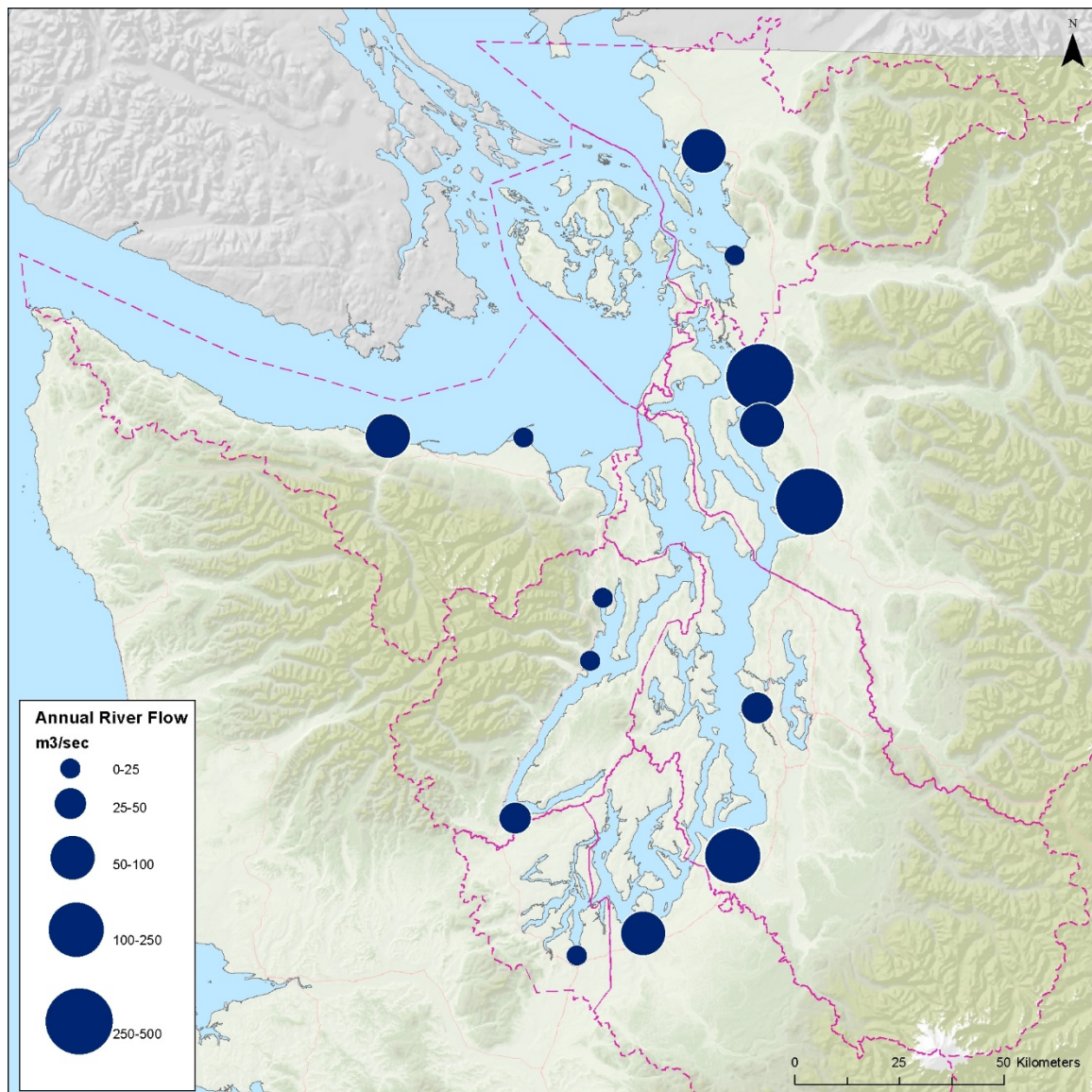


Figure 14. Annual river discharge into greater Puget Sound (Czuba et al. 2011). Fraser River data are not included in the figure.

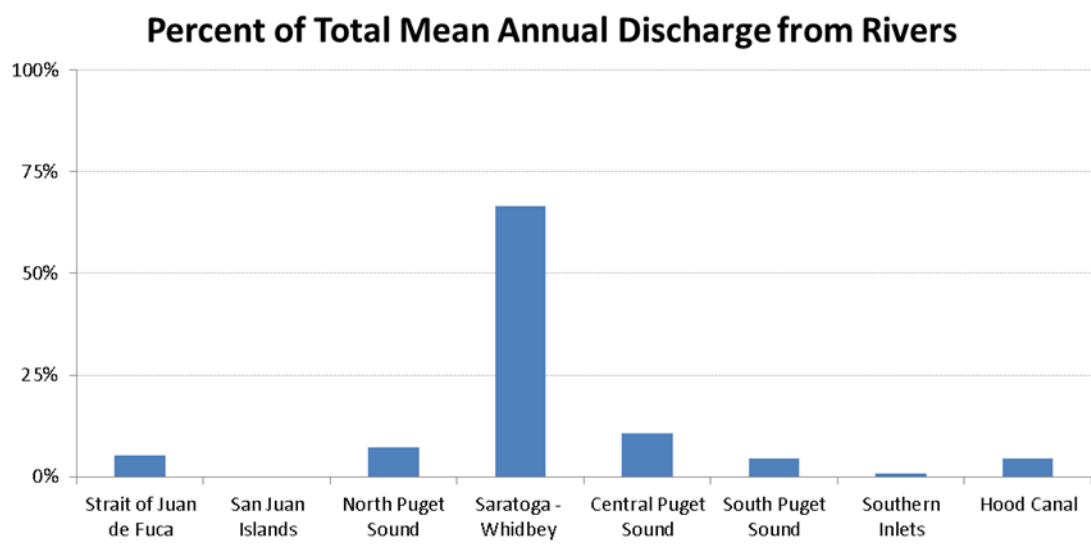


Figure 15. Percent of mean annual river discharge in each Puget Sound basin (Czuba et al. 2011).

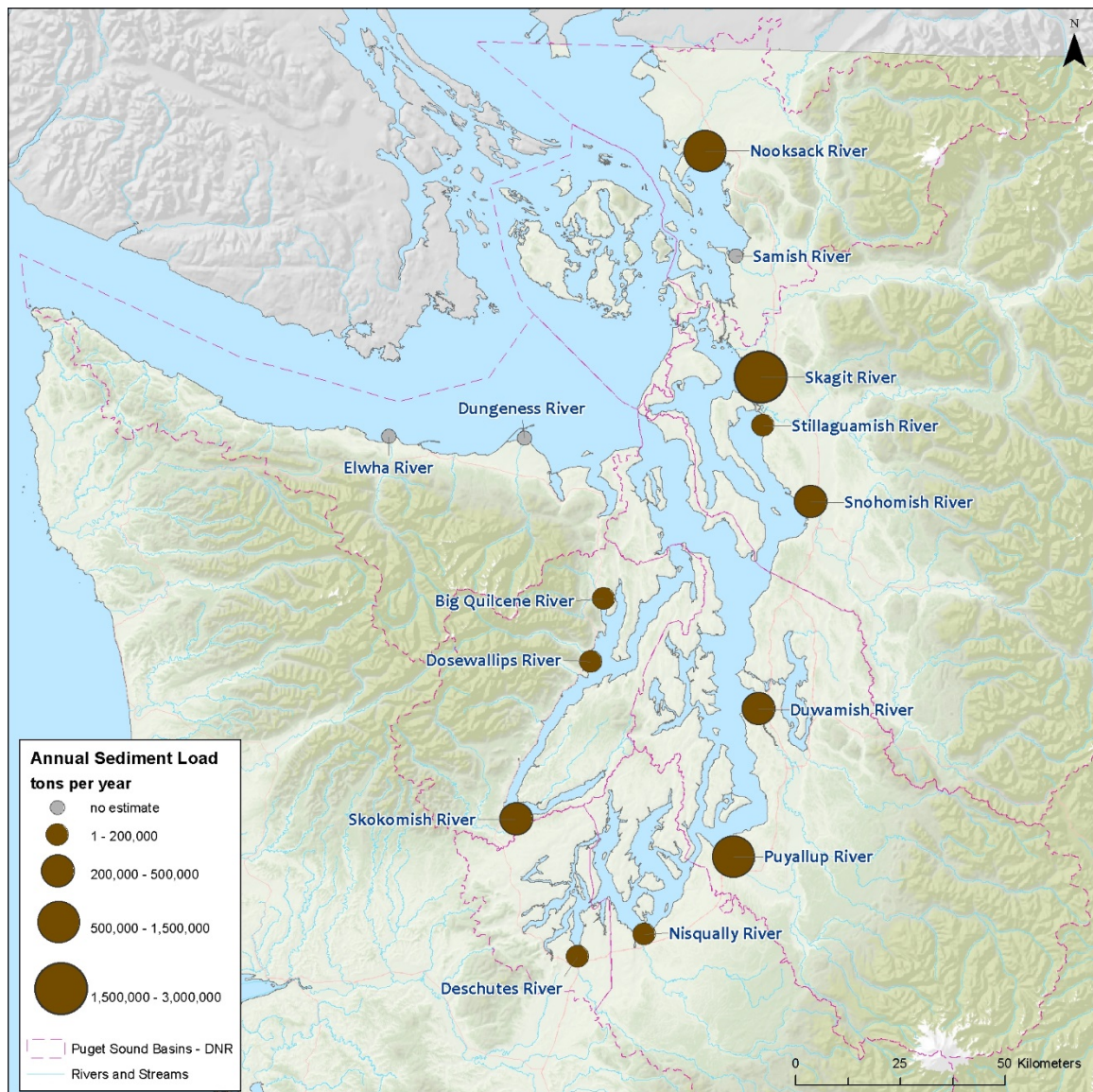


Figure 16. Annual sediment loads (tons yr⁻¹) from major rivers discharging into greater Puget Sound (Czuba et al. 2011).

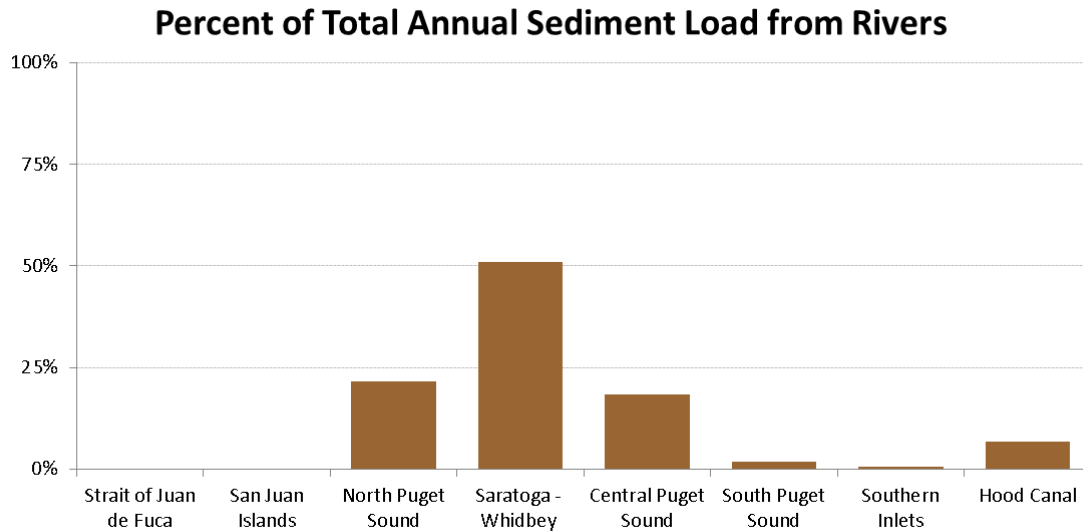


Figure 17. Percent of annual riverine sediment loads in each basin of the greater Puget Sound study area (Czuba et al. 2011).

3.2.3 Chemical Loading: Metals and Contaminants

Chemicals from anthropogenic activities have been detected throughout greater Puget Sound. The Washington State Department of Ecology conducted a study from 2007 – 2011 that found chemicals in surface runoff, atmospheric deposition, publicly owned treatment works (referred to in this report as outfalls), ocean exchange and major tributaries, and groundwater (Table 5; Norton et al. 2011). Surface runoff was found to be the largest contributor of harmful chemicals into Puget Sound (Norton et al. 2011). In surface water, chemicals were detected more frequently and at higher concentrations in commercial and industrial areas compared to other land-use types. Developed lands were found to have higher concentrations of chemicals compared to undeveloped forest lands (Ecology and King County 2011). In addition, chemical concentrations in stormwater were higher during storm events (Ecology and King County 2011). However, atmospheric deposition, a result of fossil fuel combustion, was an important loading pathway for PBDE's and PAH's directly into marine waters of Puget Sound (Ecology and King County 2011). NPDES outfalls accounted for less than one-tenth of the metal and contaminant delivery into greater Puget Sound, and PBDE loads were larger for outfalls than in surface water (Ecology and King County 2011).

Table 5. Chemical Release and Loading into Puget Sound (adapted from Norton et al. 2011).

Chemical of Concern	Total Release into Puget Sound Basin (metric tons yr ⁻¹)	Major Source	Total Loading to Puget Sound (metric tons yr ⁻¹)	Major Pathway
Arsenic	0.8	Industrial air emissions. CCA-treated wood leaching. Roofing material leaching.	14-25	Surface Runoff
Cadmium	1	Roofing material leaching.	0.05 - 0.53	Groundwater Atm. Deposition
Copper	180-250	Pesticides use on urban lawns and gardens. Residential plumbing component leaching. Brake pad abrasion. Roofing material leaching. Vessel anti-fouling paint leaching.	22 - 80	Surface Runoff
Lead	520	Ammunition and hunting shot use. Loss of fishing sinkers and wheel weights. Roofing material leaching. Aviation fuel combustion.	3.6 - 80	Surface Runoff
Mercury	0.5	Consumer product improper disposal. Crematoria and industrial air emissions.	0.11 - 0.37	Surface Runoff
Zinc	1,500	Roofing material leaching. Vehicle tire abrasion.	140 - 200	Surface Runoff
Total PCB's	2.2	Electrical equipment spills and leakage. Residential trash burning. Building sealant (caulk) volatilization and abrasion.	0.003 - 0.02	Surface Runoff
Total PBDE's	0.7	Furniture, computer monitors, and other components of residential and commercial indoor environments.	0.028 - 0.054	Atm. Deposition POTWs
Total PAH's	310	Woodstoves and fireplace combustion emissions. Vehicle combustion emissions. Creosote-treated piling, railroad ties, and utility poles.	0.19 - 1.0	Groundwater Surface Runoff

For NPDES permitted outfalls in Puget Sound, chemicals with sufficient data were estimated to be approximately 1.4 to 7.0 percent of the total loading to greater Puget Sound (EnviroVision et al. 2008a). Study of outfall concentrations of metals show that even though loading and concentrations vary throughout greater Puget Sound, metal concentration values in effluent are higher at locations where relative size of the outfall loading is higher (EnviroVision et al. 2008a). Specific chemicals aside, the top 15 largest

outfalls, in terms of volume, discharged 56 – 84% of the estimated toxic chemical loads into greater Puget Sound (EnviroVision et al. 2008a). The Central Puget Sound basin contains the two largest permitted outfalls, based on loading, to greater Puget Sound (Figure 11), followed by outfalls in South Puget Sound, Saratoga-Whidbey and North Puget Sound basins.

Department of Ecology compared NPDES permitted outfalls and found, except for concentrations of mercury and chloroform, municipal outfalls discharge a more diverse suite of chemicals, approximately 1.4 – 5.9 times, than industrial sources (EnviroVision et al. 2008a). Between the volume and diversity of the chemicals, 12 of the 15 largest dischargers were municipal outfalls.

Ecology evaluated chemicals of concern observed in Puget Sound water and sediment that caused effects to aquatic life, benthic organisms, wildlife and human health (Norton et al. 2011). Chemicals were classified as Level 1 if the measured concentrations exceeded levels in organisms where effects were observed. Level 2 classification identified concentrations of chemicals that were below threshold levels identified to cause effects to organisms.

Copper, mercury, zinc, and PCB's were all classified as a Level 1 chemicals in at least one of the three categories that defined Puget Sound surface waters which consisted of freshwater, nearshore marine and offshore marine components (Table 6). Arsenic, cadmium, copper, mercury, zinc, PCB's, PBE's and PAH's were classified as Level 2 chemicals in the three components of marine sediments; freshwater, nearshore marine and offshore marine (Table 6). Lead was the only chemical found in surface waters and sediments with concentrations below threshold levels and therefore classified as a Level 2 priority concern. Mercury was the only chemical in nearshore sediments identified as a Level 1 chemical of concern, while mercury and PCB's were identified as Level 1 in offshore marine sediments.

Table 6. Levels of concern for chemical concentration inputs to Puget Sound surface waters and sediments. Chemicals with a Level 1 (orange) are considered high priority concerns and have exceeded certain thresholds such as a water quality criteria. A Level 2 (grey) concern indicates a chemical value below a threshold. Unknown (-) indicates insufficient data or not assessed (adapted from Norton et al. 2011).

<i>Chemical</i>	<i>Surface Water</i>			<i>Sediment</i>		
	Freshwater	Nearshore marine	Offshore Marine	Freshwater	Nearshore marine	Offshore Marine
Arsenic	-	-	-	1	2	2
Cadmium	-	-	-	1	2	2
Copper	1	1	2	1	2	2
Lead	2	2	-	2	2	2
Mercury	1	-	-	1	1	1
Zinc	2	-	1	1	2	2
PCB's	1	-	2	1	2	1
PBE's	-	-	-	-	-	-
PAH's	2	-	2	1 to 2	2	2

Ecology conducted subsequent studies of chemical concentrations in sediment at 10 long-term stations throughout greater Puget Sound from 1989 – 2000. At most stations, sediment metal concentrations were lower in 2000 compared to 1989, however, at some sampling stations an increase in chemical concentrations was observed (Partridge et al. 2005). Sinclair Inlet (Central Puget Sound basin) had higher, and more variable, concentrations of metals than other stations in the study, with mercury as the primary metal of concern since it frequently showed levels above sediment quality standards (Partridge et al. 2005). Increased metal concentrations were also observed at Shilshole (Central Puget Sound basin), Commencement Bay (Central Puget Sound basin), and East Anderson Island (South Puget Sound basin).

3.2.4 Dissolved Inorganic Nitrogen Loading

The Washington State Department of Ecology conducted a study from 1998 – 2008 to determine estimates of natural and anthropogenic sources of dissolved inorganic nitrogen (DIN) loading into Puget Sound. While not considering oceanic inputs of DIN, load rates for natural conditions in Puget Sound and the Straits of Georgia and Juan de Fuca were estimated to be approximately 17,600 kg/day (Table 7; Mohamedali et al. 2011). If oceanic inputs are not considered, human inputs account for slightly more than double the natural conditions, with approximately 46,000 kg/day of DIN loading, which is 72% of total non-oceanic DIN inputs into an area that included the Straits of Georgia and Juan de Fuca and Puget Sound proper (Mohamedali et al. 2011). Atmospheric deposition accounted for approximately 4% of all DIN loads to greater Puget Sound. Both rivers and outfalls have also been identified as significant sources of DIN in Puget Sound (Mohamedali et al. 2011). Riverine discharge volume and DIN loads are greater than human point and non-

point sources (Mohamedali et al. 2011). Riverine DIN loads are approximately 51% of total non-oceanic DIN loads in the greater Puget Sound study area and the southern Strait of Georgia compared to 44% from waste water treatment plants and 4% from atmospheric deposition (Mohamedali et al. 2011).

Table 7. Estimates of non-oceanic DIN loading (kg/day) from both natural and anthropogenic sources between 1998 and 2000 (adapted from Mohamedali et al. 2011). Puget Sound includes waters south of Deception Pass and Admiralty Inlet while the Straits include both the Strait of Georgia and the Strait of Juan de Fuca.

	Average Annual DIN Load (kg/day)			
	<i>Natural Conditions</i>	<i>Human Nonpoint sources (in rivers)</i>	<i>Human Point Sources (outfalls)</i>	<i>Total Human</i>
<i>Puget Sound (subtotal)</i>	14,900	7,700	32,200	40,000
<i>Straits (subtotal)</i>	2,700	3,900	2,100	6,000
<i>TOTAL</i>	17,600	11,600	34,300	46,000

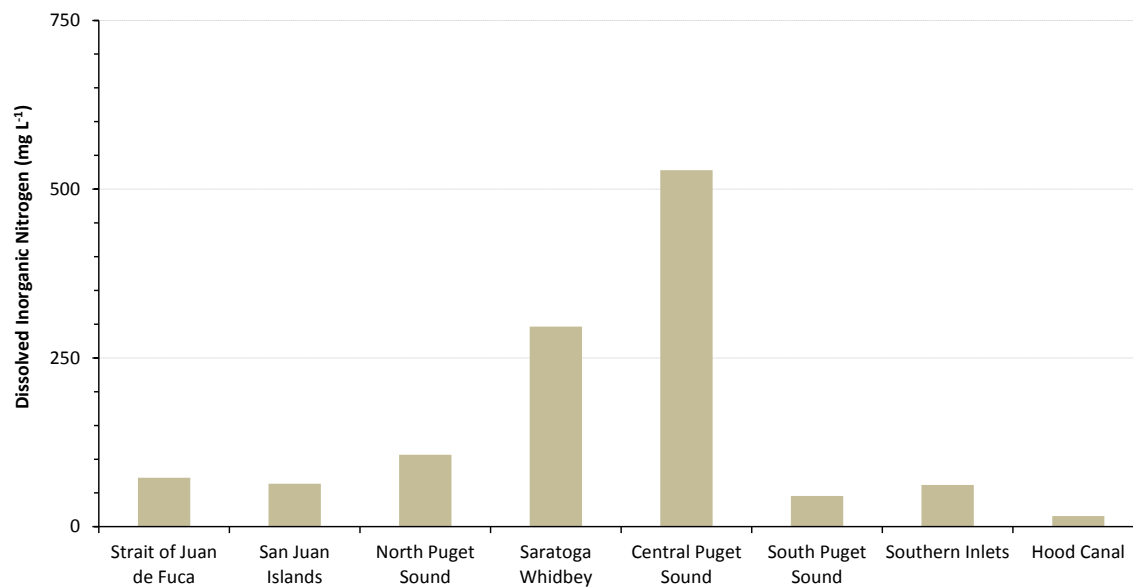


Figure 18. Dissolved Inorganic Nitrogen (DIN) loading into the Puget Sound basins from NPDES municipal outfalls (Mohamedali et al. 2011).

Ten of the major 15 rivers drain United States watersheds and contribute DIN loads to Puget Sound. The remaining five rivers drain from Canada into greater Puget Sound. The largest river loading of DIN is from the Fraser River, with over 33,000 kg/day of DIN, which is over five times the loading of the Snohomish River located in the Saratoga-Whidbey basin (Table 8).

Table 8. Contribution of daily DIN loads from rivers throughout the greater Puget Sound basins (adapted from Mohamedali et al. 2011).

Basin	Number of Rivers	River DIN (kg/day)	Percent of Total
Strait of Juan de Fuca	7	477	2.1%
San Juan Islands	3	390	1.7%
North Puget Sound	4	5,751	25.6%
Saratoga-Whidbey	4	5,945	26.5%
Central Puget Sound	12	4,941	22.0%
South Puget Sound	7	2,596	11.6%
Southern Inlets	9	1,524	6.8%
Hood Canal	11	811	3.6%
TOTALS	57	22,435	100.0%

In Puget Sound, wastewater treatment plants contribute nearly 60% of the annual DIN loading (Table 8 and Table 9; Mohamedali et al. 2011).

Table 9. Contribution of daily DIN loads from NPDES municipal outfalls throughout the greater Puget Sound basins (adapted from Mohamedali et al. 2011). Data represents NPDES outfalls with known DIN values.

Study Area	Number of NPDES municipal outfalls	Outfall DIN (kg/day)	Percent of Total
Strait of Juan de Fuca	8	344	1.0%
San Juan Islands	7	26	0.1%
North Puget Sound	12	1,728	5.0%
Saratoga-Whidbey	18	3,471	10.1%
Central Puget Sound	28	26,164	76.3%
South Puget Sound	5	2,316	6.8%
Southern Inlets	7	226	0.7%
Hood Canal	2	1	0.0%
TOTALS	87	34,276	100.0%

Dissolved inorganic nitrogen (DIN) loads from Canadian wastewater treatment plants and rivers exceed loads from US counterparts (Mohamedali et al. 2011), but are not discussed

in detail in this report. One consideration for excess loading in Canadian sources is the sheer size of the Fraser River and the lack of wastewater treatment at some locations. For example, wastewater from Victoria, BC, lacks advanced treatment prior to being discharged into the Strait of Juan de Fuca and Haro Strait. The immediate impact is unknown but likely affects water quality conditions in the North Puget Sound, San Juan Islands, and the Strait of Juan de Fuca basins.

4 Discussion

4.1 Human Population in Puget Sound

Human population is increasing in the Puget Sound region and it is anticipated that more than 1.5 million more people will reside in the area by 2025 (www.psparchives.com). Populated and developed areas depend on wastewater treatment facilities and outfalls to treat and convey wastewater, surface, and stormwater to receiving areas. Most of the treated wastewater within the eight basins is discharged directly into the waters of greater Puget Sound or into major tributaries. The location of the discharge from outfalls varies from the edge of a bluff, seawall or the mouth of a river to a range of distances and depths offshore. The types of outfalls that discharge into the nearshore waters include: municipal and industrial wastewater outfalls, combined sewer overflow (CSO) outfalls, man-made and natural forming surface and stormwater outfalls. The effluent from these outfalls can be treated in the case of municipal and industrial wastewater. Untreated effluent is discharged at highest volumes through CSOs and, to a lesser degree, via man-made and natural forming surface and stormwater outfalls.

Highly populated areas (such as Urban Growth Areas) are connected to sewage treatment facilities but rural areas (i.e. Strait of Juan de Fuca, Hood Canal) rely heavily on the use of septic systems for waste water management. There are continued efforts to connect more communities to waste treatment in the region (i.e., sewage system in Belfair). Human nitrogen contributions are expected to increase as a result of future population growth and land use change (Roberts et al. 2014). It is anticipated through modelling that the combination of natural and anthropogenic nutrient loads will affect DO in areas of the Central Puget Sound, Southern Puget Sound and the Southern Inlets basins (Ahmed et al. 2014). To respond to increasing loading, demand for enhanced treatment beyond what is currently practiced at both waste water treatment plants and septic systems is anticipated.

4.2 Loading Sources

4.2.1 Permitted Outfalls

Municipal and industrial permitted outfalls include discharge from a range of residential, commercial and industrial sources, while combined sewer overflows are outfalls that are designed to handle overflow of similar wastewater during periods of high rainfall or snowmelt. Combined Sewer Overflows (CSOs) discharge directly to nearby streams, lakes, and harbors, discharging not only stormwater but also untreated human and industrial

waste, toxic materials, and debris. However, the cumulative effects of CSOs are not fully understood as additional CSOs drain into water bodies (e.g., Lake Washington and Lake Union) that ultimately discharge into Puget Sound.

4.2.2 Distribution

Eelgrass requires favorable environmental conditions (e.g., clear, low turbidity water) with adequate light, to survive and persist. While there is evidence that effluent from outfalls can degrade water quality (see Gaeckle 2012), it is difficult to demonstrate a cause and effect relationship between eelgrass decline and outfall effluent due to many variables (e.g., tidal circulation, hydrodynamics, and other confounding stressors). However, it is well documented that increased development in coastal and estuarine areas, such as increases in housing units and population density, intensifies vulnerability of nearshore habitat, such as eelgrass beds (Short and Burdick 1996, Orth & Moore 1993, Dennison et al. 1993). With continued population growth in the Puget Sound area, the proximity of outfalls to eelgrass beds and the health of those beds could be a preliminary way to assess whether certain areas are likely to be vulnerable to the effects of poor water quality associated with outfalls. Although the focus of this report was to provide spatial specificity between outfalls and eelgrass throughout Puget Sound, the available data do not allow such fine scale analysis. Currently, there is no comprehensive understanding of the specific location of eelgrass throughout Puget Sound. ShoreZone (2001) characterizes eelgrass presence in shoreline segments of varying length throughout the Sound. While the SVMP samples sites at random throughout greater Puget Sound, the program has only completed 15% of the total number of available sites. A more comprehensive and accurate assessment of eelgrass presence in greater Puget Sound can improve insight on areas that may be at risk due to the effects of increase loading over time.

4.2.3 Distance from Shore

Outfalls that discharge along the shoreline will likely have the potential for greater impacts on the nearshore environment, specifically in the case of eelgrass, because of the potential effects on environmental characteristics, such as water quality and clarity. The Central Puget Sound and the Saratoga-Whidbey basins have the highest number of outfalls that discharge within 100 m of shore (Table 3).

Conduits, or stormwater drainage structures, that discharge above the high water mark create channels across the intertidal and subtidal zones. Many of these stormwater drains remove rainwater and other runoff from roads and residential or commercial properties and are often heavily loaded with metals and organic contaminants (EnviroVision et al. 2008b, Hart Crowser et al. 2007). The outfall assessment conducted by Carmichael et al. (2009) is the only comprehensive inventory of drainage pathways into Puget Sound, but there are caveats to this inventory. Although the inventory was conducted soundwide, it was limited due to the data provided by each jurisdiction at the time of inquiry and the inventory

omitted some conduits (e.g., tightlines, pipes, downspouts) or other input sources (e.g., sheet flow, groundwater) that redirect stormwater into the Sound but are not regulated by municipalities or the Washington State Department of Ecology. These sources may have a negative impact on eelgrass by adding nutrients and contaminants directly into the nearshore habitat and by scouring nearshore sediments.

Septic systems, designed to facilitate the removal of pathogens and nutrients, can add a significant source of contamination to nearshore environments (De Sienes 2011). Furthermore, many septic systems were designed for seasonal use in homes that have now been converted to year round residences. The increased use saturates soil leading to greater seepage into nearshore environments reducing salinity and increasing nutrient and contaminant loads (Short and Burdick 1996).

The management of residential and commercial waste and stormwater varies throughout greater Puget Sound. In many communities, these systems are separated where residential and commercial waste is treated at municipal waste water treatment facilities while stormwater flows directly into nearby lakes, rivers, and Puget Sound. In some communities (e.g., Seattle), sewer pipes convey both residential and commercial waste and stormwater through CSOs. When the system is overtaxed with rainwater, these pipes release untreated waste directly into lakes, rivers, and Puget Sound. Again, the loading directly into the nearshore may have adverse impacts on nearshore habitats such as eelgrass beds.

4.2.4 Discharge Depth

There is an abundance of eelgrass along the shores and across vast flats in the Central Puget Sound and Saratoga-Whidbey basins (Gaeckle et al. 2011, ShoreZone 2001), the basins with the highest population density and density of outfalls per kilometer of shoreline. These two basins also have the highest number of CSOs – a major source of untreated effluent during high flow events. The potential effect on eelgrass from the quantity of outfalls (and associated loading) in the Central Puget Sound and Saratoga-Whidbey basins could be detrimental to eelgrass considering the anticipated population growth over the next decade.

In the other basins of Puget Sound, there is an abundance of outfalls that discharge in waters shallower than 30 m (MLLW, Figure 10). Although the specifications of these outfalls meet the dilution criteria set by the NPDES permit process, the potential for the effluent to affect marine vegetation such as eelgrass is unknown. Some of the outfalls discharge in waters as shallow as -10 m (MLLW) or less, the potential depth zone for eelgrass throughout much of the Sound. The concern for such shallow outfall discharge depths is that nearshore waters risk becoming loaded with nutrients that can cause nuisance algal blooms and an increase in fine particulates, both of which affect eelgrass growth, productivity and resilience (Dennison et al. 1993, Kenworthy and Haurert 1991,

McGlathery 2002, Nielsen et al. 2002). The effect that these shallow discharge points could have on eelgrass is of greater concern considering the projected influx of 1.5 million more people into the region which will lead to greater discharge volume and loads.

It is evident from the scientific literature that excess nutrient loads promote phytoplankton and algae blooms, and epiphytic growth on eelgrass (Short et al. 1995, Short and Burdick 1996). Therefore, it is assumed that outfalls, that discharge into depths where eelgrass primarily grows (shallower than -10 m, MLLW), may have the greatest likelihood of causing impacts to the habitat compared to outfalls that discharge in deeper, well circulated, waters. However, it is not clear what the cumulative effects of effluent from deeper outfall discharge points could be on nearshore habitats or the health of Puget Sound in general.

4.2.5 Outfall Discharge Volume

As expected, due to population density (Table 1), the Central Puget Sound basin receives the largest volume of wastewater discharge compared to the other basins in the Sound (Section 3.2.1.5, Figure 11). The Central Puget Sound basin contains the two largest outfalls in terms of loading to greater Puget Sound followed by outfalls in South Puget Sound, Saratoga-Whidbey and North Puget Sound basins and as a result loading is greatest for these areas. An increase in population density in the absence of expanded beneficial reuse or advanced treatment will lead to increased discharge volumes with high levels of nitrogen and phosphorus that should raise concerns over potential impacts to eelgrass. Models already predict impacts from dissolved oxygen due to increased human derived nitrogen in basins with longer residence times such as the Southern Puget Sound and Southern Inlets (Roberts et al. 2014). It is also possible that water quality conditions in the North Puget Sound and the San Juan Islands basins may be affected due to increased discharge volume from Canadian cities and more year-round use of seasonal residences.

Enhancements in wastewater treatment will improve nearshore habitats that require good water quality, particularly those that will be affected by changes in available light. One such improvement is the development of treatment plants that conduct upland disposal of treated waste as demonstrated by the Belfair Wastewater and Reclamation Facility. Upland disposal will reduce the amount of nutrients and particles discharged into Puget Sound. Loading from wastewater treatment sources has a potential to cause stress on eelgrass by affecting water quality with sediments, nutrients, metals, organic contaminants and toxics (Lewis and Devereux 2009).

4.2.6 Rivers

River and streams transport a wide range of materials and substances into Puget Sound such as sediments, nutrients, wood debris, treated sewage, surface runoff, metals and

organic contaminants. Natural river discharge and sediment loads are essential for maintaining riverine, estuarine and nearshore coastal processes and associated habitats.

River discharge rates and flow patterns have changed with the development of lower estuaries and deltas for commercial, residential and industrial interests. Stretches of many of the rivers flowing into Puget Sound are now channelized and lack heterogeneity caused by natural meandering distributaries. The concentration of many distributaries into a few river channels increases and focuses water and sediment discharge across deltaic areas. In the Skagit River, a system with water and sediment discharge rates that far exceed the amount from the other major rivers in greater Puget Sound (Czuba et al. 2011), current discharge patterns and rates may limit eelgrass across the intertidal and shallow subtidal environment of the delta (Grossman et al. 2011, Grossman 2013). Similar changes at other rivers may be limiting eelgrass elsewhere in Puget Sound.

4.2.7 Chemical Loading: Metals and Contaminants

The suite of chemicals entering Puget Sound from various sources is alarming. However, the effect these chemical have on eelgrass is not well understood. Seagrass is shielded from certain contaminants because of the structural integrity of the plant and antibacterial biofilm on the leaves (Gunnarsson et al. 1999). Direct physical damage to eelgrass and its habitat such as the installation of outfalls or the scour from effluent, is often irrecoverable. Other impacts are caused by changes in water quality that create unfavorable conditions for eelgrass such as extreme changes in temperature or other chemical constituents that can affect seagrass physiology and cause immediate loss of habitat (Lewis and Devereaux 2009).

Although evidence exists that seagrass can be used as an indicator of metals (Govers et al. 2014) and other chemicals in the marine environment (Lewis and Devereaux 2009), little evidence suggests seagrass bio-accumulate these chemicals to lethal levels. It is clear, however, that concentrations of certain chemicals can cause physiological impairment, such as affecting photosynthetic processes, in seagrass (Lewis and Devereaux 2009).

The greatest impact from chemical loading on eelgrass will likely be outfalls or sources that discharge directly into eelgrass beds. There are 24 NPDES outfalls that discharge in less than 10 m of water, and a large number of CSOs that drain stormwater and untreated sewage from high density, urban growth areas, during periods of excess precipitation and flow. Stormwater tends to have some of the highest loading rates of chemicals from developed areas (EnviroVision et al. 2008a, 2008b, Hart Crowser et al. 2007). The highest concentration of CSOs are in the Central Puget Sound, Saratoga-Whidbey, and North Puget Sound basins (Figure 7c).

4.2.8 Dissolved Inorganic Nitrogen (DIN)

Puget Sound receives nitrogen through natural pathways including atmospheric deposition, oceanic upwelling, and upland runoff from natural areas. The addition of anthropogenic nitrogen, from outfalls, rivers and stormwater runoff, can be detrimental to eelgrass in certain areas. In Puget Sound, it is estimated that the average annual dissolved inorganic nitrogen (DIN, sum of ammonium, nitrite, and nitrate) loading from anthropogenic sources is 2.7 times the natural loading conditions from the watershed (Mohamedali et al. 2011). Annual DIN loads from anthropogenic sources are greatest in the Central Puget Sound basin and almost entirely a result of discharge from residential wastewater treatment facilities. The DIN loads between Edmonds and the Tacoma Narrows bridge, an area with the greatest concentration of outfalls (Carmichael et al. 2009), were 3.6 times the average for greater Puget Sound, not including the Strait of Juan de Fuca (Mohamedali et al. 2011). The continued addition of DIN in excess of natural conditions may shift the nutrient balance in some areas of Puget Sound with a risk of developing eutrophic conditions that are less suitable for eelgrass.

5 Conclusions

For decades the discharge of unmediated anthropogenic waste into aquatic systems was the norm, with the understanding that the pollution would be diluted by receiving waters. As human population increased, wastewater management was necessary to minimize impacts to human health and natural systems from outfall discharges (e.g., Clean Water Act 1948, 1972, NPDES permit process). The development of sewage treatment facilities and advancements in technology improved effluent quality in systems regulated by the Clean Water Act. Even so, systems still discharge into greater Puget Sound that do not apply the highest level of treatment technology or lack treatment altogether (e.g., CSOs and effluent from Victoria, BC, Canada). The effects of wastewater, whether through a permitted outfall, down a stormwater drain, or diluted in a major river, are difficult to identify and monitor. It is a challenge to adequately capture the broad nature of the direct and indirect physical, biological and chemical effects of discharges into Puget Sound. Additionally, it is difficult to tease apart the effects of individual outfalls from the cumulative impacts of approximately 100 wastewater treatment plants and thousands of other discharge pipes in Puget Sound (Carmichael et al. 2009, Mohamedali et al. 2011, PARIS 2014).

Eelgrass is considered an indicator of ecosystem health (Dennison et al. 1993, Krause-Jensen et al. 2005, Orth et al. 2006), and has been identified as an indicator species to track the recovery of Puget Sound. To further assess stressors that cause eelgrass decline in the Sound (Thom et al. 2011), it is important to understand what effects additional loading beyond natural sources has on eelgrass particularly since increases in loadings are projected (Roberts et al. 2014). Outfalls that discharge residential, commercial, and industrial wastewater along with upland stormwater are abundant throughout developed coastal areas, particularly in Puget Sound. Outfall impacts to eelgrass range from physical effects on the environment where it grows, such as the installation of an outfall pipe, to physiological effects on the plants caused by shading due to nutrient triggered plankton blooms or compromised photosynthetic potential because of metal or contaminant toxicity (Lewis and Devereux 2009).

The areas within Puget Sound where eelgrass is most at risk include locations along the eastern side of the Sound where population density is highest (e.g., urban growth areas), near outfall discharge points, and at the mouths of major rivers. However, the major outfall discharge points that would be a direct source of contamination for eelgrass typically discharge deeper than the extent of existing eelgrass beds in Puget Sound (e.g., West Point Wastewater Treatment Plant, Brightwater Treatment Plant). Most other treatment facilities in Puget Sound discharge at or beyond the deepest extent of eelgrass (Figure 10).

Other discharge points of concern include CSO and stormwater outlets. These sources typically discharge near eelgrass beds and tend to contain high concentrations of nutrients, metals, and contaminants. CSOs are mostly contained in areas of high population density near major cities (e.g., Seattle, Bremerton, Everett, Anacortes, Bellingham; Figure 7c), most of which have eelgrass growing along the waterfront (ShoreZone; Figure 12).

Another area of concern where eelgrass may be affected includes major river deltas that have high flow and sediment discharge and contain inputs from sewage treatment facilities among other upland sources. Eelgrass is currently growing at most of the major river deltas but restoring historical flow volumes, drainage patterns and filtration potential may enhance eelgrass across deltaic fronts (Grossman 2013, Grossman et al. 2011). In addition, improvements in sewage treatment will only enhance riverine water quality and provide a range of benefits downstream and into the Sound.

Recommendations:

- Promote inter-agency coordination to conduct research that evaluates nutrient sources and assesses the impacts of loading to the Puget Sound nearshore.
- Conduct research to evaluate the effects of nutrient and sediment loading on eelgrass beds in Puget Sound, including conditions in which changes in dissolved oxygen concentrations are both below and above the regulatory threshold.
- Analyze eelgrass trends related to changes in treatment and location of current outfall discharges to isolate nitrogen impacts.
- Evaluate the effects of Combined Sewer Overflow and stormwater discharge on eelgrass to determine strategies to redesign systems that minimize impacts to this critical habitat.

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7 Appendix

Appendix A – Data sources

Data Source	Citation	Data Collection Timeline	Outfall	River	Eelgrass	Sediment	Population	Other
US Census 2000	U.S. Census Bureau 2000	2000					x	
US Census 2010	U.S. Census Bureau 2010	2010					x	
Puget Sound Dissolved Oxygen Model Nutrient Load Summary for 1999 - 2008	Mohamedali et al. 2011	1999-2008	x	x				
USGS River Sediment Loading	Czuba et al. 2011	1981		x		x		
Temporal Monitoring of Puget Sound Sediments: Results of the Puget Sound Ambient Monitoring Program, 1989 – 2000	Partridge et al. 2005	1989				x		
Control of Toxic Chemicals in Puget Sound: Assessment of Selected Toxic Chemicals in the Puget Sound Basin, 2007 - 2011	Norton et al. 2011	2006-2007	x	x		x		x
Control of Toxic Chemicals in Puget Sound: Improved Estimates of Loadings from Dischargers of Municipal and Industrial Wastewater	EnviroVision & Herrera 2008	2006-2007	x					
Washington State Water Quality Permit Data	PARIS	present	x					
Washington State Water Quality	Water Quality	present	x					

Assessment Program	Assessment Program 2014							
ShoreZone	ShoreZone 2001	2000-2007			x			