FINAL

External Nutrient Loads to Willard Spur, Great Salt Lake, 2011–2013: Development of Water Quality Standards for Willard Spur

Prepared for

Utah Division of Water Quality

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Executive Summary

Concerns about potential impacts from the Perry Willard Regional Wastewater Treatment Plant (Plant) on Willard Spur led to an extensive effort to develop estimates of surface water nutrient loads transported into Willard Spur. The goal was to understand the quantity, timing, and relative contribution of all external surface water nutrient sources to Willard Spur, including those from the Plant.

Conditions within Willard Spur from 2011 through 2013 were extremely dynamic and driven by wide-ranging inflows of surface water from Bear River Basin, a local East Side Drainage Basin, and Weber River Basin. The year 2011 was a wet one, with high inflows and nutrient loads. The years 2012 and 2013, by contrast, were characterized by a significantly smaller volume of surface water inflow and corresponding smaller nutrient load. The Bear River Basin contributed the vast majority of the surface water nutrient load, representing more than 82 percent of the total phosphorus load and 71 percent of the total nitrogen load during the months that were evaluated each year. The Plant's "end-of-pipe" effluent represented a contribution of less than 5 percent of the total external surface water nutrient load during the months that were evaluated each year.

As surface water inflows and nutrient loads decreased during dry summer months, the Plant's relative nutrient contribution increased. The Plant's relative end-of-pipe nutrient contribution increased to up to 33 percent of the total phosphorus surface water load and up to 25 percent of the total nitrogen surface water load during summer months to Willard Spur. This change was a result of reductions in other sources of surface water inflow and nutrient loads observed during these months while the Plant's effluent flow rate remained consistent.

Much of the Plant's effluent was observed to be lost during the summers of 2012 and 2013 to evaporation and infiltration as the effluent traveled through and across the vegetation and mudflats on its way to the open water. Importantly, the Plant's effluent did not reach the open water of Willard Spur during most if not all of each month in the period of July–October for both 2012 and 2013; during the same period, Willard Spur was impounded, with no outflow to Bear River Bay.

The impounded condition is considered to be the critical condition for Willard Spur, one where the Plant has the potential to have the most impact upon water quality. Nutrients from Plant effluent that may reach the impounded open water are likely retained and assimilated until the higher, flushing flows return in the fall. Nutrients from Plant effluent that reach the open water during a flowing condition are more likely to be diluted, dispersed, assimilated, and exported to Bear River Bay.

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Acronyms and Abbreviations

BOD	biochemical oxygen demand
BOD_5	5-day biochemical oxygen demand
BRMBR	Bear River Migratory Bird Refuge
GSL	Great Salt Lake
HCWMA	Harold S. Crane Waterfowl Management Area
L	liter
mg	milligram
PDSI	Palmer Drought Severity Index
TKN	total Kjeldahl nitrogen
UDWQ	Utah Department of Environmental Quality, Division of Water Quality
UDWR	Utah Department of Natural Resources, Division of Wildlife Resources
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

Introduction

The characteristics of Willard Spur, located within Great Salt Lake's (GSL) Bear River Bay (see Figure 1 for vicinity map), were relatively unknown at the outset of this project. There were only a few data points describing the chemistry of the water in Willard Spur, and no data describing nutrient loading to Willard Spur. Central to determining the impact of the Perry Willard Regional Wastewater Treatment Plant (Plant) upon Willard Spur was understanding how the Plant's effluent might impact the ecology of Willard Spur. Would the effluent from the Plant constitute a large influx of nutrients, exceeding the assimilative capacity of the system and impairing Willard Spur's beneficial uses? This study was designed with the objective of understanding external surface water nutrient loads to Willard Spur so that, in conjunction with the Plant's effluent, their impact on Willard Spur's beneficial uses could be determined.

1.1 Background

Construction of the Plant was completed in 2010. Utah Department of Environmental Quality, Division of Water Quality (UDWQ) received numerous comments as part of the public notice process for the Plant's Utah Pollutant Discharge Elimination System permit to discharge to Willard Spur. Many of these comments expressed concern over the potential impact the effluent could have on the water body. Further, the groups who provided comments also petitioned the UDWQ to prohibit all wastewater discharges to Willard Spur or to alternatively reclassify Willard Spur to protect the wetlands and current uses of the water.

Although the Utah Water Quality Board denied the petition, the Water Quality Board directed UDWQ to develop a study design to establish defensible protections (site-specific numeric criteria, antidegradation protection clauses, beneficial use changes, etc.) for the water body. The Water Quality Board also directed UDWQ to pay for phosphorus reductions at the Plant while the study was conducted. This path forward, developed in conjunction with stakeholders, allowed the Plant to operate while the studies were underway, with reasonable assurances that the effluent would not harm the ecosystem.

Understanding the dynamics and complexity of the Willard Spur food web, how it is interwoven with the varying and unique habitat and hydrology, and the role water quality serves as a critical linkage is the challenge that UDWQ's Development of Water Quality Standards for Willard Spur project (Project) begins to address.

1.2 Site Description

Willard Spur is a unique and dynamic ecosystem located in the eastern part of the Bear River Bay of GSL (see Figure 1). Willard Spur encompasses over 11,780 hectares (approximately 29,100 acres, or almost 45.5 square miles) of wetlands with almost 20 percent of that area contained within the Bear River Migratory Bird Refuge (BRMBR). Its waters are generally bounded on the north by the southern dike of the BRMBR (also known as the D-line Dike), on the east by the natural rise of topography and eventually Interstate 15, and on the south by the northern dikes of Willard Bay Reservoir, the Harold S. Crane Waterfowl Management Area (HCWMA), and Great Salt Lake Minerals. The waters and mudflats of Bear River Bay stretch to the west of Willard Spur. The open waters of GSL are located south of Bear River Bay. This study focuses only on the open waters of Willard Spur as shown in Figure 1.

The unique habitat of Willard Spur varies dynamically throughout any given year and is directly linked to the hydrologic cycle of GSL's watershed. Willard Spur is where GSL's saline waters and fresh water entering from the Bear River and Weber River Basins begin to mix when lake levels exceed approximately 4,201.9 feet (CH2M HILL, 2014a). Fresh water entering Willard Spur from the Bear River and Weber River Basins makes up an average of 42 percent of the total annual inflow to GSL (HDR Engineering, Inc., 2014). When GSL water levels fall below an elevation of approximately 4,201.9 feet, Willard Spur no longer mingles with GSL's saline waters, and its habitat is then controlled largely by the freshwater inflows. Great Salt Lake was last at an elevation of 4,201.9 feet in July 2000; Willard Spur has since been transitioning into freshwater-dominated wetlands (U.S. Geological Survey (USGS), 2011). As inflows to Willard Spur decrease and water levels in Willard Spur drop, a natural rise in the lake bottom on the western boundary of Willard Spur (locally known as the "sand bar") disconnects the waters of Willard Spur from Bear River Bay and the waterbody becomes a natural impoundment. This can happen on an annual basis depending on available inflows.

The U.S. Fish and Wildlife Service (USFWS) has developed five management categories describing different habitat in the Willard Spur wetlands within the boundaries of the BRMBR (USFWS, 2004). The areal extent of each of these categories is largely dependent on the hydrology in a given growing season:

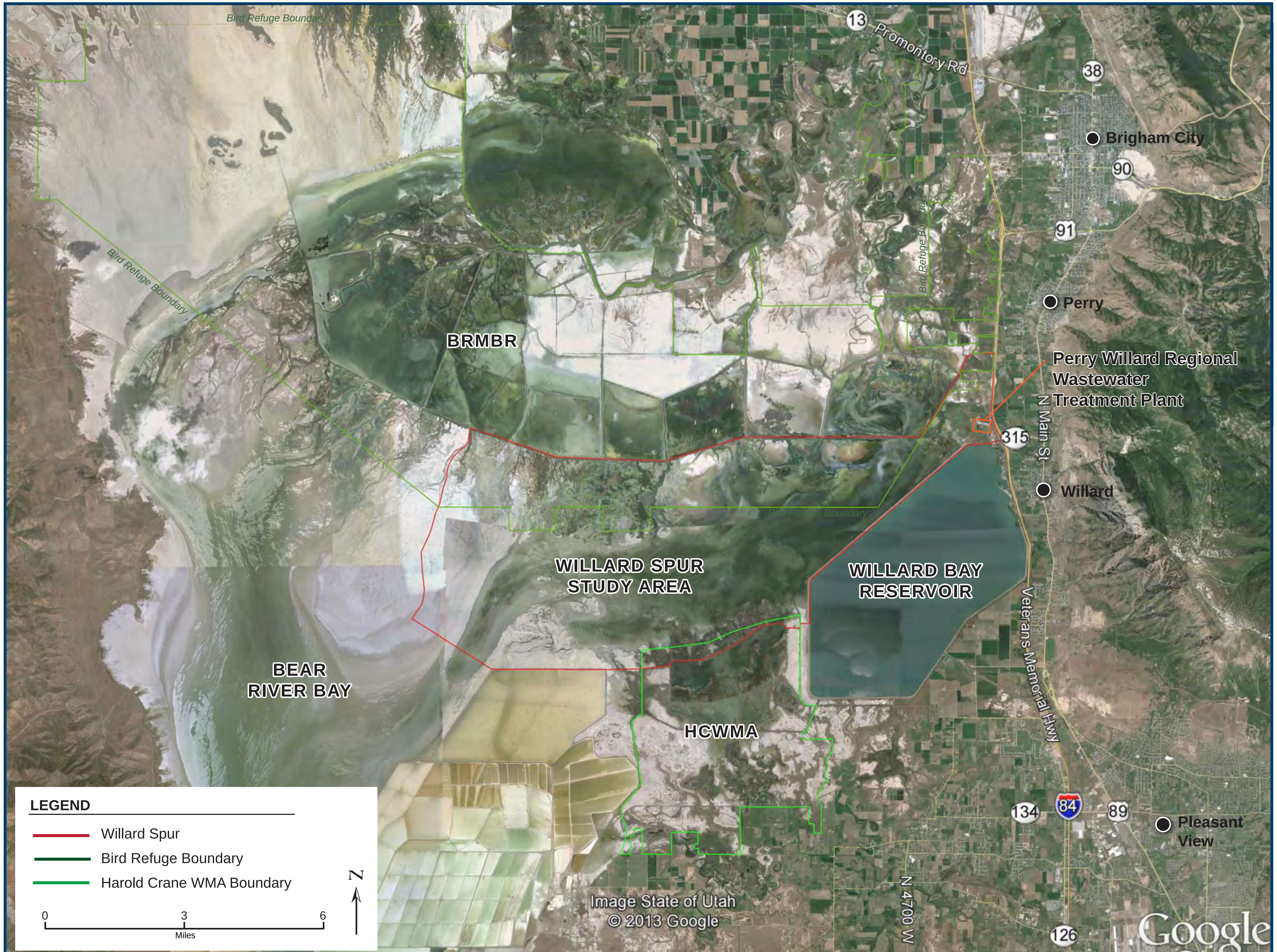
- Deep submergent wetlands (18–24 inches of water, dominated by sago pondweed [*Stuckenia pectinata*] with very little emergent vegetation)
- Shallow submergent wetlands (4–18 inches of water, dominated by sago pondweed with sparse emergent vegetation)
- Mid-depth emergent wetlands (8–12 inches of water, 50 percent emergent vegetation with alkali bulrush [*Schoenoplectus maritimus*] largely in shallower areas and hardstem bulrush [*Schoenoplectus acutus*] in deeper areas, large stands of cattails [*Typha latifolia and T. angustifolia*] and phragmites [*Phragmites australis*] possible)
- Shallow emergent wetlands (2–8 inches of water, predominantly alkali bulrush, some stands of cattails, and phragmites)
- Vegetated mudflats (0–2 inches of surface water during high-inflow periods or large precipitation events, highly saline soils, often unvegetated, can support shallow-rooted vegetation such as pickleweed [*Salicornia rubra* and *S. utahensis*], saltgrass [*Distichlis spicata*], and seepweed [*Suaeda calceoliformis* and *S. moquinii*])

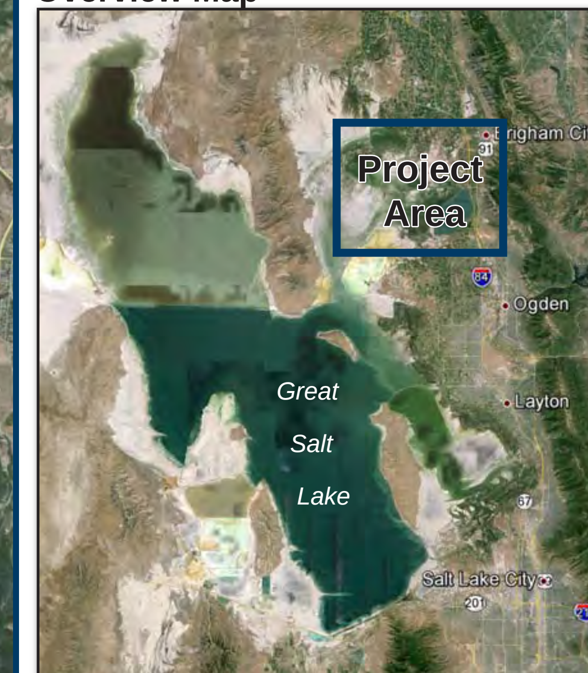
The varied habitat that Willard Spur provides is a haven for birds and fish; the immense populations of birds are perhaps what Willard Spur is most well known for. USFWS has documented over 210 bird species that regularly use the adjacent BRMBR, at least 67 of which nest in the area. The vegetation, macroinvertebrates, and fish the wetlands of BRMBR and Willard Spur provide are ideally suited for these migrating populations of waterfowl, shorebirds, and other waterbirds from the Pacific Flyway and Central Flyway. These waters, in conjunction with other waters of GSL, were recognized for their importance to shorebirds as a Western Hemisphere Shorebird Reserve Network Site in 1992 (USFWS, 2004).

1.3 Hydrologic Context

The water depth, surface area, and salinity of Willard Spur vary largely as a result of changes in inflow from precipitation, tributaries, and groundwater, as well as from losses through evaporation. Understanding the watershed's recent hydrologic regime helps to place Willard Spur's response during the study period in context.

The study period (2011–2013) provided a unique opportunity to observe the dynamics of Willard Spur during both very wet and dry periods. One of the indices used by the State of Utah to define and compare cumulative drought events, the Palmer Drought Severity Index (PDSI), indicates that Willard Spur's watershed moved from a very wet period in 2011 into a drought condition during 2012 and 2013 (Utah Division of Water Resources, 2007). Table 1 and Figure 2 illustrate the PDSI for Utah climate division 5 (largely representing the Bear River and Weber River watersheds). The same pattern is illustrated in terms of Bear River flow rates at Corinne and Great Salt Lake water levels at Saltair as measured by USGS (see Figure 2). An analysis of Bear River flows at Corinne for the time period of 1950-2013 (minus 1957-1963 due to inadequate data) reveals that the annual flow volume in 2011 was in the 84th percentile, while flow





Aerial image © Google Earth, 2013. Image Dates 8/11/2011 and 6/4/2013. Annotation by CH2M HILL, 2014.

FIGURE 1
Vicinity Map of BRMBR and Willard Spur
Flow Measurement Methods at BRMBR

volumes in 2012 and 2013 were only in the 29th and 7th percentiles, respectively. The range of conditions observed during 2011–2013 presented an excellent opportunity for the project to characterize the ecosystem of Willard Spur for wide-ranging conditions.

Table 1. Palmer Drought Severity Index for 2011–2013 for Utah Climate Division 5

Study Period (2011–2013)	PDSI Category
January–March 2011	(+3.0 to +3.9) Very Wet
April–July 2011	(+4.0 and above) Extremely Wet
August 2011 through February 2012	(-1.9 to +1.9) Near Normal
March–April 2012	(-2.0 to -2.9) Moderate Drought
May 2012 through August 2013	(-3.0 to -3.9) Severe Drought
September–December 2013	(-2.0 to -2.9) Moderate Drought

http://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php

1.4 Document Organization

The remainder of this document is divided in the following sections:

- Section 2 defines the objectives for the overall project, specifically for the nutrient study.
- Section 3 provides a summary of the considerations, assumptions, and methodology used to evaluate the nutrient cycling of Willard Spur.
- Section 4 provides a summary of the results of the nutrient study.

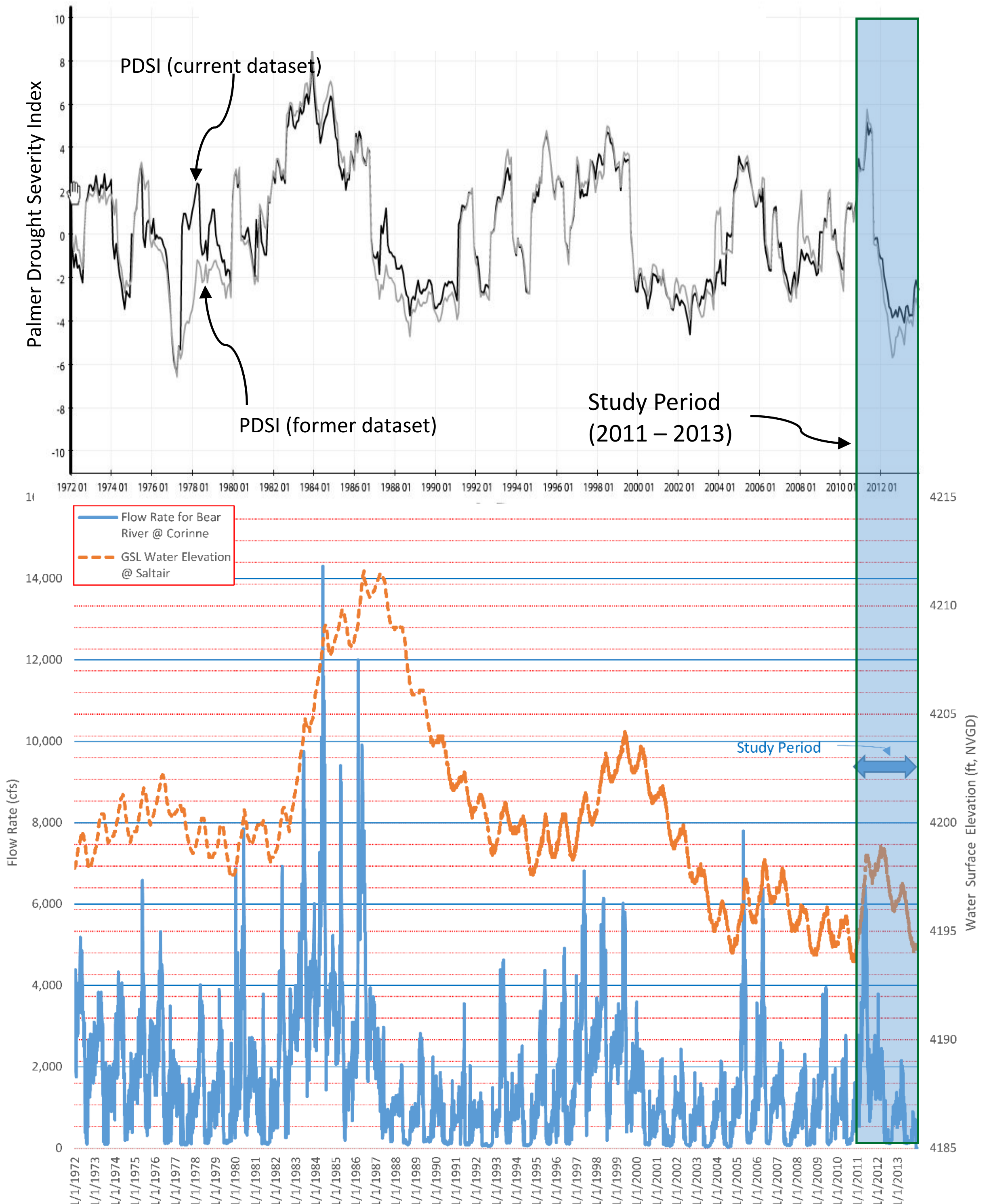


Figure 2. Variations in Palmer Drought Severity Index, Bear River Flows, and Great Salt Lake Water Elevations for 1972–2013

http://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php

SECTION 2

Objectives

The objective of the Project was to determine appropriate and defensible modifications to Utah's water quality standards to provide long-term protection of Willard Spur's aquatic life uses. Central to achieving this objective was the completion of research to answer two questions:

1. What are the potential impacts of the Plant on Willard Spur?
2. What changes to water quality standards will be required to provide long-term protection of Willard Spur as they relate to the proposed Plant discharge?

Research Area Number 2 (CH2M HILL, 2011a) focused on understanding the overall hydrology and nutrient loads to Willard Spur to better understand the influence of the Plant's effluent. The hydrology and external nutrient loads are the drivers of potential responses to nutrients within Willard Spur. The assessment of external, surface water nutrient loads to Willard Spur, as documented herein, used the best available information to quantify and evaluate external nutrient loads from surface water flowing into Willard Spur for the period of 2011 through 2013. This in turn informed an understanding of the ecosystem's dynamics, potential impacts from the Plant, and the development of long-term protection strategies. Some of the questions that this study attempted to answer include the following:

1. What are the contributions of nutrients from surrounding areas to Willard Spur? How do nutrient contributions change from these locations throughout the year?
2. What is the nutrient load from the Plant? How does this load change by the time it reaches the open water of Willard Spur?

This report summarizes the methods used and the results that were developed, and provides a discussion of key observations.

SECTION 3

Methods

An important means of evaluating and understanding the potential impacts from the Plant was to quantify external nutrient loads contributed by the various surface water inflows to Willard Spur. Monthly loads were compiled for all known surface water sources to Willard Spur and for various potential Plant operating scenarios. All nutrient load estimates reported herein represent “end-of-pipe” loads unless noted otherwise. That is, reported nutrient loads represent estimated loads where surface water entered the outer boundary of Willard Spur rather than at the confluence of the surface water inflow and the open water of Willard Spur. The load estimates do not account for the transformation and assimilation of nutrients as the water flows through vegetation, across mudflats, or is mixed within the open water within the boundary of Willard Spur. This section summarizes the methodology used to quantify external surface water nutrient loads to Willard Spur.

UDWQ worked closely with the Willard Spur Science Panel to develop comprehensive annual sampling and analysis plans. Each of the plans, the 2011 sampling plan, 2012 sampling and analysis plan, and the 2013 sampling plan, included a rigorous program of collecting water samples to augment flow monitoring at each of the inflow sites (see Figure 3) (CH2M HILL, 2011b, 2012, 2013) . Data were collected starting in April 2011 and completed during the growing season, generally from March through November of each year; collection ended in November 2013. Nutrient concentrations (total phosphorus, dissolved phosphorus, ammonia, total Kjeldahl nitrogen (TKN), nitrate, nitrite, and total nitrogen) were integrated with estimated flow rates to develop estimated daily nutrient loads for each inflow site for 2011–2013.

3.1 External Surface Water Sources

The project team completed an initial reconnaissance of the study area in late February 2011 to identify potential points of surface water inflows and nutrient loads to Willard Spur. The watershed contributing surface water to Willard Spur was divided into three basins: the Bear River Basin to the north (that is, BRMBR drainage), the East Side Drainage Basin, and the Weber River Basin to the south (HCWMA drainage) (see Figure 2). A total of 32 inflow points were sampled by UDWQ and USGS for the period of May 2011 through November 2012, and 21 were sampled between March 2013 and November 2013 using various methods and at various intervals, depending upon the site characteristics and volume of inflow. Daily values for water inflows were combined into hydrographs typically representing flows at the discharge point from the facility that is, end of pipe) and not accounting for gains or losses once the flow enters the mudflats, fringe wetlands, or open water of Willard Spur. Please see Hydrology Assessment of Willard Spur, Great Salt Lake, 2011–2013 (CH2M HILL, 2015) for a detailed discussion of surface water inflows for the study period. Surface water hydrographs were combined to represent 18 distinct external nutrient sources to Willard Spur and then used to estimate nutrient loads from each source.

3.1.1 Contributing Drainage Basins

3.1.1.1 Bear River Basin

There are 11 possible inflow points contributing surface water from the Bear River into Willard Spur through the BRMBR (see Figure 3). Inflows from the BRMBR to Willard Spur are highly dependent upon flows in the Bear River upstream of the BRMBR and upon the USFWS’s water management objectives at BRMBR. The Bear River represented the most significant source of inflow and nutrient loads for Willard Spur for all three years of the study period.

3.1.1.2 East Side Drainage Basin

There are three possible sources of inflow from the east side of Willard Spur:

- Local runoff through an irrigation return flow ditch
- Perry Willard Regional Wastewater Treatment Plant
- Willard Bay Reservoir (see Figure 3)

The Plant provided data documenting its effluent flow rates and location of discharge, and the Weber Basin Water Conservancy District provided data documenting water released from the Willard Bay Reservoir. UDWQ supplemented these data with measured flows in various ditches and the Willard Bay outlet structure and outlet channel.

While inflow from the East Side Drainage Basin is generally negligible, it represents in part the wastewater effluent of concern and potentially includes significant flows from the Willard Bay Reservoir. The Willard Bay Reservoir contributed significant flow to Willard Spur during the spring of 2011 but did not provide substantial flows after that.

3.1.1.3 Weber River Basin

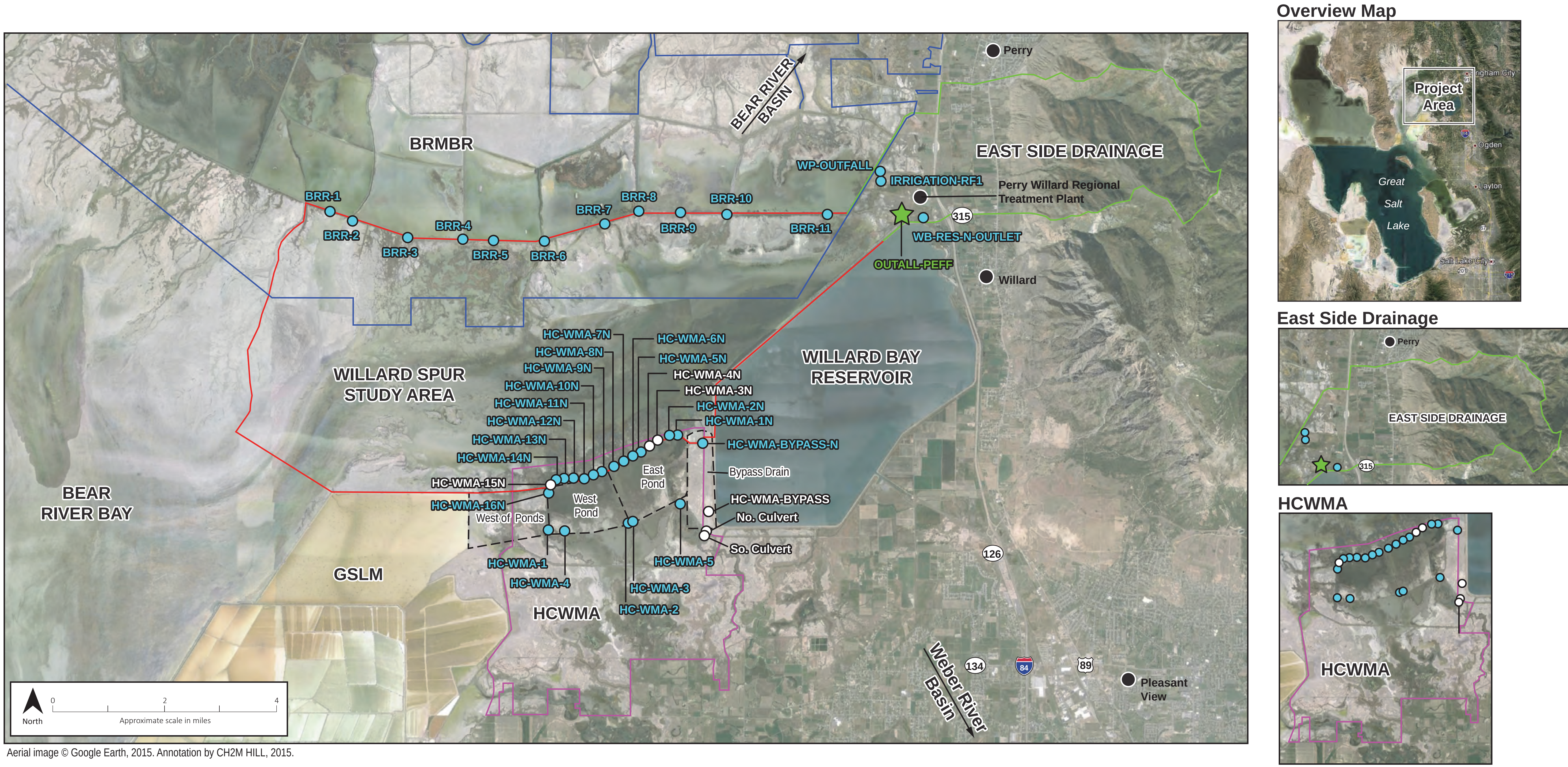
The second most significant source of inflow to Willard Spur was from the Weber River Basin via HCWMA. UDWQ worked closely with the Utah Department of Natural Resources, Division of Wildlife Resources (UDWR), to monitor flows through HCWMA's impoundments and bypass drain (see Figure 3). Nutrient loads were estimated for four different sources at the HCWMA: the bypass drain, east pond, west pond, and then from the mudflats west of the west pond. A significant peak flow from HCWMA observed during 2011 was a result of flood flows diverted from the Weber River Basin to HCWMA to minimize flooding in Weber County. Flows through HCWMA are generally consistent throughout the summer, likely due to the dominance of irrigation return flows delivered to HCWMA. While HCWMA appears to be a consistent source of water to the mudflats of Willard Spur, the percentage of the water that reaches the open water of Willard Spur appears to depend upon water levels in Willard Spur and evaporation and infiltration rates in the mudflats north of HCWMA.

3.1.2 Summary of Hydrology, 2011–2013

Conditions within Willard Spur from 2011 through 2013 were extremely dynamic and driven by wide-ranging inflows of surface water from Bear River Basin, Weber River Basin, and the East Side Drainage Basin. The year 2011 was a remarkably wet one characterized by an almost complete inundation of Willard Spur, water depths of up to 6 feet, and continuous outflow to Bear River Bay throughout the year. The years 2012 and 2013, by contrast, were characterized by a significantly smaller volume of surface water inflow, a complete cutoff of outflow to Bear River Bay when spring runoff was complete, a rapidly shrinking and even disappearing footprint of open water, but then a restoration of outflow to Bear River Bay during the subsequent winters and springs. The range of flood and drought conditions observed during the project's study period provided a unique opportunity to understand how external surface water nutrient loads to Willard Spur can vary.

Surface water inflows were dominated by contributions from the Bear River Basin and in almost all respects the surface water inflows were managed by water users at the fringes of Willard Spur. Water volumes contributed by the Plant were negligible compared to volumes from other surface water sources. Groundwater interactions were observed that could explain how surface water inflows from all sources, but in particular from the Plant, often failed to reach the open water impoundment of Willard Spur during the summer months of 2012 and 2013. The mudflats at the western edge of Willard Spur appear to serve as a natural weir that created the impounded condition and play a significant role in shaping the hydrologic and ecologic characteristics of Willard Spur.

Increasing surface water inflows, typically beginning at the end of the annual irrigation season (generally in mid-October), likely recharge the local groundwater table, raise the water level of the open water of Willard Spur, reconnect all surface water inflow sources directly to the open water, and then flow out to Bear River Bay through May or June of the subsequent year. A review of historical aerial photography indicates that an

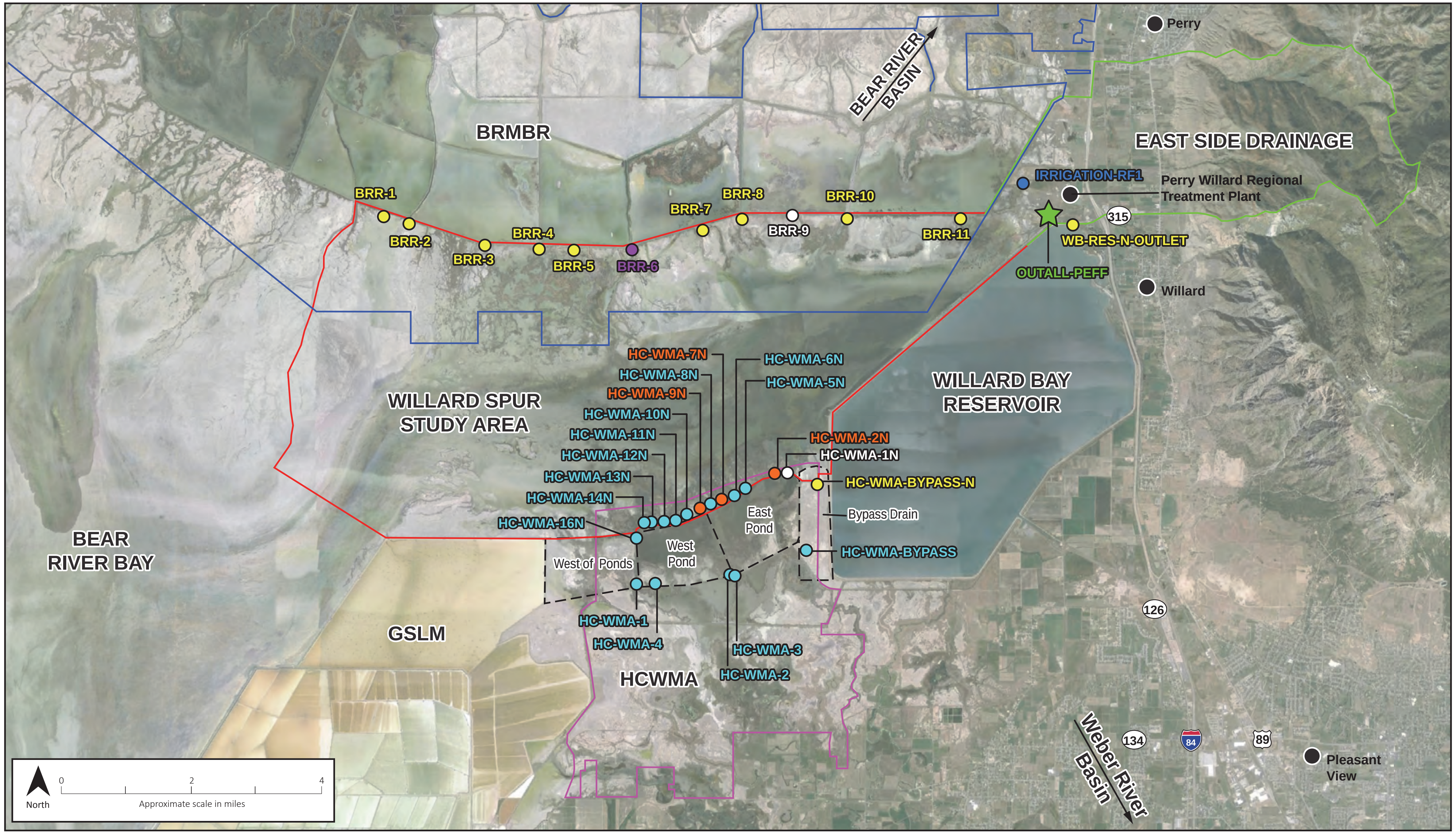


Aerial image © Google Earth, 2015. Annotation by CH2M HILL, 2015.

LEGEND

- ○ Flow Monitoring Station
- ● Flow Monitoring Station and Sampling Point
- ★ POTW Discharge to Outlet Channel
- Willard Spur (red line)
- Bear River Migratory Bird Refuge (BRMBR) (blue line)
- Harold S. Crane Waterfowl Management Area (HCWMA) Boundary (purple line)
- East Side Boundary (green line)

Figure 3
Willard Spur Drainage Basins, Flow Monitoring Stations and Sampling Sites
Development of Water Quality Standards for Willard Spur



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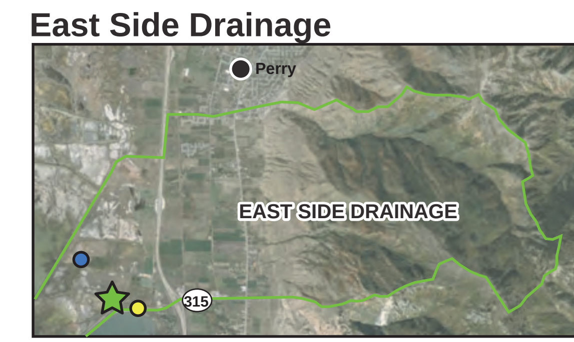

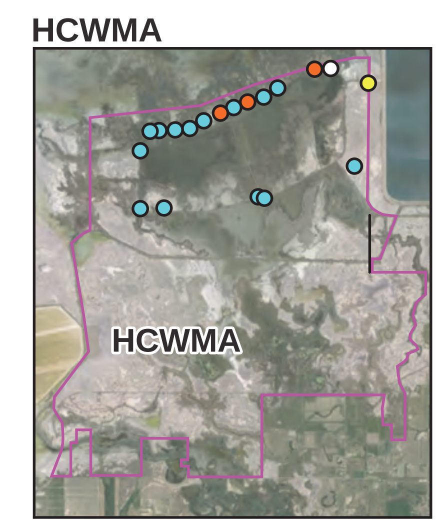

LEGEND

- Sampled in 2011, 2012, 2013
- Sampled in 2011
- Sampled in 2012
- Sampled in 2011 and 2012
- Sampled in 2011 and 2013
- Sampled in 2012 and 2013
- POTW Discharge to Outlet Channel
- Willard Spur
- Bear River Migratory Bird Refuge (BRMBR)
- Harold S. Crane Waterfowl Management Area (HCWMA) Boundary
- East Side Boundary

Figure 4
Willard Spur Sampling Locations and Dates
Development of Water Quality Standards for Willard Spur

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impounded condition during summer months followed by outflows during the fall, winter, and spring months is likely a typical annual pattern for Willard Spur. Thus, the higher, flushing flows observed during the fall–spring months, while contributing the majority of the nutrient load to Willard Spur, are likely the most significant factor in preserving Willard Spur's present condition.

3.2 Water Chemistry

Water samples were collected by UDWQ according to each year's sampling and analysis plan at each of the identified inlets to Willard Spur (see Figures 3 and 4 for specific locations). Water samples were also collected at the confluence of the old Plant discharge location with Willard Spur, at the outfall's mixing zone and at another site in the Willard Bay tailrace, at the confluence of the Willard Bay tailrace with Willard Spur, and at the confluence of the HCWMA bypass drain and Willard Spur.

These samples were collected, if there was flow, at a minimum of once a month during the growing season (May–October in 2011, April–November in 2012, and March–November in 2013), with additional sampling during the spring snowmelt flows to account for variances during this high-volume period. (See Table 2 for a summary of sampling locations and collection frequency 2011–2013, and Table 3 for a summary of parameters analyzed.) For the sake of estimating daily nutrient loads, during times when water samples were collected once a month, measurements were assumed to represent the preceding two weeks and following two weeks relative to when the sample was taken.

Figure 5. Irrigation Ditch at Sampling Site IRRIGATION-RF1, Looking South
Photo Courtesy UDWQ

Water chemistry for the Plant's effluent was provided by the Plant in its discharge monitoring reports and represented their end-of-pipe discharge. However, water samples were also collected at various locations downstream of the discharge point to better understand how the Plant's nutrient load was assimilated prior to reaching the open water of Willard Spur.

Table 2. Sampling Locations and Frequency 2011–2013

			Number of Additional Biweekly Samples Collected during Spring Flows[a]			Number of Monthly Samples Collected[b]		
Site Description	**STORET ID**	**Type of Site**	**2011**	**2012**	**2013**	**2011**	**2012**	**2013**
BRMBR								
BRR-1	4984710	Inflow	—	1	—	5	7	7
BRR-2	4984715	Inflow	—	2	—	4	7	9
BRR-3	4985659	Inflow	—	1	—	3	4	9
BRR-4	4984720	Inflow	2	1	2	8	5	6

Table 2. Sampling Locations and Frequency 2011–2013

Site Description	STORET ID	Type of Site	Number of Additional Biweekly Samples Collected during Spring Flows[a]			Number of Monthly Samples Collected[b]		
			2011	2012	2013	2011	2012	2013
BRR-5	4984717	Inflow	—	—	—	1	1	7
BRR-6	4984725	Inflow	—	—	—	3	—	8
BRR-7	4985653	Inflow	—	1	—	6	2	5
BRR-8	4984750	Inflow	2	2	2	8	7	9
BRR-9	4984752	Inflow	—	BRR-9 CLOSED		3	BRR-9 CLOSED	
BRR-10	4984755	Inflow	2	1	2	8	2	5
BRR-11	4984758	Inflow	2	1	2	8	2	4
East Side								
Irrigation RF-1	4984760	Inflow	—	2	2	—	5	5
WB-RES-N-OUTLET	4920420	Inflow	2	2	2	6	7	9
HCWMA								
HC-WMA-Bypass-N	4984657	Inflow	—	2	2	1	9	9
HC-WMA-1	4984610	Inflow	—	1	—	7	2	—
HC-WMA-2	4984620	Inflow	—	1	—	8	2	—
HC-WMA-3	4984630	Inflow	—	1	—	8	2	—
HC-WMA-4	4984640	Inflow	—		—	3	1	—
HC-WMA-5	4984650	Inflow	—	1	—	8	2	—
HC-WMA-1N	5984770	Inflow	—		—	1	—	—
HC-WMA-2N	5984775	Inflow	—	2	—	—	7	—
HC-WMA-3N	5984780	Inflow	—	—	—	—	—	—
HC-WMA-4N	5984785	Inflow	—	—	—	—	—	—
HC-WMA-5N	5984790	Inflow	—	—	—	1	4	—
HC-WMA-6N	5984800	Inflow	—	—	—	1	1	—
HC-WMA-7N	5984805	Inflow	—	—	—	—	3	—
HC-WMA-8N	5984810	Inflow	—	2	—	1	7	—
HC-WMA-9N	5984815	Inflow	—	1	—	—	4	—
HC-WMA-10N	5984820	Inflow	—	—	—	1	1	—
HC-WMA-11N	5984825	Inflow	—	1	—	1	4	—
HC-WMA-12N	5984830	Inflow	—	2	—	1	5	—

Table 2. Sampling Locations and Frequency 2011–2013

Site Description	STORET ID	Type of Site	Number of Additional Biweekly Samples Collected during Spring Flows[a]			Number of Monthly Samples Collected[b]		
			2011	2012	2013	2011	2012	2013
HC-WMA-13N	5984835	Inflow	—	—	—	1	2	—
HC-WMA-14N	5984840	Inflow	—	1	—	1	5	—
HC-WMA-15N	5984845	Inflow	—	—	—	—	—	—
HC-WMA-16N	5984850	Inflow	—	—	—	1	2	—
HC-WMA-East Pond Outflow	5984770	Inflow	—	—	2	—	—	9
HC-WMA-West Pond Outflow	5984775	Inflow	—	—	1	—	—	6

[a] Biweekly sampling May–June.
[b] Monthly sampling May 23 through Oct. 31, 2011; April 12 through Nov. 26, 2012; and March 7 through Nov. 30, 2013.

Table 3. Water Chemistry Parameters Analyzed for Inflow and Open Water Sites 2011–2013

Description	Parameters
Standard Water Chemistry Parameters Analyzed during Inflow, Monthly and Biweekly Monitoring	
Field parameters	Temperature, specific conductance, pH, dissolved oxygen
General chemistry	Sulfate, total alkalinity, total suspended solids, total volatile solids, total dissolved solids, turbidity
Total (nonfiltered) nutrients	Ammonia, nitrate/nitrite, total phosphorus, TKN
Other	Chlorophyll-a
Extensive Water Chemistry Parameters Analyzed for Inflow Sampling Sites for the Months of May and August	
Field parameters	Temperature, specific conductance, pH, dissolved oxygen
BOD	Carbonaceous BOD_5
Total (nonfiltered) nutrients	Ammonia, nitrate/nitrite, total phosphorus, TKN
Dissolved (filtered) nutrients	Nitrate/nitrite and total nitrogen, dissolved phosphorus
General chemistry	Sulfate, alkalinity, turbidity, specific conductance, total suspended solids, total volatile solids, total dissolved solids
Total (nonfiltered) metals	Total selenium, total mercury
Dissolved (filtered) metals	Aluminum, arsenic, barium, boron, cadmium, calcium, chromium, copper, iron, lead, magnesium, manganese, nickel, potassium, and hardness
Other	Chlorophyll-a

TKN, total Kjeldahl nitrogen; BOD, biochemical oxygen demand; BOD_5, 5-day biochemical oxygen demand.

3.3 Calculation of Nutrient Loads

External nutrient loads were estimated on a daily basis for total nitrogen and total phosphorus using average daily flows and nutrient concentrations from monthly or biweekly water samples. Total nitrogen is composed of the sum of nitrite-nitrogen (NO_3), nitrate-nitrogen (NO_2), and total Kjeldahl nitrogen (ammonia, and organic and reduced nitrogen) as reported from water samples. Total phosphorus was directly reported from water samples. Monthly and biweekly nutrient concentrations were assumed to represent daily concentrations during the period between sampling events. External nutrient loads from all sources were calculated by multiplying daily flow volumes by daily concentrations to develop a daily nutrient load at the end of pipe for each source (Equation 1):

$$\text{Nutrient Load}_{\text{daily end of pipe}} = \text{Flow}_{\text{daily}} \times \text{Concentration}_{\text{daily}} \qquad \text{(Equation 1)}$$

SECTION 4

Results

The results from the external nutrient load assessment are organized into four sections:

- **Observed Nutrient Loads at "End of Pipe" for 2011–2013.** All observed, external nutrient loads to Willard Spur, including actual end-of-pipe nutrient loads from the Plant, are summarized for 2011–2013.
- **Nutrient Loads for Alternative Plant Scenarios at End of Pipe.** Two alternative, higher, end-of-pipe Plant nutrient load scenarios are introduced (representing different Plant nutrient removal processes) and compared to other observed, external nutrient loads to Willard Spur for 2011–2013.
- **Estimated Plant Nutrient Loads Reaching the Open Water of Willard Spur for 2011–2013.** Effluent flow rates are revised to account for water losses as the effluent flowed from end of pipe toward the open water of Willard Spur. Plant nutrient loads to the open water for 2011–2013 are presented and compared to other end-of-pipe nutrient loads.
- **Location of Discharge Consideration.** Hypothetical scenarios evaluating the contribution of discharge location to the likelihood of flow reaching open water are examined, providing information to assist with decision making into the future.

4.1 Observed Nutrient Loads at End of Pipe for 2011–2013

4.1.1 Annual Nutrient Load Contributions

The external nutrient load to Willard Spur is dictated largely by the quantity of water entering the system. The Bear River, providing flows through BRMBR, and the Weber River, providing water through HCWMA, are two of the three main tributaries to the GSL. Because of this, inflows from the BRMBR represent the greatest source of nutrient loading to Willard Spur, with HCWMA generally providing the second largest source (see Figures 3 and 4). In June 2011, there was a large contribution from Willard Bay Reservoir (in the East Side Drainage Basin) due to the bypass of high flows from the Weber River to prevent flooding in Weber County; thus it is included as one of the four primary external sources of nutrients to Willard Spur. The yearly contribution of the Plant compared to other sources to Willard Spur is illustrated in Figure 6. Table 4 summarizes annual nutrient load contributions from each of the four major sources of external nutrient loads to Willard Spur.

4.1.2 Monthly Nutrient Load Contributions

While the Plant's annual nutrient load is minimal compared to those from other external surface water sources, a review of monthly nutrient loads illustrates important seasonal characteristics. Figures 7 and 8 illustrate that the Plant's contribution of nutrients is negligible during high flows, such as during all of 2011 and during the springs of 2012 and 2013, when snowmelt results in high surface water inflows. However, during months of the year when there are low surface water inflow rates, the contribution from the Plant can make up a larger portion of the total external surface water nutrient load entering Willard Spur (see Figures 7 and 8).

4.1.3 Inorganic Nitrogen Load

An additional consideration is how much of the overall nitrogen load is the inorganic fraction (NO_3, NO_2, and NH_4). A large percentage of the Plant's total nitrogen load, a larger percentage than the other contributing sources', is inorganic. When the total load of inorganic nitrogen is broken down by source (Table 5), the Plant contributes a slightly higher amount than overall total nitrogen for 2011 and 2013 but a more important contribution in 2012 (a very dry year).

Table 4. Total Nitrogen and Phosphorous Loads for the Study Period, 2011–2013

	Pounds					Percentages			
Year	BRMBR	HCWMA	Willard Bay	Plant	Total	BRMBR	HCWMA	Willard Bay	Plant
Total Nitrogen									
2011	936,114	257,655	82,620	9,618	1,286,007	73	20	6	1
2012	159,939	52,146	461	11,191	223,736	71	23	0	5
2013	725,102	64,407	1,274	17,320	808,102	90	8	0	2
Total Phosphorus									
2011	142,201	11,397	8,895	1,391	163,884	87	7	5	1
2012	35,050	5,711	82	1,911	42,754	82	13	0	4
2013	82,030	4,604	177	1,275	88,086	93	5	0	1

Specific dates of data: May 23 through Oct. 31, 2011; April 12 through Nov. 26, 2012; and March 7 through Nov. 30, 2013.

Table 5. Comparison of Total Nitrogen and Inorganic Nitrogen Loading for Study Period, 2011–2013

	Pounds					Percentages			
Year	BRMBR	HCWMA	Willard Bay	Plant	Total	BRMBR	HCWMA	Willard Bay	Plant
Total Nitrogen									
2011	936,114	257,655	82,620	9,618	1,286,007	73	20	6	1
2012	159,939	52,146	461	11,191	223,736	71	23	0	5
2013	725,102	64,407	1,274	17,320	808,102	90	8	0	2
Inorganic Nitrogen									
2011	270,856	98,522	23,841	8,143	401,361	67	25	6	2
2012	34,285	11,570	98	9,793	55,747	62	21	0	18
2013	409,039	14,099	442	16,074	439,654	93	3	0	4

Specific dates of data: May 23 through Oct. 31, 2011; April 12 through Nov. 26, 2012; and March 7 through Nov. 30, 2013.

Figure 6. Yearly Contribution of Total Phosphorus and Total Nitrogen Loads by Source Basin

4.1.4 Nutrient Contributions within Each Basin

Nutrient loads from each of the three drainage basins also vary by source within each basin. Distribution of contributions within each larger source category is far from even across all inlets, and varies from year to year depending on management of these areas and where surface water is diverted. The annual nutrient load contribution from each source within each of the three drainage basins is represented in Figure 10.

4.1.4.1 Bear River Basin

Four structures—BRR 4 (O-line Canal), BRR 8 (Whistler Canal), BRR 10 (5s Drain), and BRR 11 (Unit 5C Outlet)—delivered the majority of the external, surface water nutrient load from the Bear River Basin during the spring–fall monitoring periods. BRR 4, BRR 8, and BRR 10 are typically used to bypass water from the Bear River through the BRMBR and directly to Willard Spur. Bear River diversions for the O-line Canal (BRR 4) and Whistler Canal (BRR 8) are located farther downstream on the Bear River than the diversions for the Reeder Canal (BRR 10 and BRR 11). Figure 9 (2011 flows, top) illustrates that BRR 10 and BRR 11 conveyed the majority of nutrients from BRMBR to Willard Spur in 2011. Figure 9 (2012 flows, middle) also indicates that BBR-10 and BRR-8 conveyed the majority of nutrients to Willard Spur in 2012. Figure 9 (2013 flows, bottom), however, indicates that BRR 8 carried the most nutrients, with BRR-11, BRR-6, BRR-4, and BRR-2 carrying the rest of the majority of nutrients to Willard Spur. It appears that during times of increased flow (2011) the Reeder Canal is more likely to be used, while during drier years the canals farther downstream are used.

4.1.4.2 East Side Drainage Basin

Although the Plant's contribution within the larger context of all nutrients entering Willard Spur is small, it makes up the majority of nutrients coming from the East Side Drainage Basin during normal/dry years. During the high flows/wet conditions observed in 2011, surface water inflows and nutrient loads from the Willard Bay Reservoir Channel are much greater than those from the Plant.

Figure 10 illustrates average daily flows from the east side sources. Figures 11 and 12 illustrate the fluctuation of nutrient concentrations in and nutrients loads from the Plant's effluent over the 3 years monitored. These values reflect phosphorous removal processes incorporated by the Plant during the study period. Nutrient contributions in 2011 fluctuated more significantly than in 2012 and 2013. This is likely due to Plant startup and as the cities brought their wastewater collection systems online they encountered significant groundwater infiltration issues that had to be addressed. The increase in phosphorous load during 2012 cannot be explained by a spike in flow, and appears to be attributable to inconsistent treatment at the Plant. Contributions in 2013 were evenly distributed as the Plant resolved outstanding issues and became more consistent in treatment. Variations in flow from the Plant can be seen in Figure 10, which provides a partial explanation for the nutrient variations.

4.1.4.3 Weber River Basin

Nutrients contributed through HCWMA were fairly evenly distributed between the east and west ponds, except for in 2013. Nutrients contributed through the bypass drain and west ponds illustrate the influence water management by HCWMA has upon nutrient contributions. Surface water inflows and corresponding nutrient loads were higher during the wet year of 2011 and were less in 2012 and 2013, when surface water inflows were less and HCWMA prioritized water deliveries through the east and west ponds. Water was detected and sampled flowing west of the ponds only during the high flows of 2011.

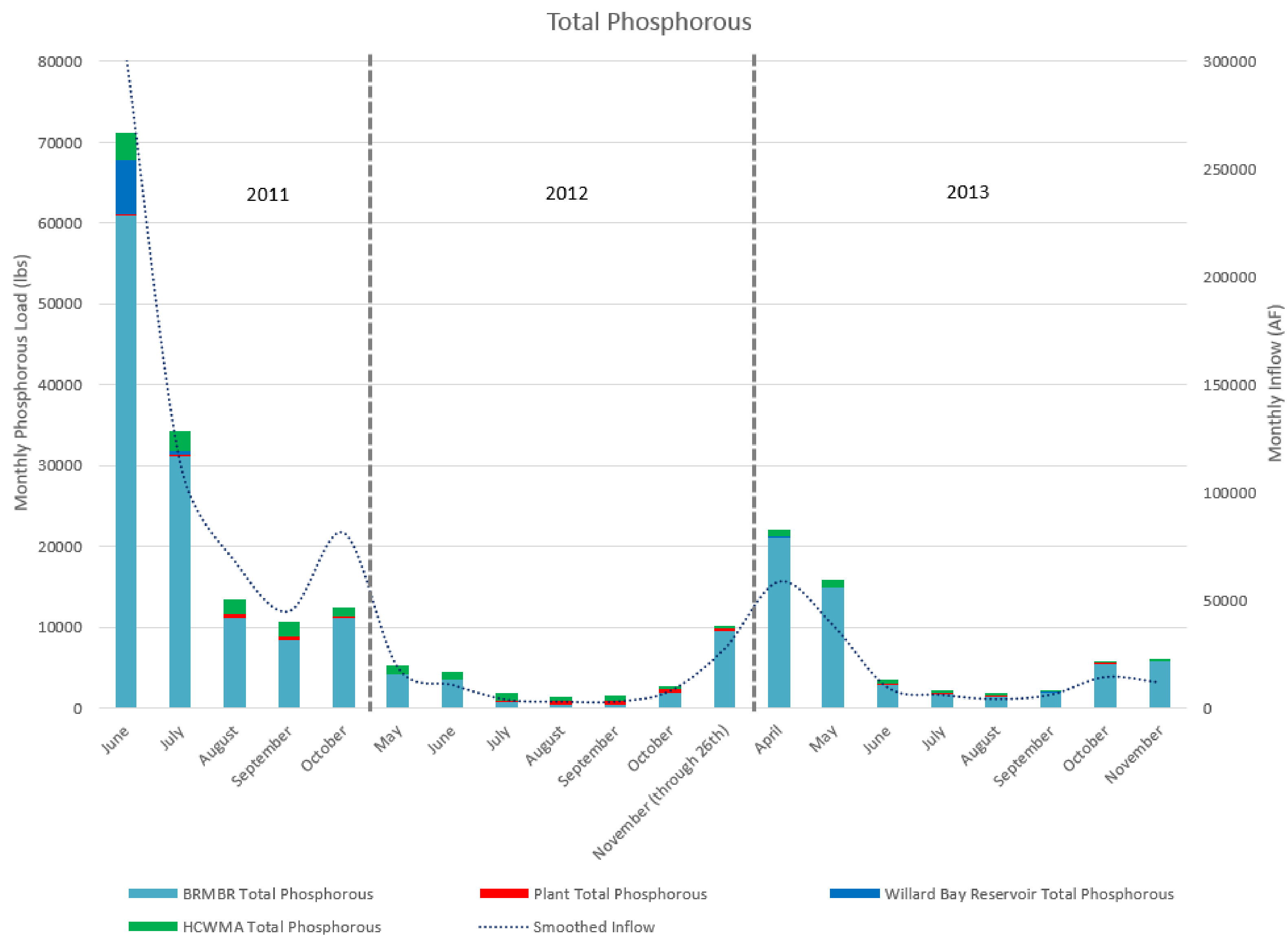


Figure 7. Total Phosphorous Load into Willard Spur by Location 2011–2013

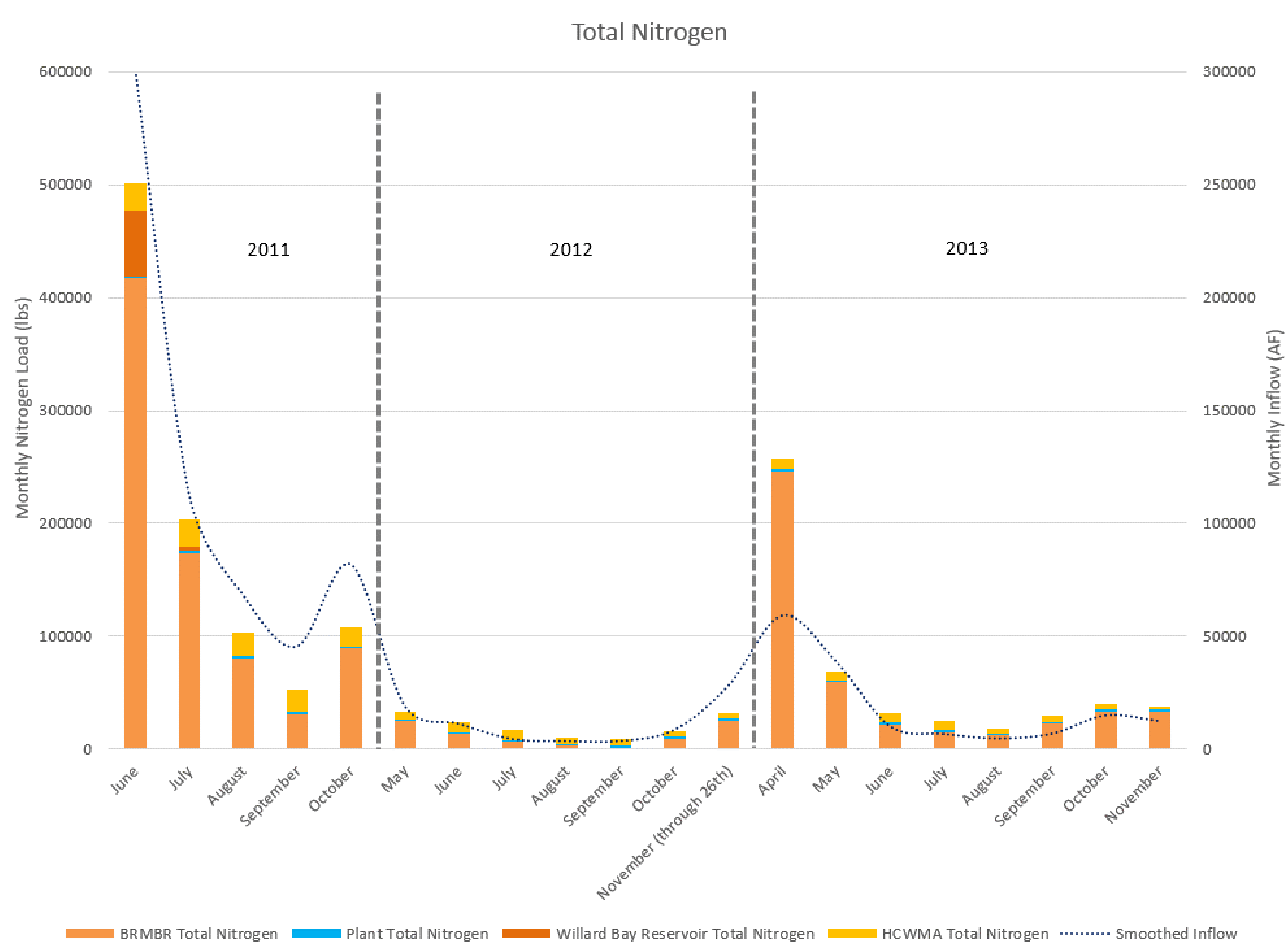


Figure 8. Total Nitrogen Load into Willard Spur by Location 2011–2013

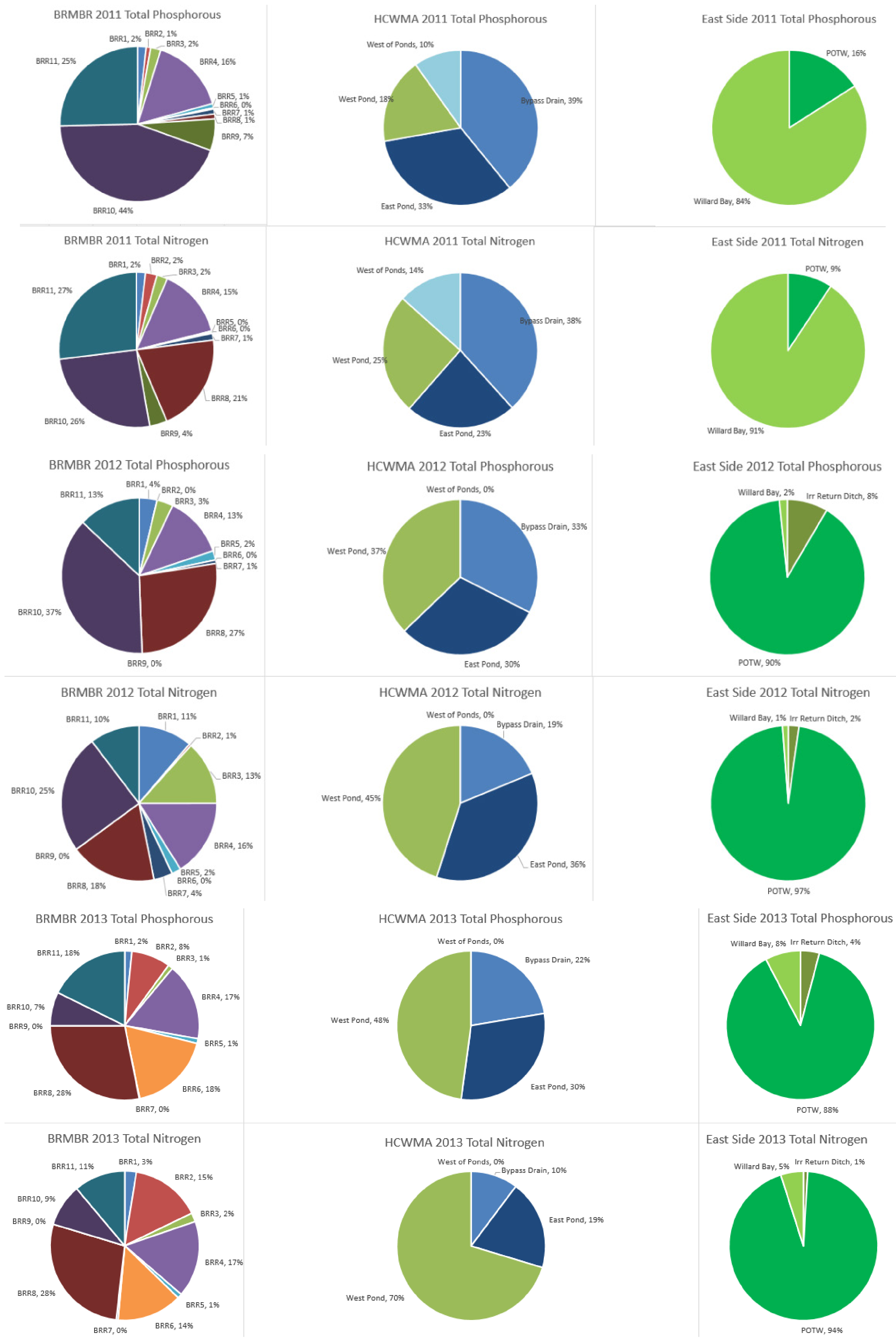


Figure 9. Breakdown of Nutrient Contributions from Sources within Each Drainage Basin

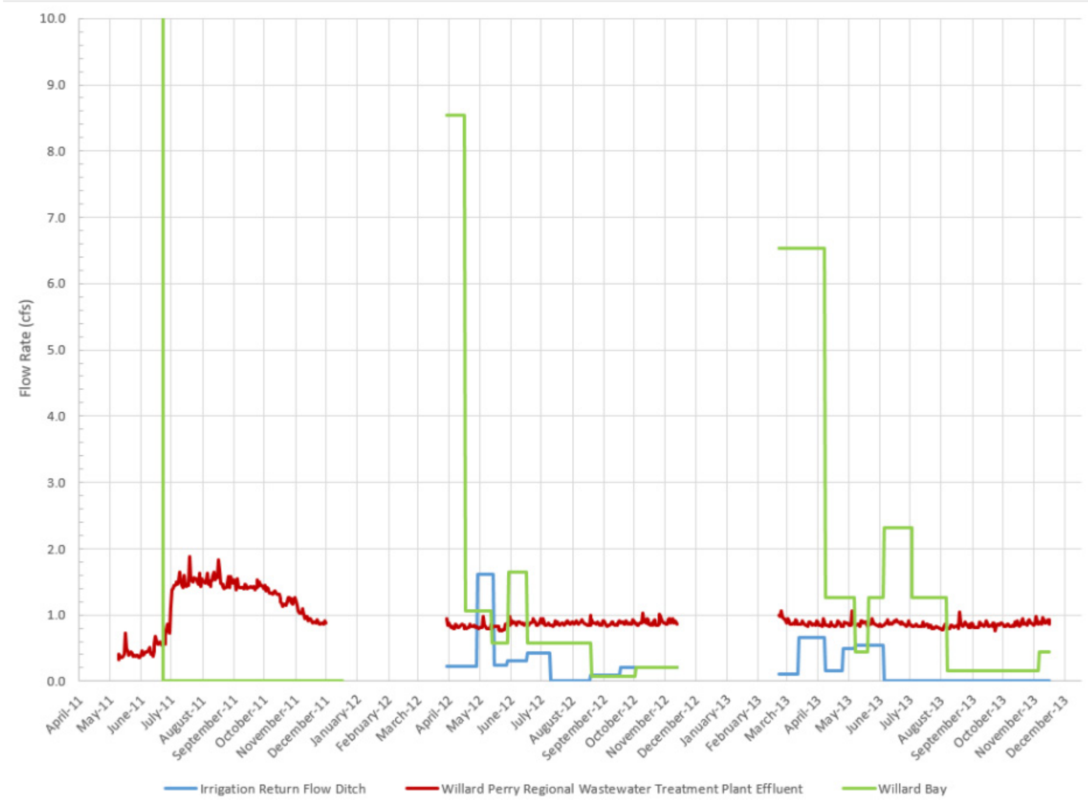
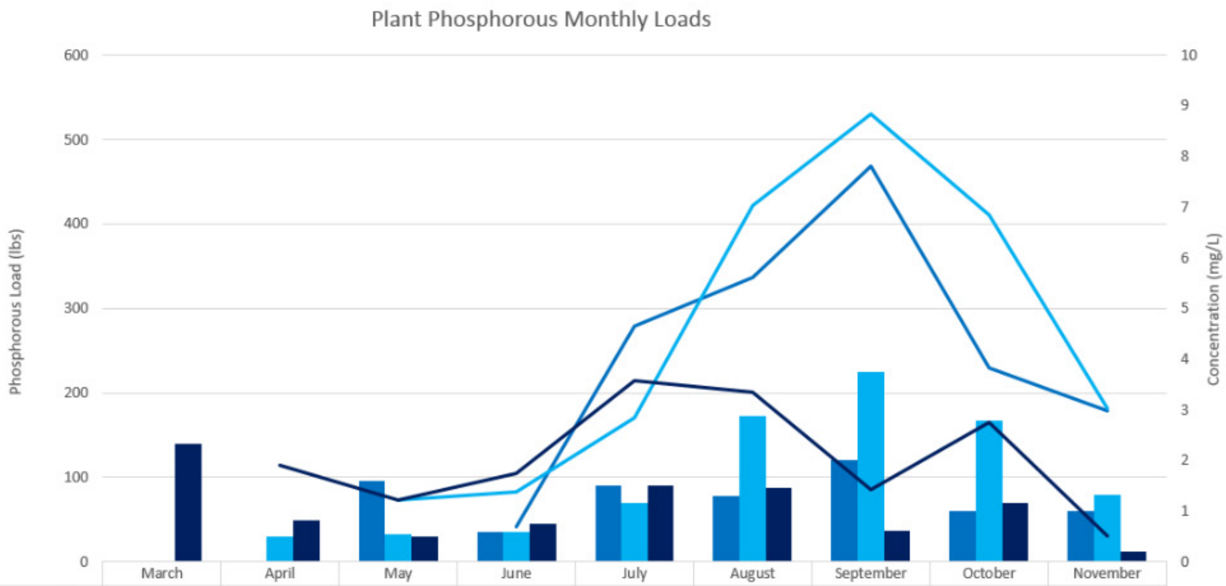


Figure 10. Consolidated East Side Inflow Hydrograph to Willard Spur 2011–2013

4.2 Nutrient Loads for Alternative Plant Scenarios at End of Pipe

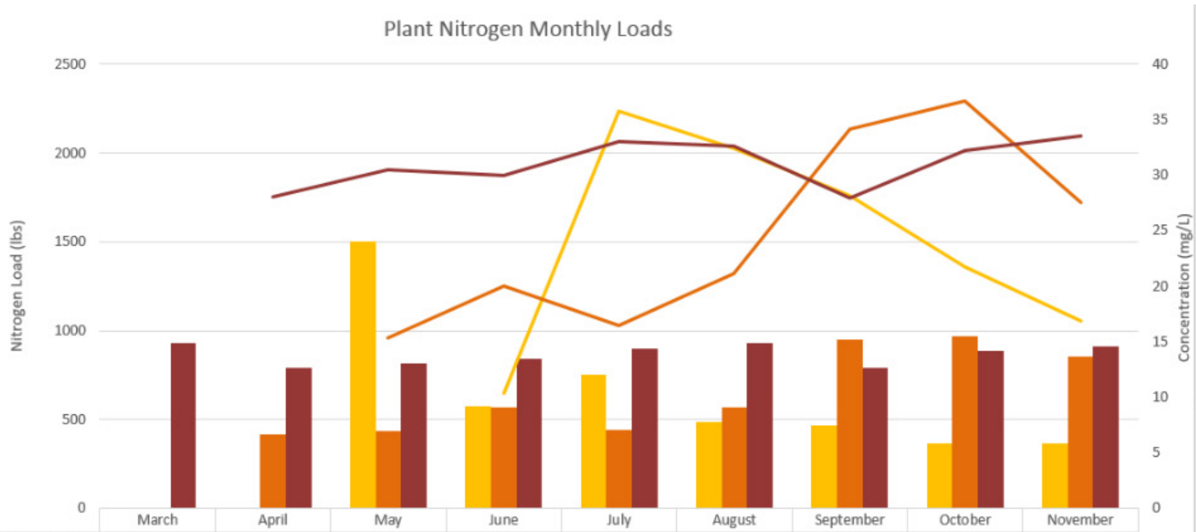
Alternative scenarios were considered in which the Plant flow remained the same but nutrient concentrations were set at “medium” (4 milligrams per liter [mg/L] for phosphorous and 20 mg/L for nitrogen) and “high” (5 mg/L for phosphorous and 30 mg/L for nitrogen) levels as determined for this study (von Stackelberg, 2010). These scenarios represent what loads might look like if phosphorous removal was no longer pursued at the Plant, and if nutrient concentrations were to increase.

Figures 13 and 14 illustrate the anticipated Plant nutrient loads using the medium and high nutrient concentrations with actual effluent flow rates from 2011 through 2013. Figures 15, 16, and 17 illustrate these higher Plant nutrient concentrations and loads in relation to the other external, surface water nutrient loads to Willard Spur. The figures include all months where nutrient concentration and flow data were available. As expected, and as Figures 15, 16, and 17 illustrate, increasing Plant loads increases the Plant’s overall percentage of nutrient load to Willard Spur. This analysis assumes that all effluent from the Plant and external surface water inflows reach open water.



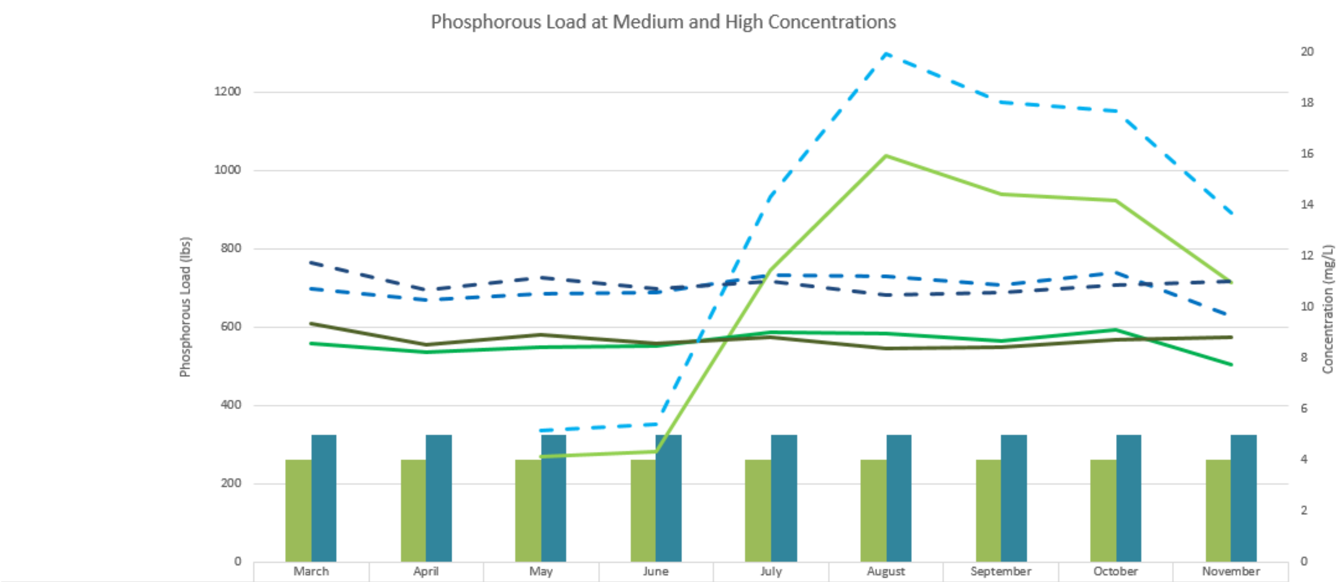
	March	April	May	June	July	August	September	October	November
2011 Average Concentration			1.6	0.6	1.5	1.3	2.0	1.0	1.0
2012 Average Concentration		0.5	0.5	0.6	1.2	2.9	3.8	2.8	1.3
2013 Average Concentration	2.3	0.8	0.5	0.7	1.5	1.5	0.6	1.2	0.2
2011 Total Load				42	280	337	469	230	178
2012 Total Load			74	83	170	421	530	411	181
2013 Total Load		114	74	104	215	201	85	166	30

Figure 11. Total Phosphorous Loads from Plant at End of Pipe



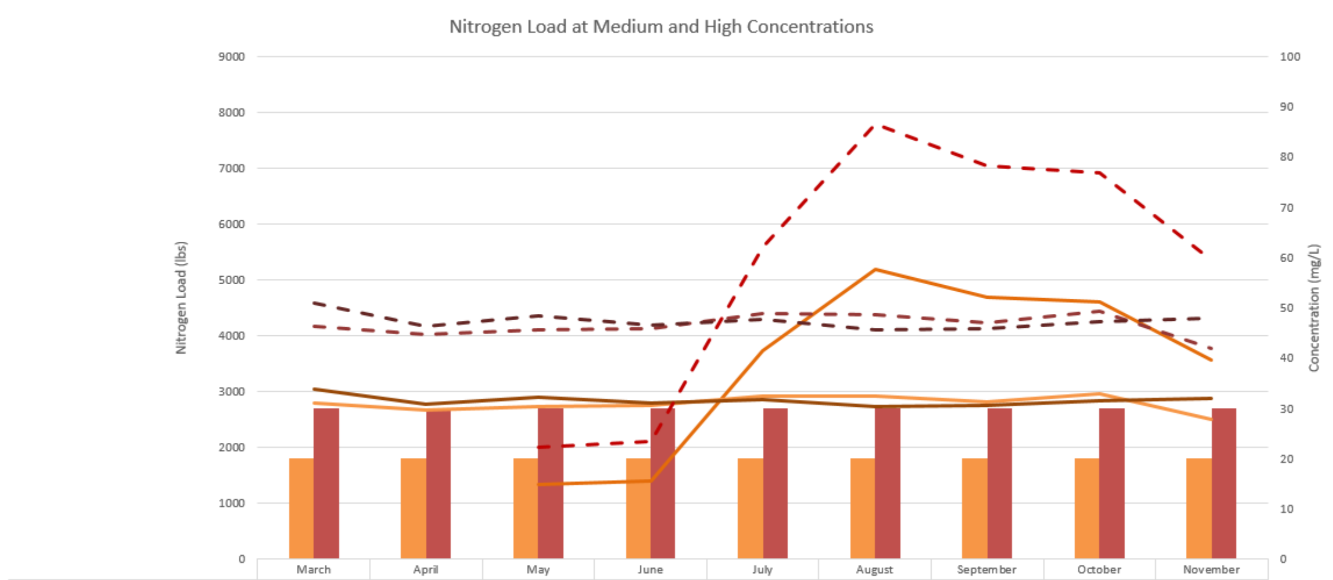
	March	April	May	June	July	August	September	October	November
2011 Average Concentration			24.0	9.2	12.0	7.8	7.5	5.9	5.9
2012 Average Concentration		6.7	7.0	9.1	7.0	9.1	15.2	15.5	13.7
2013 Average Concentration	14.9	12.6	13.1	13.4	14.4	14.9	12.7	14.2	14.6
2011 Total Load				649	2237	2024	1760	1359	1053
2012 Total Load			957	1254	1032	1325	2137	2290	1719
2013 Total Load		1754	1905	1877	2067	2038	1745	2014	2098

Figure 12. Total Nitrogen Loads from Plant at End of Pipe



	March	April	May	June	July	August	September	October	November
Medium Concentration	4	4	4	4	4	4	4	4	4
High Concentration	5	5	5	5	5	5	5	5	5
2011 Load at Medium Concentration			268	282	746	1038	939	921	714
2012 Load at Medium Concentration	557	536	549	551	585	584	565	592	502
2013 Load at Medium Concentration	610	556	581	559	573	546	550	567	574
2011 Load at High Concentration			335	353	932	1297	1173	1152	892
2012 Load at High Concentration	697	670	686	689	731	730	706	740	628
2013 Load at High Concentration	763	695	727	699	717	683	687	708	718

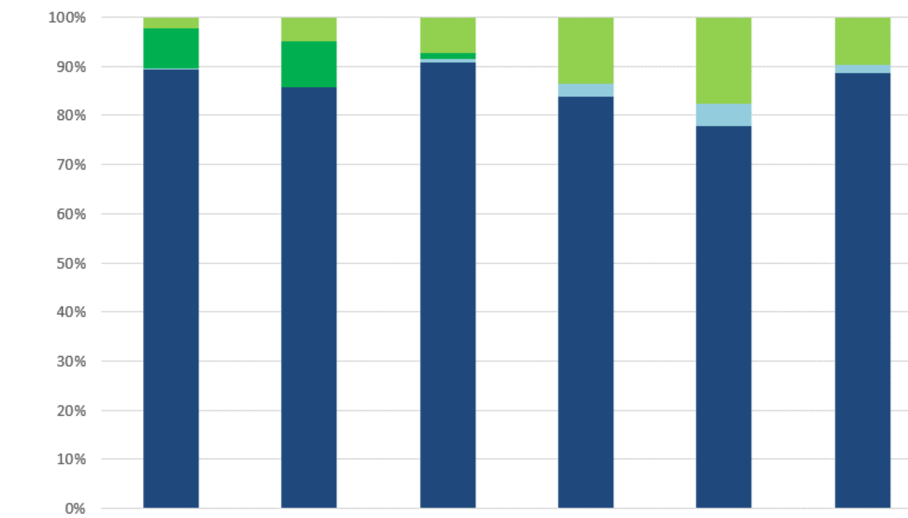
Figure 13. Total Phosphorus Loads from Plant at Medium and High Concentrations



	March	April	May	June	July	August	September	October	November
Medium Concentration	20	20	20	20	20	20	20	20	20
High Concentration	30	30	30	30	30	30	30	30	30
2011 Load at Medium Concentration			1339	1410	3728	5189	4694	4607	3568
2012 Load at Medium Concentration	2786	2678	2743	2756	2926	2918	2826	2958	2512
2013 Load at Medium Concentration	3050	2780	2906	2794	2866	2732	2748	2833	2871
2011 Load at High Concentration			2008	2115	5592	7784	7040	6910	5352
2012 Load at High Concentration	4180	4017	4114	4133	4389	4377	4239	4438	3768
2013 Load at High Concentration	4575	4170	4359	4191	4300	4097	4122	4250	4307

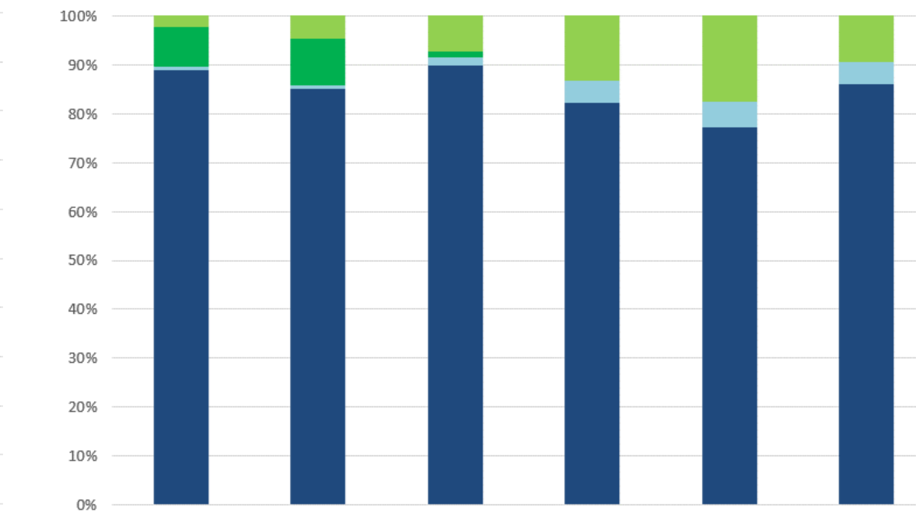
Figure 14. Total Nitrogen Loads from Plant at Medium and High Concentrations

2011 Plant Flows & TP Loads at End of Pipe



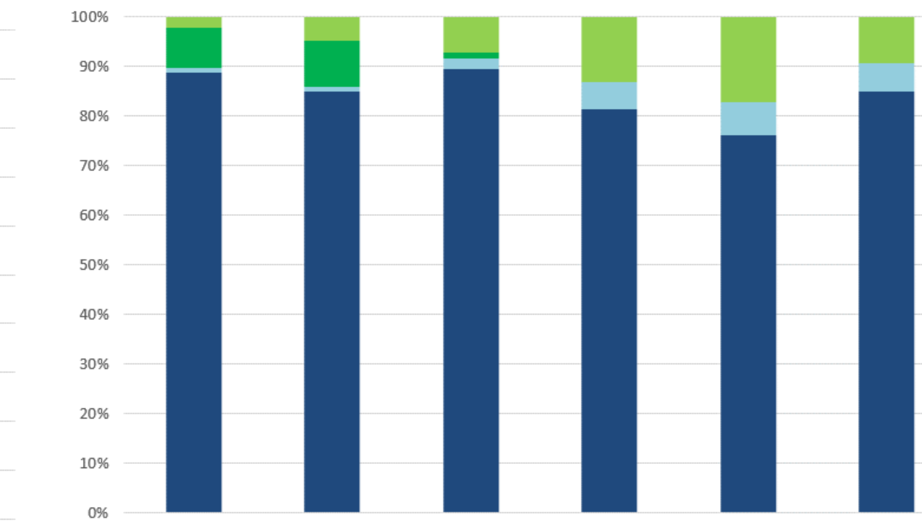
	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11
HCWMA	2%	5%	7%	14%	18%	10%
WB Outfall	8%	10%	1%	0%	0%	0%
POTW	0%	0%	1%	3%	4%	2%
BRMBR	89%	86%	91%	84%	78%	89%

2011 Plant Flows, Medium TP Loads at End of Pipe



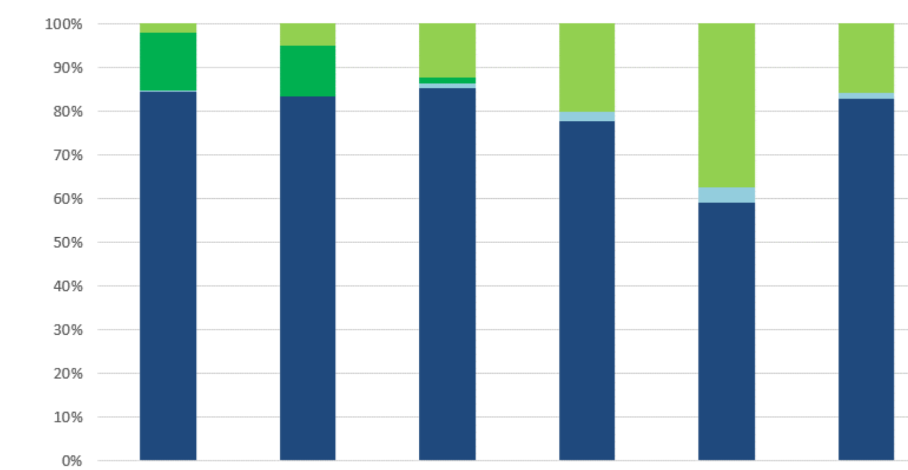
	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11
HCWMA	2%	5%	7%	13%	18%	9%
WB Outfall	8%	9%	1%	0%	0%	0%
POTW	1%	1%	2%	4%	5%	5%
BRMBR	89%	85%	90%	82%	77%	86%

2011 Plant Flows, High TP Loads at End of Pipe



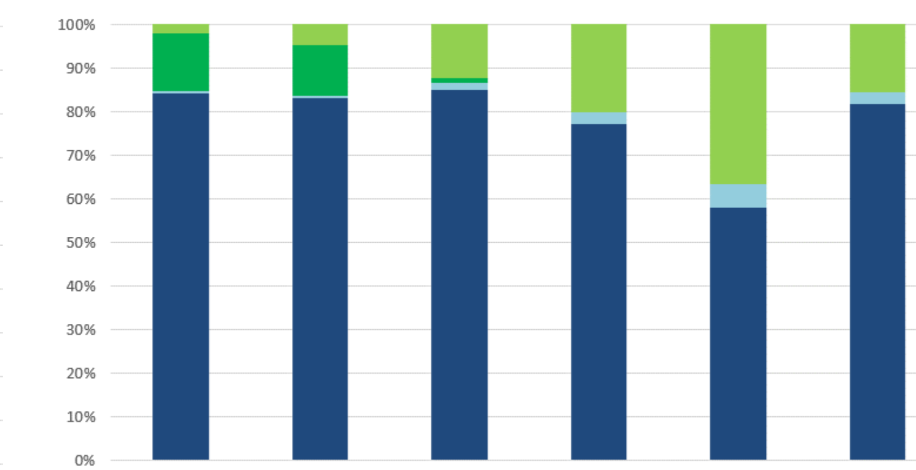
	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11
HCWMA	2%	5%	7%	13%	17%	9%
WB Outfall	8%	9%	1%	0%	0%	0%
POTW	1%	1%	2%	5%	7%	6%
BRMBR	89%	85%	89%	81%	76%	85%

2011 Plant Flows & TN Loads at End of Pipe



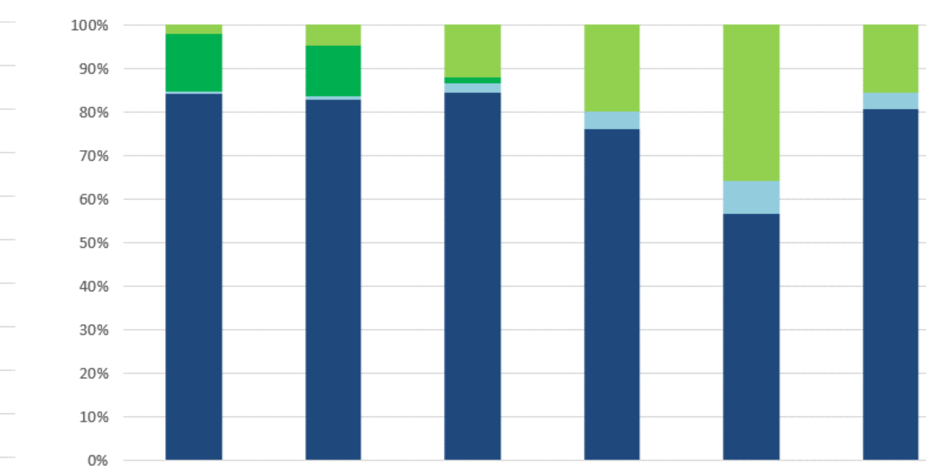
	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11
HCWMA	2%	5%	12%	20%	38%	16%
WB Outfall	13%	12%	1%	0%	0%	0%
POTW	0%	0%	1%	2%	3%	1%
BRMBR	84%	83%	85%	78%	59%	83%

2011 Plant Flows & Medium TN Loads at End of Pipe



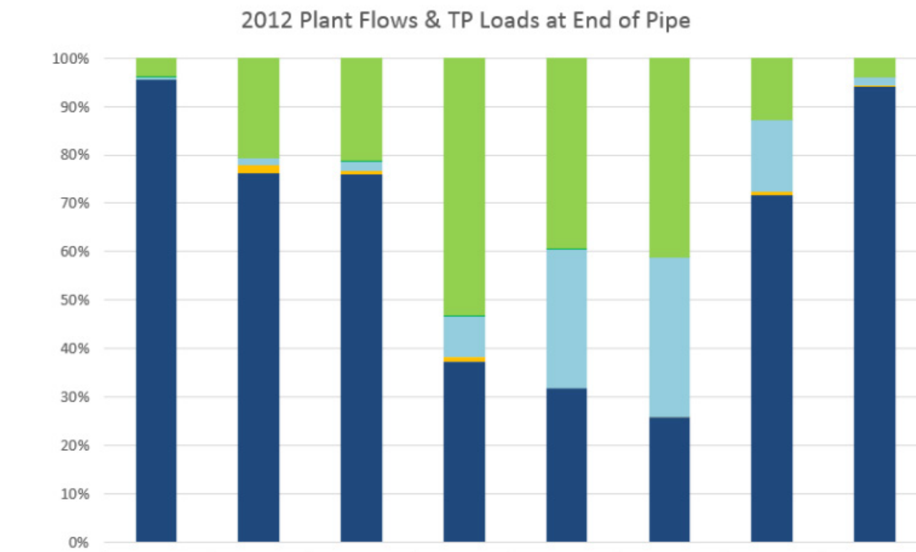
	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11
HCWMA	2%	5%	12%	20%	37%	16%
WB Outfall	13%	12%	1%	0%	0%	0%
POTW	1%	1%	1%	3%	5%	3%
BRMBR	84%	83%	85%	77%	58%	82%

2011 Plant Flows & High TN Loads at End of Pipe

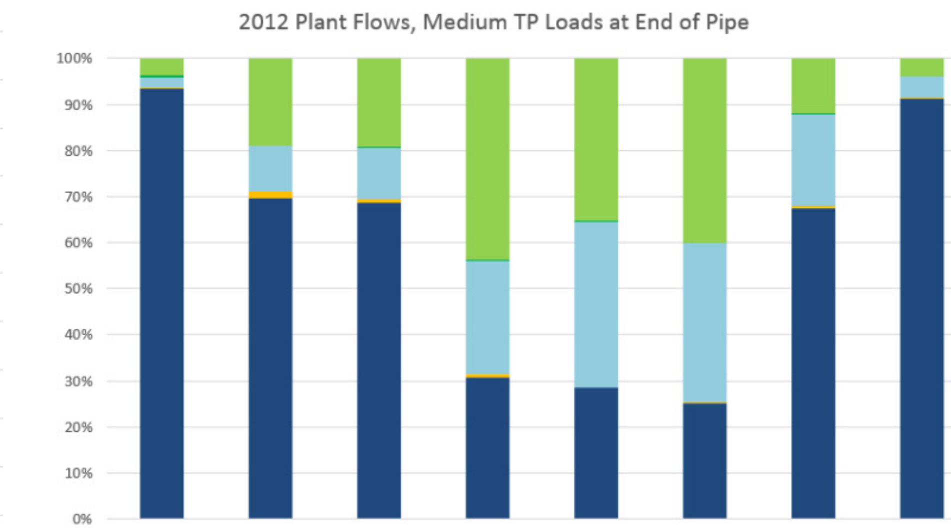


	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11
HCWMA	2%	5%	12%	20%	36%	15%
WB Outfall	13%	12%	1%	0%	0%	0%
POTW	1%	1%	2%	4%	8%	4%
BRMBR	84%	83%	84%	76%	56%	81%

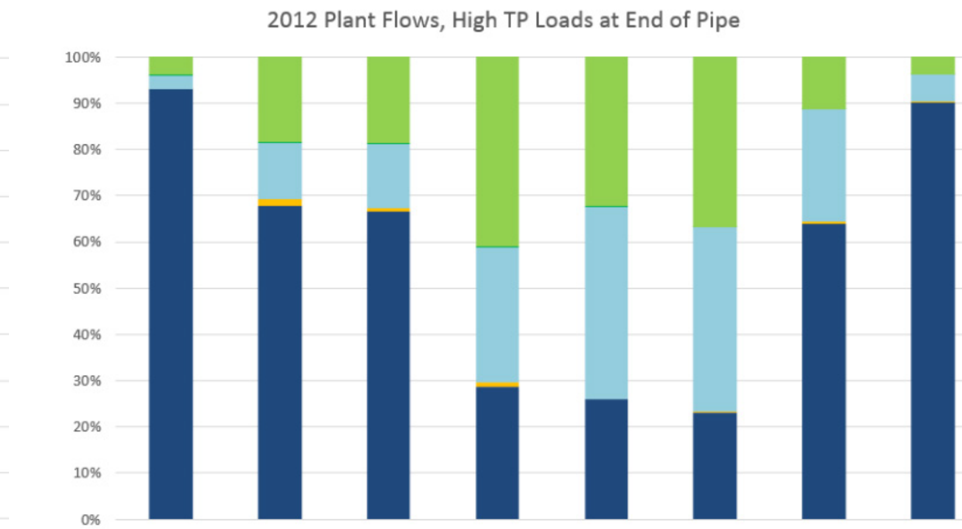
Figure 15. Overall Nutrient Loads as Measured at End of Pipe for Actual Concentrations, at Medium Concentrations and at High Concentrations for 2011 Flow Rates



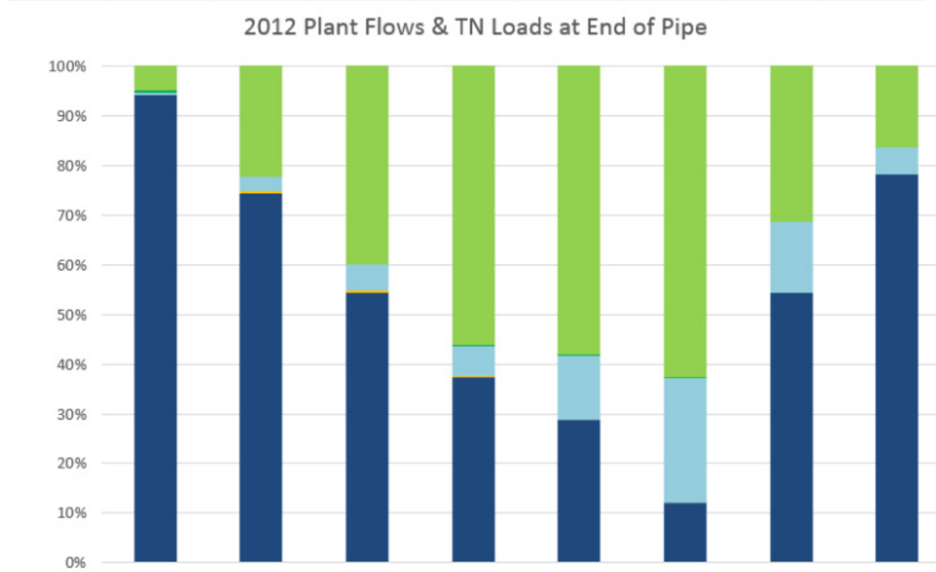
	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12
HCWMA	4%	21%	21%	53%	39%	41%	13%	4%
WB Outfall	0%	0%	0%	0%	0%	0%	0%	0%
POTW	0%	1%	2%	8%	29%	33%	15%	2%
Irr Ditch	0%	2%	1%	1%	0%	0%	1%	0%
BRMBR	96%	76%	76%	37%	32%	26%	72%	94%



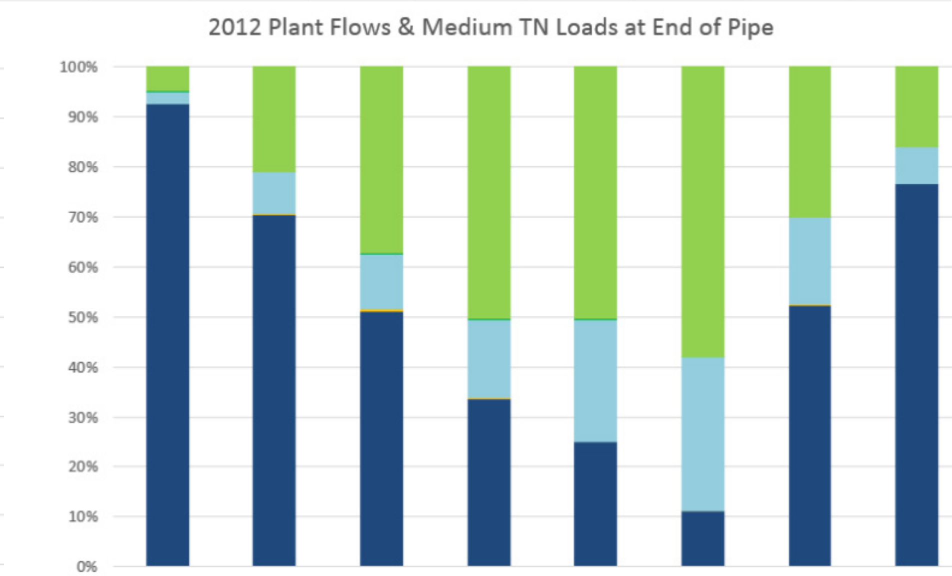
	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12
HCWMA	4%	19%	19%	44%	35%	40%	12%	4%
WB Outfall	0%	0%	0%	0%	0%	0%	0%	0%
POTW	2%	10%	11%	25%	36%	34%	20%	5%
Irr Ditch	0%	1%	1%	1%	0%	0%	1%	0%
BRMBR	94%	70%	69%	31%	29%	25%	67%	91%



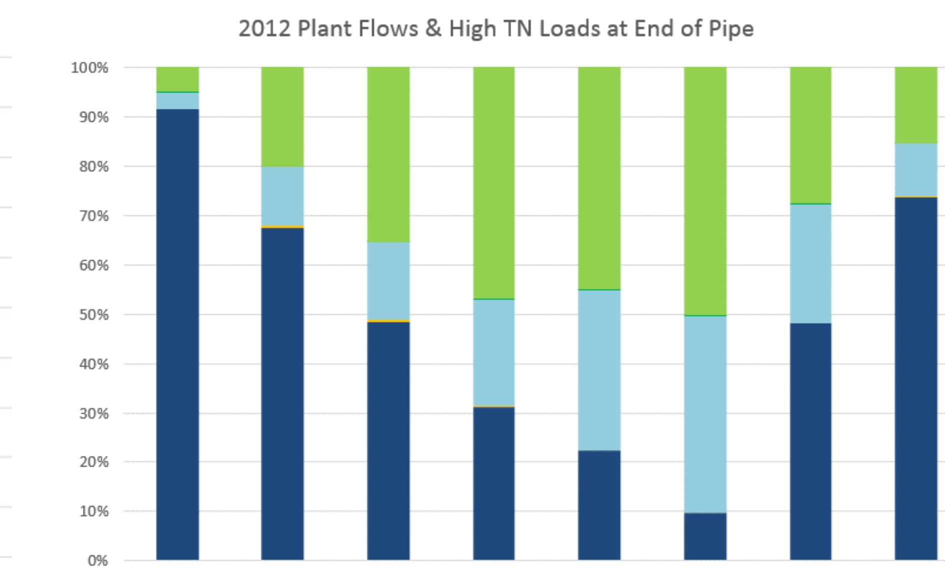
	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12
HCWMA	4%	18%	19%	41%	32%	37%	11%	4%
WB Outfall	0%	0%	0%	0%	0%	0%	0%	0%
POTW	3%	12%	14%	29%	42%	40%	24%	6%
Irr Ditch	0%	1%	1%	1%	0%	0%	1%	0%
BRMBR	93%	68%	67%	29%	26%	23%	64%	90%



	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12
HCWMA	5%	22%	40%	56%	58%	63%	31%	16%
WB Outfall	0%	0%	0%	0%	0%	0%	0%	0%
POTW	1%	3%	5%	6%	13%	25%	14%	5%
Irr Ditch	0%	0%	0%	0%	0%	0%	0%	0%
BRMBR	94%	74%	54%	37%	29%	12%	54%	78%



	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12
HCWMA	5%	21%	37%	51%	50%	58%	30%	16%
WB Outfall	0%	0%	0%	0%	0%	0%	0%	0%
POTW	2%	8%	11%	16%	24%	31%	18%	7%
Irr Ditch	0%	0%	0%	0%	0%	0%	0%	0%
BRMBR	93%	70%	51%	34%	25%	11%	52%	76%



	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12
HCWMA	5%	20%	35%	47%	45%	50%	28%	15%
WB Outfall	0%	0%	0%	0%	0%	0%	0%	0%
POTW	3%	12%	16%	22%	33%	40%	24%	11%
Irr Ditch	0%	0%	0%	0%	0%	0%	0%	0%
BRMBR	92%	68%	48%	31%	22%	10%	48%	74%

Figure 16. Overall Nutrient Loads as Measured at End of Pipe for Actual Concentrations, at Medium Concentrations and at High Concentrations for 2012 Flow Rates

2013 Plant Flows & TP Loads at End of Pipe

	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13
HCWMA	4%	4%	5%	12%	15%	13%	13%	4%	3%
WB Outfall	0%	1%	0%	4%	6%	3%	0%	0%	0%
POTW	1%	1%	0%	3%	9%	11%	4%	3%	0%
Irr Ditch	0%	0%	0%	1%	0%	0%	0%	0%	0%
BRMBR	95%	95%	94%	80%	71%	73%	83%	94%	96%

2013 Plant Flows, Medium TP Loads at End of Pipe

	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13
HCWMA	4%	4%	5%	11%	13%	11%	11%	3%	3%
WB Outfall	0%	1%	0%	3%	5%	2%	0%	0%	0%
POTW	2%	3%	4%	14%	21%	26%	20%	9%	9%
Irr Ditch	0%	0%	0%	1%	0%	0%	0%	0%	0%
BRMBR	94%	93%	91%	71%	61%	61%	68%	87%	89%

2013 Plant Flows, High TP Loads at End of Pipe

	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13
HCWMA	4%	4%	5%	10%	12%	10%	11%	3%	3%
WB Outfall	0%	1%	0%	3%	5%	2%	0%	0%	0%
POTW	2%	3%	4%	17%	26%	30%	25%	12%	11%
Irr Ditch	0%	0%	0%	1%	0%	0%	0%	0%	0%
BRMBR	93%	92%	90%	69%	58%	57%	65%	85%	87%

2013 Plant Flows & TN Loads at End of Pipe

	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13
HCWMA	4%	4%	12%	25%	32%	25%	17%	12%	7%
WB Outfall	0%	0%	0%	0%	0%	0%	0%	0%	0%
POTW	0%	1%	3%	6%	8%	11%	6%	5%	6%
Irr Ditch	0%	0%	0%	0%	0%	0%	0%	0%	0%
BRMBR	95%	95%	86%	69%	59%	64%	77%	83%	87%

2013 Plant Flows & Medium TN Loads at End of Pipe

	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13
HCWMA	4%	4%	11%	24%	31%	24%	17%	12%	7%
WB Outfall	0%	0%	0%	0%	0%	0%	0%	0%	0%
POTW	1%	1%	4%	9%	11%	15%	9%	7%	7%
Irr Ditch	0%	0%	0%	0%	0%	0%	0%	0%	0%
BRMBR	95%	95%	84%	67%	58%	61%	74%	81%	85%

2013 Plant Flows & High TN Loads at End of Pipe

	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13
HCWMA	4%	4%	11%	23%	29%	22%	16%	12%	7%
WB Outfall	0%	0%	0%	0%	0%	0%	0%	0%	0%
POTW	1%	2%	6%	13%	16%	21%	13%	10%	11%
Irr Ditch	0%	0%	0%	0%	0%	0%	0%	0%	0%
BRMBR	95%	94%	83%	64%	54%	57%	71%	78%	82%

Figure 17. Overall Phosphorous Loads as Measured at End of Pipe for Actual Concentrations, at Medium Concentrations and at High Concentrations for 2013 Flow Rates

4.2.1 Estimated Plant Flows Reaching Open Water of Willard Spur

The Plant discharged its effluent to different locations on the east side of Willard Spur during the study period (see Figure 18 and Table 6). Figure 19 illustrates the estimated effluent flow rate that reached the open water of Willard Spur in 2012 and 2013. It is assumed that all of the Plant's effluent reached the open water in 2011 as it was a very wet year with correspondingly high groundwater and open water levels in Willard Spur. Much of the outfall ditch and adjacent wetlands and pastures were simply flooded by the open water of Willard Spur during 2011. Dry years, such as 2012 and 2013, however, were observed to have a large impact on the effluent flow rates, and by association nutrient loads, that actually reached the open water. Much of the effluent was found to evaporate and infiltrate into the mudflats during the summer months resulting in decreased and even the elimination of effluent flow rates reaching the open water (see Figure 19). The hydrology assessment (CH2M HILL, 2015) documents these operations and how the quantity of effluent that actually reaches the open water of Willard Spur can vary depending upon discharge location, season, groundwater level, and ultimately the open water level in Willard Spur.

Figure 18. Aerial view of Willard Bay Reservoir and Willard Spur, Looking West
Photo courtesy John Luft/UDWR.

Table 6. Summary of Plant Discharge Operations, 2011–2013

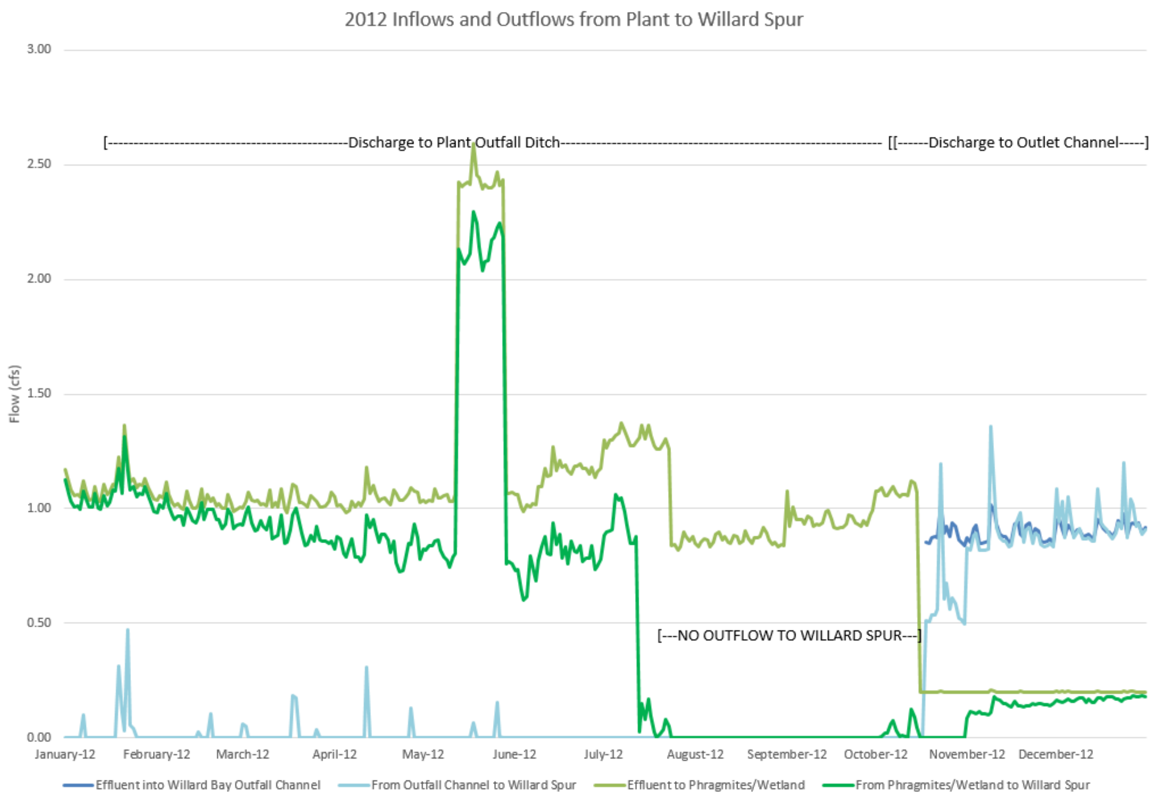
Period of Operation	Discharge Location
April 2011 through July 26, 2012	Plant Outfall Ditch
July 27–29, 2012	Outfall pipeline to the Willard Bay Outlet Channel
July 30 through October 15, 2012	Plant Outfall Ditch
October 16–17, 2012	Private wetlands/pasture
October 18 through December 24, 2012	Willard Bay Outlet Channel
December 24, 2012, through March 27, 2013	Private wetlands/pasture
March 27 through July 10, 2013	Willard Bay Outlet Channel
July 10 through August 22, 2013	Private wetlands/pasture
August 22 through October 6, 2013	Willard Bay Outlet Channel
October 6, 2013, through January 27, 2014 and continuing	Private wetlands/pasture

In order to assess the nutrient load from the Plant's effluent that actually reached the open water of Willard Spur, additional calculations were made using an adjusted Plant effluent flow rate that accounts for water gains and losses as the effluent flowed toward the open water (see Equation 2) (CH2M HILL, 2014b). The adjusted flows from this water balance were then multiplied by the nutrient concentrations at the Plant to determine an estimate of the load reaching Willard Spur (see Equation 3). Note that this adjustment does not account for assimilation of nutrients that likely occurred as the water flowed toward open water. Measurements made in August of 2013 at the point of effluent discharge to the pasture/private wetland and after the effluent had flowed across the property, at the west end of the pasture, suggest significant assimilation takes place before effluent reaches open water. According to the results from these samples, the total nitrogen concentration in the effluent was reduced by 91 percent and the total phosphorous concentration in the effluent was reduced by 71 percent between the point of discharge and the edge of the pasture/wetland. This was a one-time collection of samples and further information to quantify the reduction of nutrient concentrations was not available. Therefore, for the purposes of estimating the nutrient load, it is assumed that the nutrient concentration of the effluent at the end of pipe is the same as the effluent flow that reaches the open water.

$$\text{Flow}_{\text{daily adjusted}} = \text{Flow}_{\text{daily}} + \text{Precipitation}_{\text{daily}} - \text{Evaporation}_{\text{daily}} - \text{Infiltration}_{\text{daily}} \qquad \text{(Equation 2)}$$

$$\text{Load}_{\text{daily adjusted}} = \text{Flow}_{\text{daily adjusted}} \times \text{Concentration}_{\text{daily}} \qquad \text{(Equation 3)}$$

Figures 20 and 21 illustrates the revised Plant nutrient loads that reflect an estimate of the effluent nutrient load that reached the open water of Willard Spur in 2012 and 2013. It is assumed the Plant's entire nutrient load reached the open water of Willard Spur in 2011 due to the high water levels in Willard Spur that year. Figures 22 and 23 provide a comparison of the revised Plant nutrient loads with other external, surface water nutrient loads for 2012 and 2013. Flow rates and associated nutrient loads from all other sources entering Willard Spur were assumed to remain the same, that is, end of pipe, due to a lack of data needed to calculate water losses as water from those sources flowed across the mudflats (CH2M HILL, 2015).



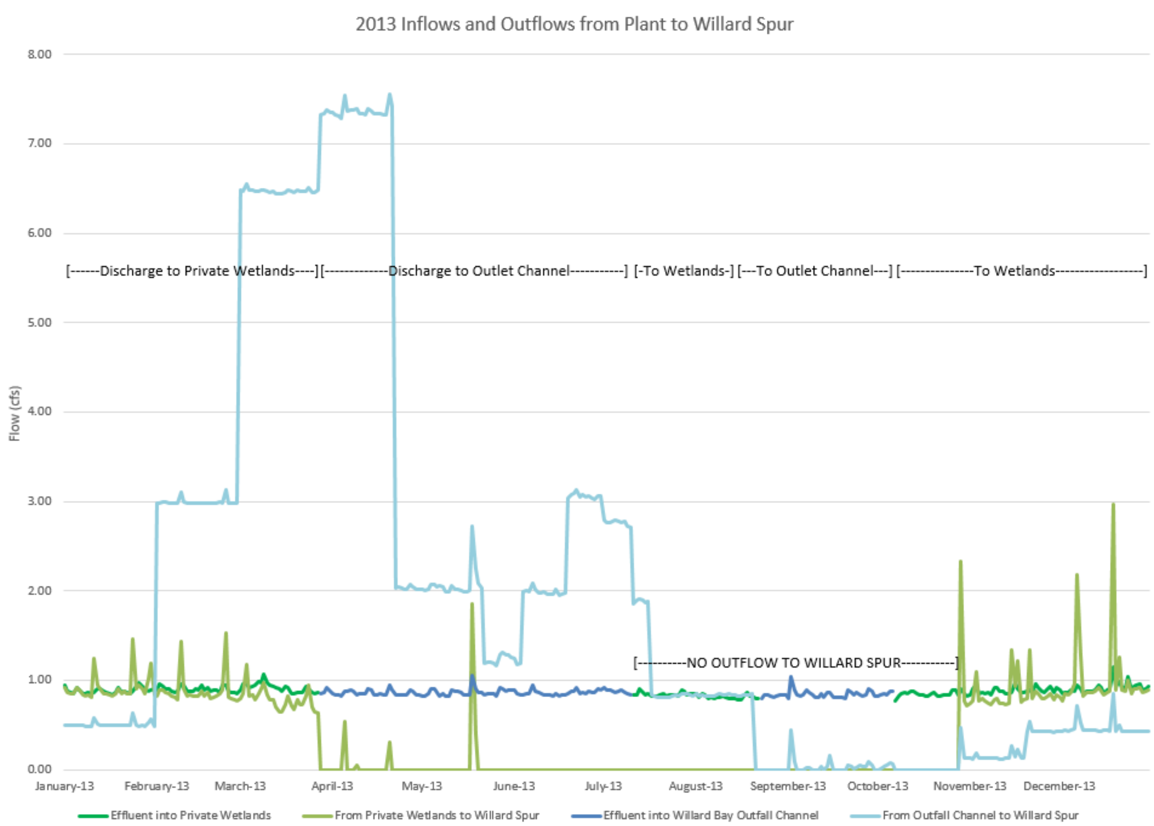
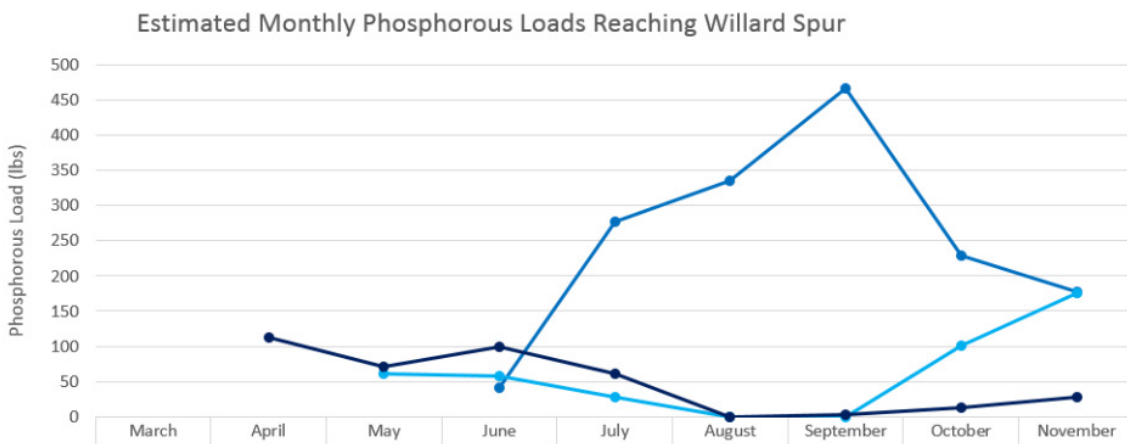
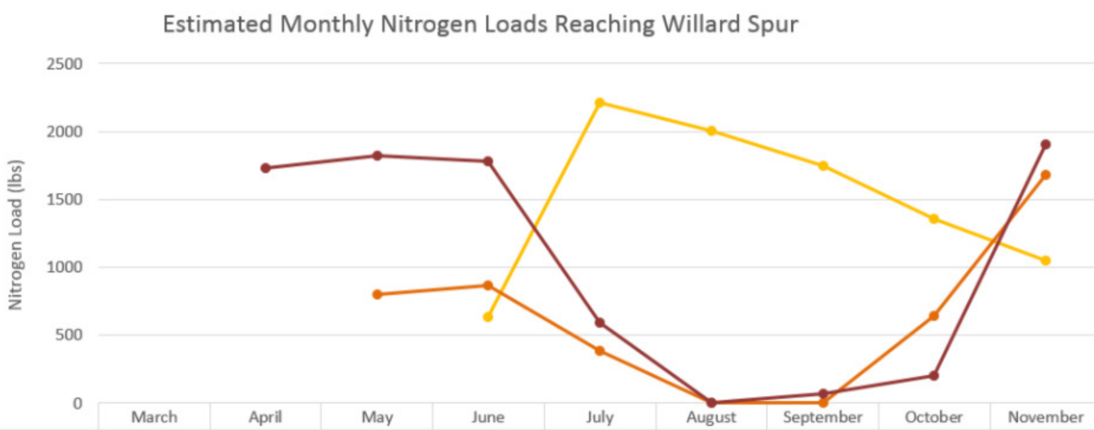


Figure 19. Flows Reaching Willard Spur 2012–2013



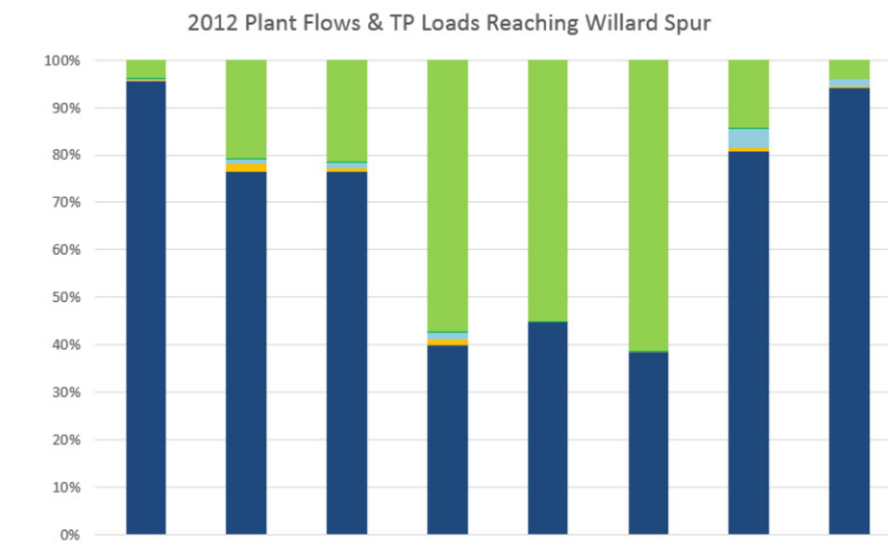
	March	April	May	June	July	August	September	October	November
2011				41	277	335	467	230	178
2012			61	57	28	0	0	101	176
2013		112	71	99	62	0	3	13	27
2011 Average Daily Load			4	1	9	11	16	8	6
2012 Average Daily Load		2	2	2	1	0	0	3	7
2013 Average Daily Load	10	4	2	3	2	0	0	0	1

Figure 20. Total Phosphorus Load for Plant Effluent Reaching the Open Water (End-of-Pipe Concentrations)

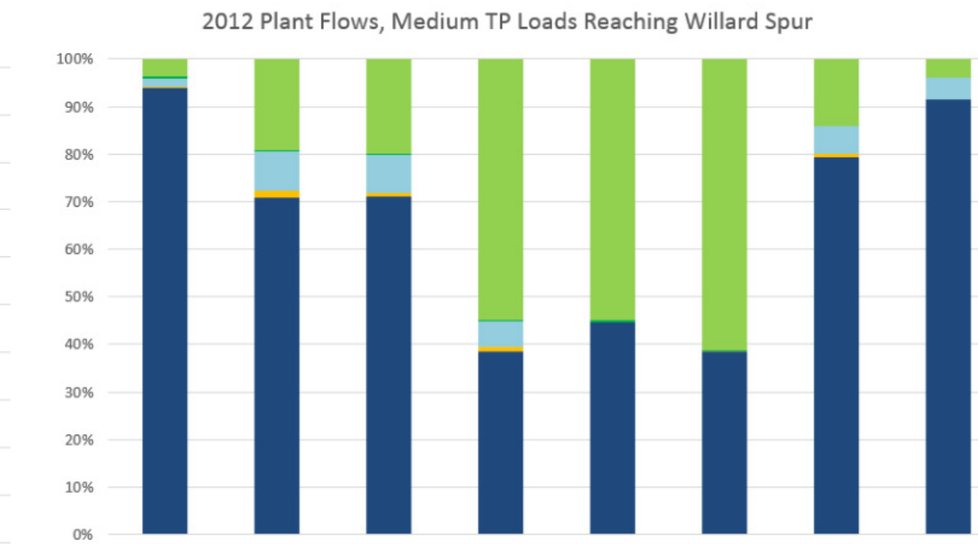


	March	April	May	June	July	August	September	October	November
2011				637	2215	2008	1750	1355	1051
2012			798	865	387	0	0	642	1680
2013		1729	1823	1779	592	0	73	201	1906
2011 Average Daily Load			54	21	71	65	58	45	35
2012 Average Daily Load		20	26	29	12	0	0	21	65
2013 Average Daily Load	63	58	59	59	19	0	2	6	64

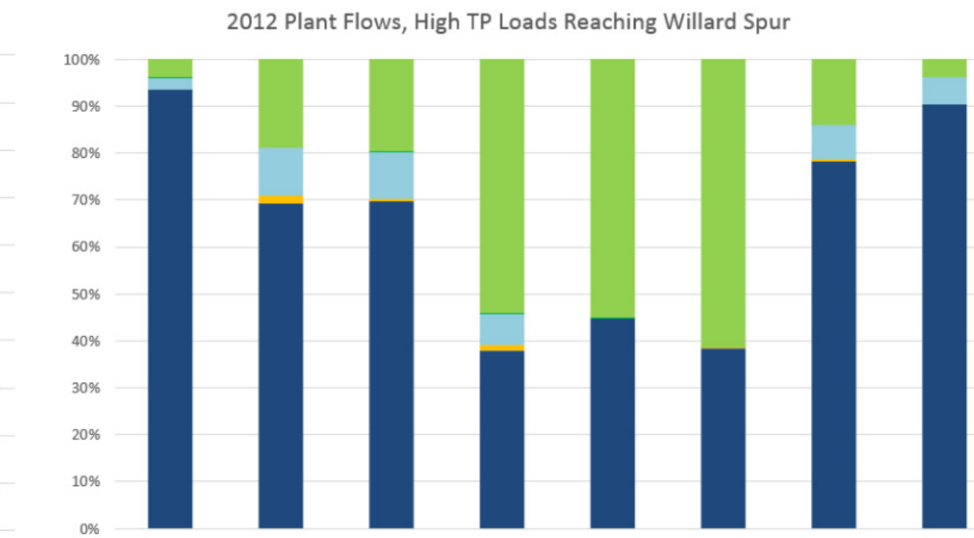
Figure 21. Total Nitrogen Load for Plant Effluent Reaching the Open Water (End-of-Pipe Concentrations)



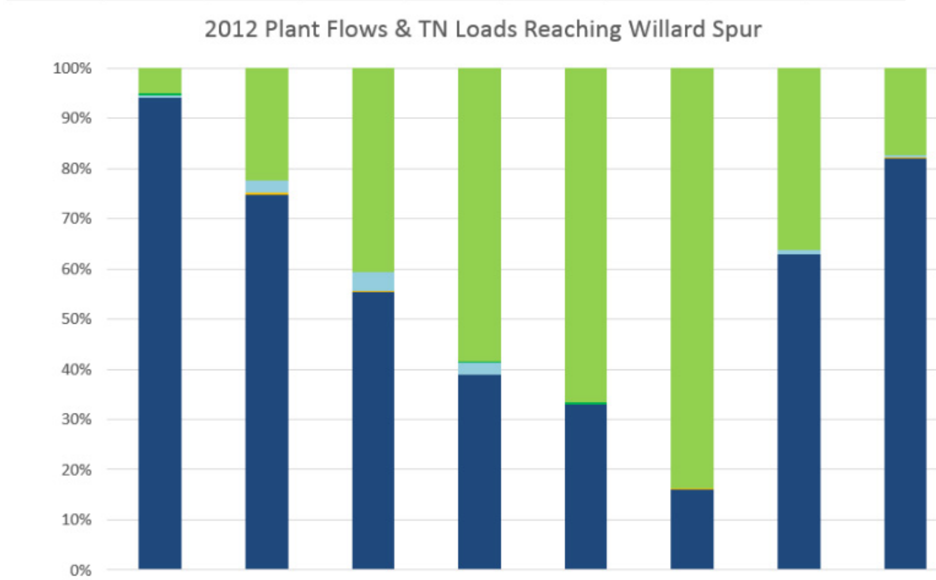
	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12
HCWMA	4%	21%	21%	57%	55%	61%	14%	4%
WB Outfall	0%	0%	0%	0%	0%	0%	0%	0%
POTW	0%	1%	1%	2%	0%	0%	4%	2%
Irr Ditch	0%	2%	1%	1%	0%	0%	1%	0%
BRMBR	96%	76%	76%	40%	45%	38%	81%	94%



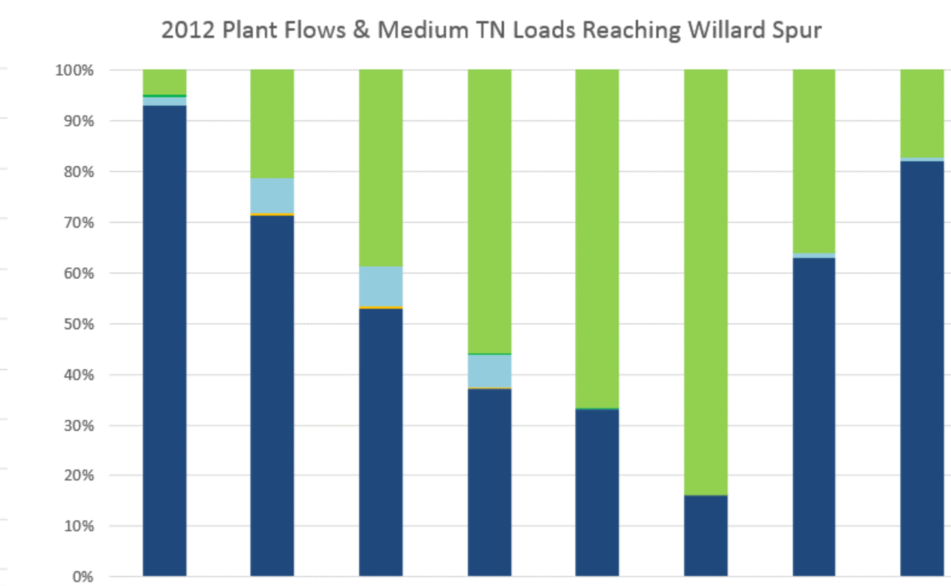
	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12
HCWMA	4%	19%	20%	55%	55%	61%	14%	4%
WB Outfall	0%	0%	0%	0%	0%	0%	0%	0%
POTW	2%	8%	8%	5%	0%	0%	6%	5%
Irr Ditch	0%	2%	1%	1%	0%	0%	1%	0%
BRMBR	94%	71%	71%	38%	45%	38%	79%	91%



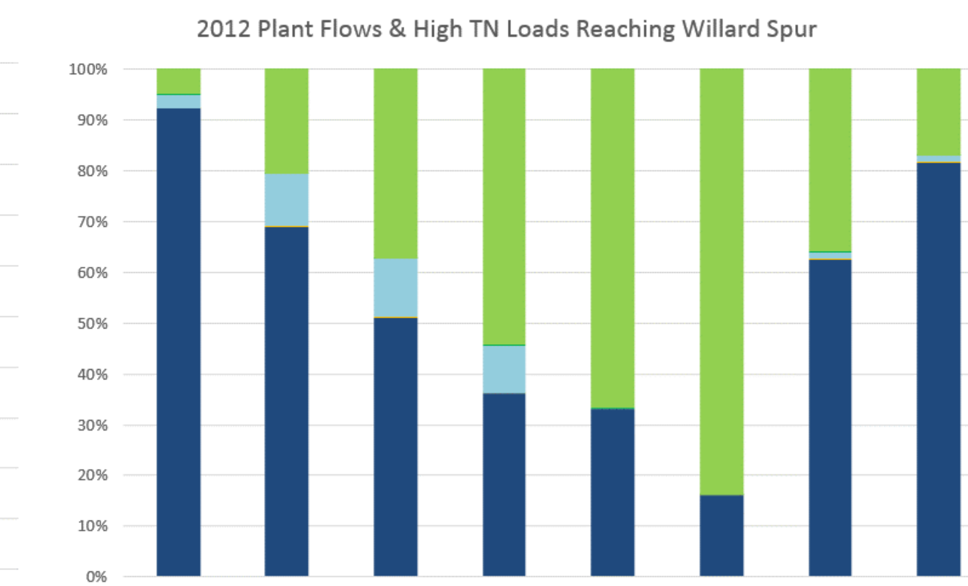
	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12
HCWMA	4%	19%	20%	54%	55%	61%	14%	4%
WB Outfall	0%	0%	0%	0%	0%	0%	0%	0%
POTW	2%	10%	10%	7%	0%	0%	7%	6%
Irr Ditch	0%	1%	1%	1%	0%	0%	1%	0%
BRMBR	93%	69%	70%	38%	45%	38%	78%	90%



	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12
HCWMA	5%	22%	41%	58%	67%	84%	36%	17%
WB Outfall	0%	0%	0%	0%	0%	0%	0%	0%
POTW	0%	2%	4%	2%	0%	0%	1%	1%
Irr Ditch	0%	0%	0%	0%	0%	0%	0%	0%
BRMBR	94%	75%	55%	39%	33%	16%	63%	82%

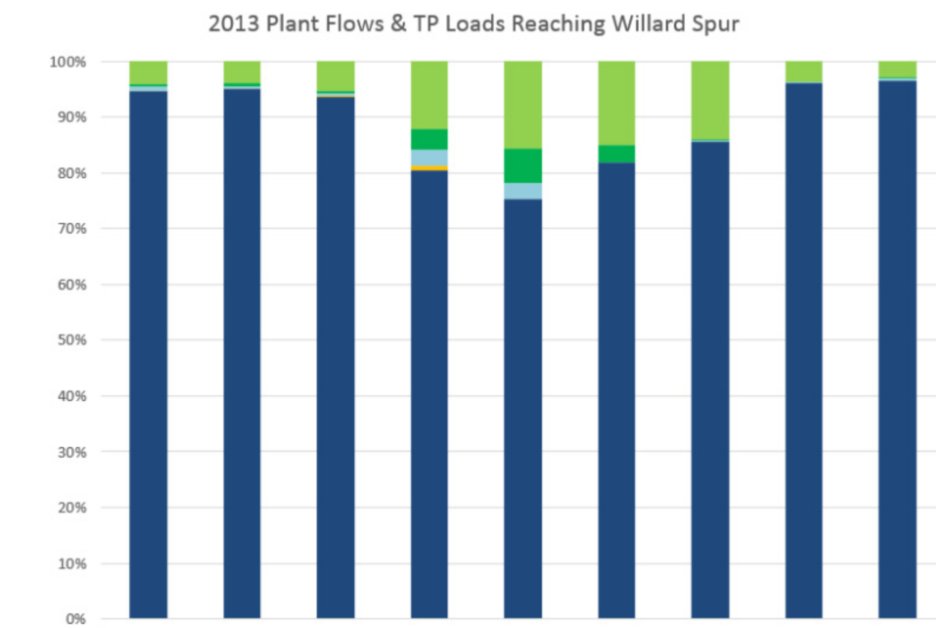


	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12
HCWMA	5%	21%	39%	56%	67%	84%	36%	17%
WB Outfall	0%	0%	0%	0%	0%	0%	0%	0%
POTW	2%	7%	8%	6%	0%	0%	1%	1%
Irr Ditch	0%	0%	0%	0%	0%	0%	0%	0%
BRMBR	93%	71%	53%	37%	33%	16%	63%	82%

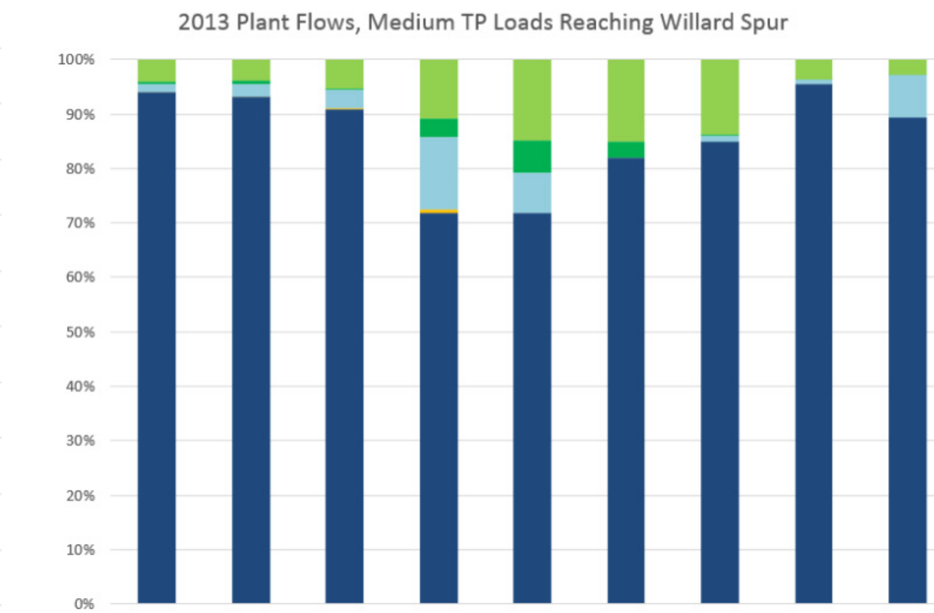


	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12
HCWMA	5%	21%	37%	54%	67%	84%	36%	17%
WB Outfall	0%	0%	0%	0%	0%	0%	0%	0%
POTW	3%	10%	11%	9%	0%	0%	1%	1%
Irr Ditch	0%	0%	0%	0%	0%	0%	0%	0%
BRMBR	92%	69%	51%	36%	33%	16%	63%	82%

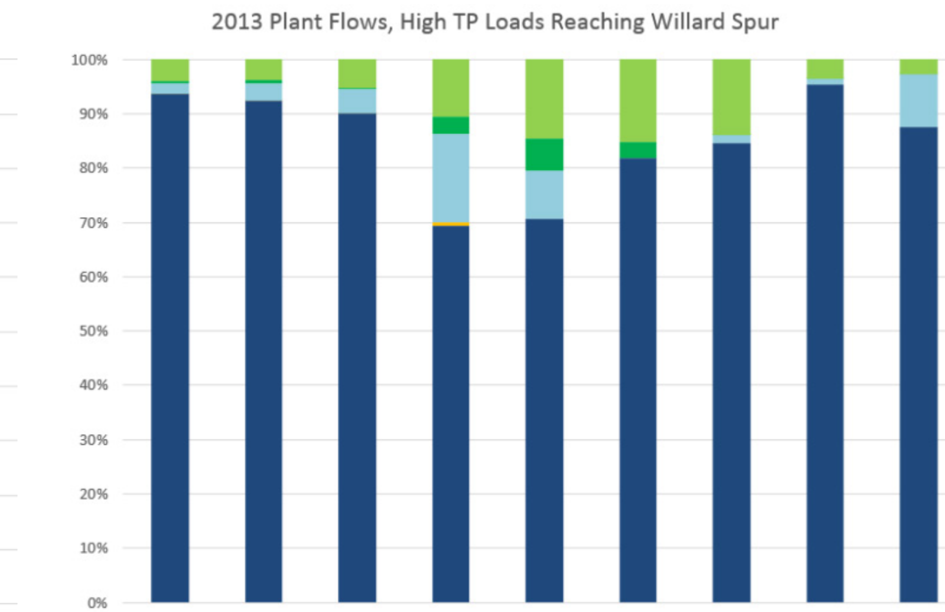
Figure 22. Revised Plant Nutrient Load Reaching the Open Water of Willard Spur in Comparison with Total Nutrients Entering Willard Spur (2012)



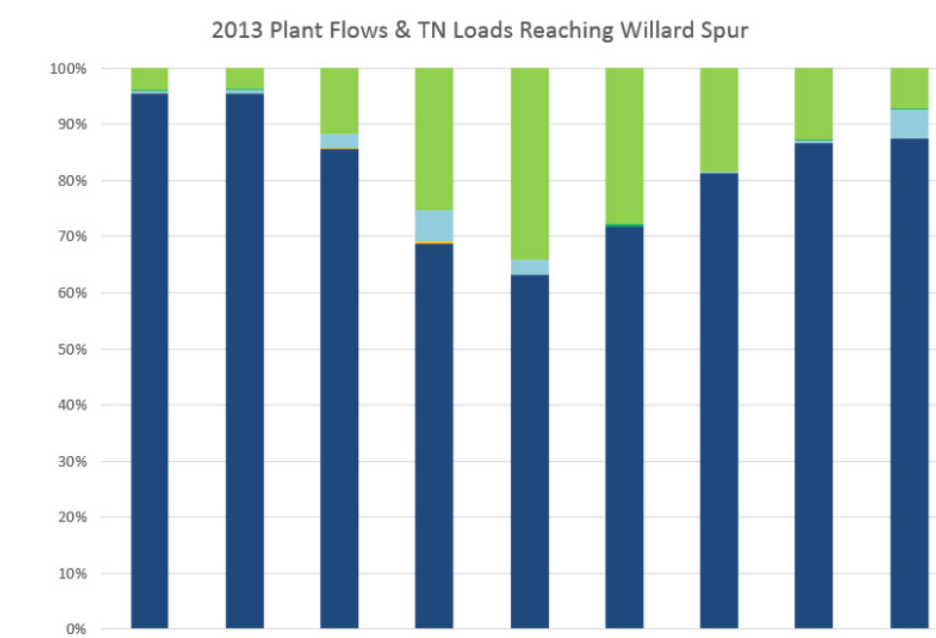
	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13
HCWMA	4%	4%	5%	12%	16%	15%	14%	4%	3%
WB Outfall	0%	1%	0%	4%	6%	3%	0%	0%	0%
POTW	1%	1%	0%	3%	3%	0%	0%	0%	0%
Irr Ditch	0%	0%	0%	1%	0%	0%	0%	0%	0%
BRMBR	95%	95%	94%	80%	75%	82%	86%	96%	97%



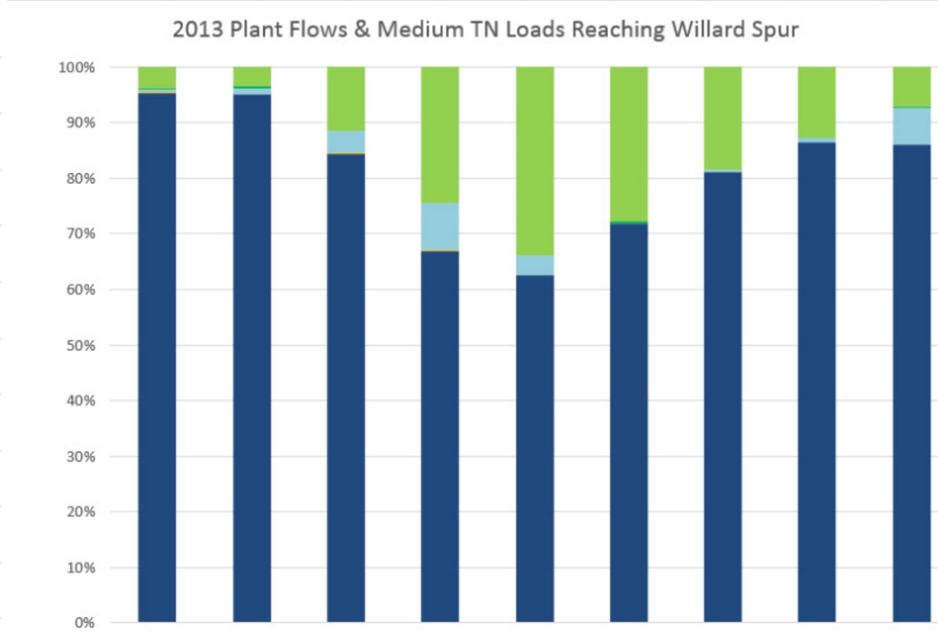
	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13
HCWMA	4%	4%	5%	11%	15%	15%	14%	4%	3%
WB Outfall	0%	1%	0%	3%	6%	3%	0%	0%	0%
POTW	1%	2%	3%	13%	7%	0%	1%	1%	8%
Irr Ditch	0%	0%	0%	1%	0%	0%	0%	0%	0%
BRMBR	94%	93%	91%	72%	72%	82%	85%	96%	89%



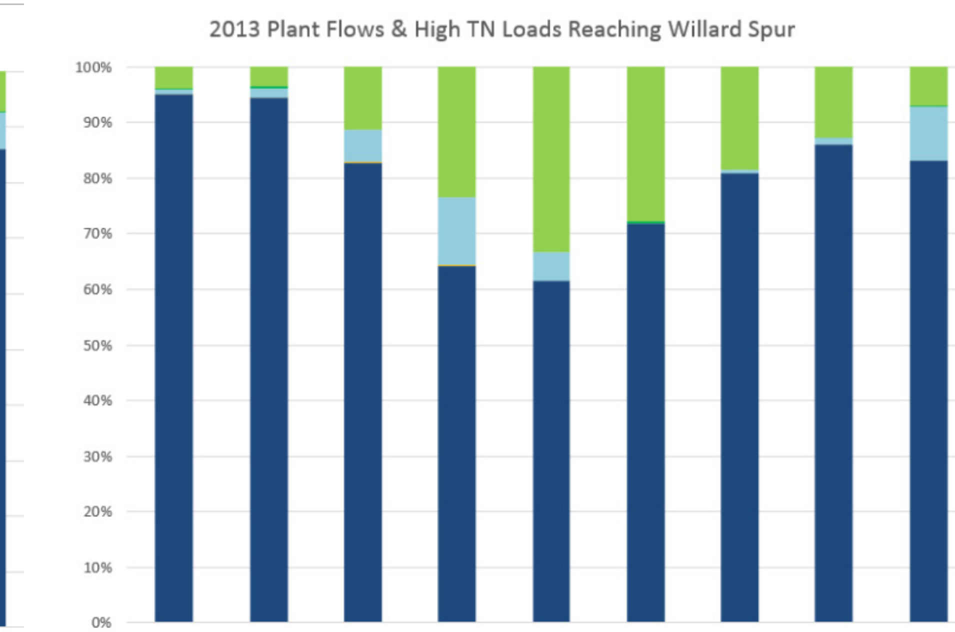
	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13
HCWMA	4%	4%	5%	11%	15%	15%	14%	4%	3%
WB Outfall	0%	1%	0%	3%	6%	3%	0%	0%	0%
POTW	2%	3%	4%	16%	9%	0%	1%	1%	10%
Irr Ditch	0%	0%	0%	1%	0%	0%	0%	0%	0%
BRMBR	94%	93%	90%	69%	71%	82%	85%	95%	87%



	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13
HCWMA	4%	4%	12%	25%	34%	28%	18%	13%	7%
WB Outfall	0%	0%	0%	0%	0%	0%	0%	0%	0%
POTW	0%	1%	3%	6%	3%	0%	0%	1%	5%
Irr Ditch	0%	0%	0%	0%	0%	0%	0%	0%	0%
BRMBR	96%	95%	86%	69%	63%	72%	81%	87%	88%



	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13
HCWMA	4%	4%	11%	25%	34%	28%	18%	13%	7%
WB Outfall	0%	0%	0%	0%	0%	0%	0%	0%	0%
POTW	1%	1%	4%	8%	4%	0%	0%	1%	7%
Irr Ditch	0%	0%	0%	0%	0%	0%	0%	0%	0%
BRMBR	95%	95%	84%	67%	63%	72%	81%	86%	86%



	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13
HCWMA	4%	4%	11%	24%	33%	28%	18%	13%	7%
WB Outfall	0%	0%	0%	0%	0%	0%	0%	0%	0%
POTW	1%	2%	6%	12%	5%	0%	1%	1%	10%
Irr Ditch	0%	0%	0%	0%	0%	0%	0%	0%	0%
BRMBR	95%	95%	83%	64%	62%	72%	81%	86%	83%

Figure 23. Revised Plant Nutrient Load Reaching the Open Water of Willard Spur in Comparison with Total Nutrients Entering Willard Spur (2013)

4.2.2 Consideration of the Location of Discharge

As discussed above, the Plant's discharge location was observed to influence the quantity of effluent that reached the open water of Willard Spur. Figures 24 and 25 compare Plant effluent nutrient loads for three scenarios:

1. Actual end-of-pipe nutrient loads
2. Estimated nutrient loads reaching open water if discharged to the Willard Bay Outlet Channel
3. Estimated nutrient loads reaching open water if discharged to the wetlands/pasture

Scenario 1 uses actual Plant effluent end-of-pipe flow rates and nutrient concentrations. Scenarios 2 and 3 use actual end-of-pipe nutrient concentrations but use estimated flow rates that reach the open water of Willard Spur. Estimated nutrient load contributions from the Plant's effluent are shown for both a wet year (2011) and a dry year (2013) to illustrate how water levels in Willard Spur can influence the quantity, and thereby nutrient load, of effluent that reaches the open water. (See Figures 21 and 22 in CH2M HILL [2014b] for the simulated flow rates for Scenarios 2 and 3.) The volume of effluent that reaches the open water appears to be less if discharged to the private wetland/pasture than if discharged to the Willard Bay Outlet Channel, and thus the Plant's nutrient load contribution to the open water is also likely less.

Figure 24. Comparison of Total Phosphorous Loads Reaching the Open Water if Discharged at Different Locations
(Wet Year vs. Dry Year Represent Different Water Levels in Willard Spur, thus Different Quantity of Effluent Reaching the Open Water)

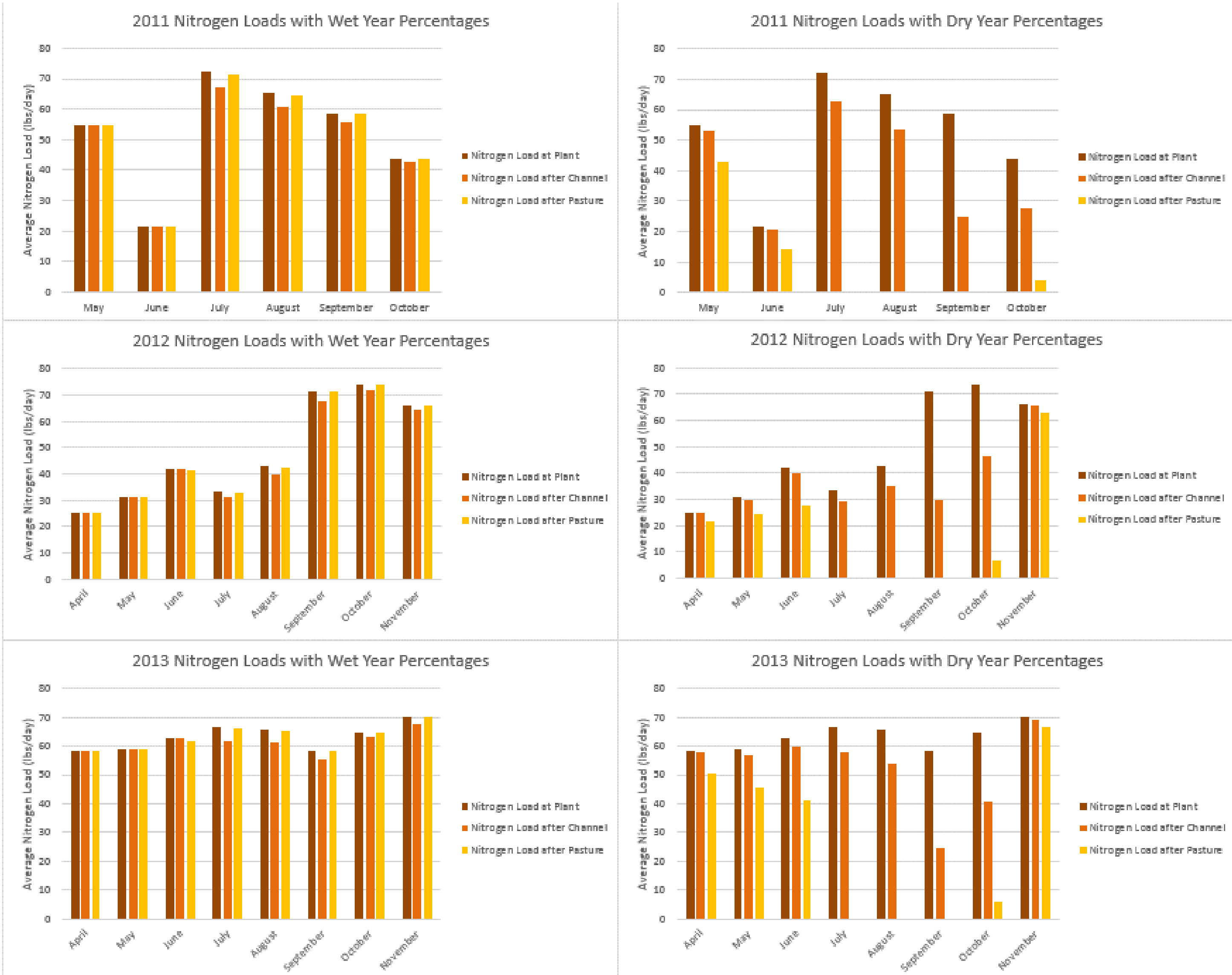


Figure 25. Comparison of Total Nitrogen Loads Reaching the Open Water if Discharged at Different Locations
(Wet Year vs. Dry Year Represent Different Water Levels in Willard Spur, thus Different Quantity of Effluent Reaching the Open Water)

SECTION 5

Observations

External surface water nutrient loads to Willard Spur are directly related to surface water flow rates entering Willard Spur. Thus, watershed hydrology as well as water management practices along the fringe of Willard Spur substantially affect the relative contribution of external surface water nutrient loads to Willard Spur from individual as well as basin sources.

The Bear River Basin contributed the majority of surface water nutrient loads to Willard Spur regardless of whether it was an exceptionally wet year (2011) or a dry year (2012 and 2013). The Weber River Basin and Willard Bay (when flowing) were the second and third most significant surface water nutrient sources with the Plant contributing the smallest fraction. The Plant contributed between 1 percent (wet year, 2011) and 4 percent (dry year, 2012) of the total phosphorus surface water load and between 1 percent (wet year, 2011) and 5 percent (dry year, 2012) of the total nitrogen surface water load to Willard Spur during the months of monitoring (generally April–November). This assumes all Plant effluent contributes to Willard Spur (i.e., end-of-pipe loads).

The Plant contributed between 1 percent (wet year, 2011) and 5 percent (dry year, 2012) of the total nitrogen surface water load and 2 percent (wet year, 2011) and 18 percent (dry year, 2012) of the total inorganic nitrogen surface water load to Willard Spur during the months of monitoring (generally April–November). This assumes all Plant effluent contributes to Willard Spur (i.e., end-of-pipe loads).

The average monthly and daily total phosphorus load of the Plant during the study period was 216 lbs/month and 7 lbs/day. The average monthly and daily total nitrogen load of the Plant during the study period was 1660 lbs/month and 54 lbs/day.

As other surface water inflow rates decreased during the summer as part of the annual hydrologic cycle, the Plant's flow rate was generally consistent throughout each year. Thus, as surface water nutrient loads from other sources decreased during the summer, the Plant's relative contribution of "end-of-pipe" nutrient load to Willard Spur increased. If it is assumed that all surface water inflows reach the open water of Willard Spur, the Plant contributed up to 33 percent of the total phosphorus surface water load and up to 25 percent of the total nitrogen surface water load during summer months to Willard Spur.

Hydrologic observations indicate that all surface water inflows to Willard Spur do not necessarily reach the open water of Willard Spur. Significant reductions in, and even complete reduction of, the effluent flow rate were observed during the summer months in 2012 and 2013. The reduction of surface water as it flows across the mudflats to the open water of Willard Spur is likely due to both evaporation and infiltration (CH2M HILL, 2015). If the Plant's nutrient loads are revised to account for the observed reductions in flow reaching the open water (but not correcting for reductions in nutrient concentrations), the Plant contributed up to 4 percent of the total phosphorus surface water load and up to 6 percent of the total nitrogen surface water load during summer months to the open water of Willard Spur.

The Plant's effluent did not reach the impounded open water of Willard Spur during most if not all of the months of July–October for both 2012 and 2013.

Reducing the rate of nutrient removal at the Plant increases the Plant's nutrient load and relative contribution of the Plant's nutrient loads to Willard Spur. Two alternative scenarios were evaluated to represent higher nutrient concentrations in the Plant's effluent—a "medium" scenario (4 mg/L for total phosphorous and 20 mg/L for total nitrogen) and a "high" scenario (5 mg/L for total phosphorous and 30 mg/L for total nitrogen):

1. Assuming all Plant effluent reaches the open water, the Plant's end-of-pipe contribution to the medium scenario for total phosphorus increased to up to 36 percent and for total nitrogen to up to 31 percent of total surface water nutrient loads to Willard Spur. The Plant's end-of-pipe contribution to the high

scenario for total phosphorus increased to up to 42 percent and for total nitrogen to up to 40 percent of total surface water nutrient loads to Willard Spur.

2. Assuming a revised Plant effluent flow rate that actually reaches the open water, the Plant's contribution to the medium scenario for total phosphorus increased to up to 13 percent and for total nitrogen to up to 8 percent of total surface water nutrient loads to Willard Spur. The Plant's contribution to the high scenario for total phosphorus increased to up to 16 percent and for total nitrogen to up to 12 percent of total surface water nutrient loads to Willard Spur.

The actual volume of effluent that reached the open water of Willard Spur is related to hydrologic conditions within Willard Spur but also to the location where the Plant discharges. A reduction in effluent volume reaching the open water was observed during summer months depending upon discharge location, thus reducing the Plant's surface water nutrient load to the open water of Willard Spur during this period. Information was not available to determine how much of a reduction in the nutrient concentration of the effluent could take place by discharging to these different locations. One data point simply identified that a substantial reduction occurred when the effluent was discharged to the private wetland/pasture. Further, information was not available to determine how much of the effluent nutrient load in this case was infiltrating to the groundwater and how that nutrient load might be transported to the open water via groundwater. Further work will be required to enumerate and determine if these natural treatment processes are effective and sustainable over the long term.

Conclusions

UDWQ invested significant resources to understand Willard Spur's nutrient balance, how it supports its ecosystem, and the role the Plant's effluent plays in these dynamics. The results provide insight into the mechanisms that support the complex ecosystem of Willard Spur and represent a foundation upon which decisions can be made regarding the potential impacts of the Plant and how Willard Spur can be protected into the future. This section summarizes the most pertinent observations made as part of this study.

6.1 Relative Importance of Loading Sources

Typically more than 95 percent of the total external, surface water nutrient loads observed during this study were from nonpoint sources and contributed by the Bear River and Weber River Basins. The Bear River Basin consistently contributed more than 82 percent of the total phosphorus and 71 percent of the total nitrogen load during the study period. The Plant's "end-of-pipe" effluent represented a contribution of less than 5 percent of the total external, surface water nutrient load. The Plant contributed up to 4 percent of the total phosphorus load at the end of pipe during this same year. The Plant contributed up to 5 percent of the total nitrogen load and 18 percent of the total inorganic load at the end of pipe during the driest year of the study period (2012).

6.2 Seasonal Variability of Nutrient Sources

The seasonal variability of external surface water nutrient loads likely follows the annual inflow hydrograph closely. The majority of the surface water is transported into Willard Spur during fall through spring, high-flow periods, thus the majority of the surface water nutrient load enters Willard Spur during this same period. Surface water loads transported into Willard Spur during summer low-flow periods are likely less than the fall through spring period.

The relative contribution of each source varied monthly and was influenced by hydrologic conditions in the watershed, water management practices along the fringe of Willard Spur as well as hydrologic conditions within Willard Spur. As surface water nutrient loads diminished during the summer, the Plant's nutrient load at the end of pipe was consistent. Thus, the Plant's relative end-of-pipe nutrient contribution increased to up to 33 percent of the total phosphorus surface water load and up to 25 percent of the total nitrogen surface water load during summer months to Willard Spur.

6.3 Nutrient Loads during Impounded Periods of the Year

Surface water nutrient loads were computed for all identified sources representing end-of-pipe nutrient loads. They do not account for water and nutrients lost as the water flows through and across the vegetation and mudflats of Willard Spur before it reaches the open water. Available information precluded the ability to estimate the actual surface water flow that reached the open water for all sources except for the Plant. Significant effort was undertaken to understand how much of the Plant's effluent actually reached the open water of Willard Spur during the year (CH2M HILL, 2015). Therefore, nutrient load estimates provided herein assume that these surface waters and associated nutrient loads reach the open water.

The only exception is the analysis presented herein accounting for the reduction of effluent flow that occurred primarily during summer months and thereby reduced the Plant's effective nutrient load to the open water. Accounting for these losses, the Plant's relative nutrient contribution to the open water even during the summer months was up to 4 percent of the total phosphorus surface water load and up to 6 percent of the total nitrogen surface water load to Willard Spur during the study period.

6.4 Discharge Location Does Influence Contribution of Effluent to Open Water

The Plant's effluent was observed to reach the open water of Willard Spur typically when open water levels were high and the effluent was more easily diluted, dispersed, and exported to Bear River Bay. Effluent was less likely to reach the open water of Willard Spur when open water levels were low and the effluent would not be diluted, dispersed, and exported as easily. This was a function of where the effluent was discharged and that the effluent had a propensity to evaporate and infiltrate as the water flowed through wetland and mudflat areas prior to reaching the open water. Effluent discharged to the Willard Bay Outlet Channel was more likely to reach the open water of Willard Spur when water levels were low than if discharged to wetlands or a pasture, simply because the dredged channel is deep and remains connected to the open water for most dry conditions.

An evaluation of different discharge locations identified evaporation and infiltration as possible means of reducing the volume of effluent reaching the open water of Willard Spur. One data point also indicated that there may be a significant reduction in nutrient concentrations, and thereby nutrient load to the open water, when the effluent flows through a ditch, wetland, or pasture. Thus, management of the effluent after leaving the Plant could reduce the Plant's nutrient load contribution to the open water depending upon where the regulatory assessment point is located (i.e., end of pipe or where the effluent reaches the open water) and the classification of the receiving waters. This study did not include a detailed engineering evaluation of the natural treatment processes or potential or long-term impacts of these practices.

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