# STORMWATER CONTROL MEASURES TO REDUCE URBAN STORMWATER AND NUTRIENT INPUTS TO BOATHOUSE CREEK, NORTH CAROLINA

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Portions of the lower White Oak River and surrounding waters in Carteret County, NC are nutrient-sensitive. Over the last few decades, land surrounding Boathouse Creek, a tributary of the lower White Oak, has experienced an increase in development, impervious surfaces, and runoff. Stormwater runoff has been identified as the primary contributor of non-point source pollution to local surface waters. The goal of this study was to characterize the overall water quality of Boathouse Creek under baseflow and stormflow conditions and reduce the volume of runoff and associated pollutants entering Boathouse Creek through the use of stormwater control measures (SCMs). In May of 2015, monitoring and sampling of surface waters at eight locations within the Boathouse Creek watershed was initiated and continued for approximately one year. Monthly monitoring included pH, temperature, dissolved oxygen, oxidation-reduction potential, specific conductance, turbidity, and stream stage and flow measurements. Samples were analyzed quarterly for total dissolved nitrogen (TDN), ammonium ($NH_4$-N), nitrate ($NO_3$-N), and phosphate ($PO_4$-P). Stable isotopic analyses ($\delta^{15}N$ and $\delta^{18}O$) of $NO_3$-N from surface waters were also conducted to determine potential sources of

$NO_3$-N. SCMs were implemented from July to September of 2016, with monitoring and sampling resuming after implementation for approximately six months. Similar methods and analyses were also used for six storm events. Dissolved oxygen concentrations were below the state standard (≥5.0 mg/L daily average) on approximately 30% of the occasions sampled. Nutrient analyses showed relatively low mean concentrations of TDN (<1.0 mg/L) and phosphate (<0.02 mg/L) during baseflow conditions, and increased concentrations of TDN during storms. Dissolved organic nitrogen was found to be the dominant form of nitrogen in Boathouse Creek and the primary cause for elevated storm TDN concentrations. Isotopic analyses indicated that the most likely sources of $NO_3$-N in surface waters are waste material from humans/animals and soil organic matter. Compared to pre-SCM site estimates, runoff was reduced by 258,000 L for the regional 1-year, 24-hour storm event. Annually, approximately 3,800,000 L of runoff was prevented from entering Boathouse Creek, while nitrogen and phosphorus loading was reduced by approximately 2.5 kg-N/ha/yr and 0.1 kg-$PO_4$-P/ha/yr, respectively. More research is needed to better understand SCM performances in the NC Coastal Plain, but future work could help refine these estimates. Continued efforts to reduce stormwater runoff related pollution are suggested to improve water quality. Additionally, because human and/or animal waste was identified as a nitrogen source in Boathouse Creek, future efforts should also focus on reducing waste-related nitrogen inputs, including loading from onsite wastewater treatment systems.

# STORMWATER CONTROL MEASURES TO REDUCE URBAN STORMWATER AND NUTRIENT INPUTS TO BOATHOUSE CREEK, NORTH CAROLINA

A Thesis

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Master of Science in Geology

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# LIST OF SYMBOLS AND ABBREVIATIONS

BFI – Baseflow Index

BMP – Best Management Practice

CAFO – Controlled Animal Feeding Operation

Cl - Chloride

CAMA – Coastal Area Management Act

DIN – Dissolved Inorganic Nitrogen

DO – Dissolved Oxygen

DOC – Dissolved Organic Carbon

DON – Dissolved Organic Nitrogen

EPA – Environmental Protection Agency

GIS – Geographic Information System

mV – millivolts

N – Nitrogen

NADP – National Atmospheric Deposition Program

NCDENR – North Carolina Department of Environment and Natural Resources

NCDEQ – North Carolina Division of Environmental Quality

NCDWR – North Carolina Division of Water Resources

$NH_3$-N – Ammonia Nitrogen

$NH_4$-N – Ammonium

NOAA – National Oceanic and Atmospheric Administration

$NO_2$-N – Nitrite

$NO_3$-N – Nitrate

NPDES – National Pollutant Discharge Elimination System

NTU – Nephelometric Turbidity Unit

O – Oxygen

ON – Organic Nitrogen

ORP – Oxidation Reduction Potential

OWTS – Onsite Wastewater Treatment System

$PO_4$-P – Phosphate

SC – Specific Conductance

SCM – Stormwater Control Measure

TKN – Total Kjeldahl Nitrogen

TN – Total Nitrogen

TP – Total Phosphorus

µS/cm – Microsiemens per centimeter

# CHAPTER 1: INTRODUCTION

Population growth, increased urbanization, and the development of land for agriculture in coastal areas have led to an expansion of impervious surfaces and a decrease in the amount of forested and vegetated land. These surfaces (roads, sidewalks, parking lots, driveways) reduce the infiltration of stormwater into the soil, causing runoff to be conveyed along their surface. The extent of impervious surfaces in a given area has a direct impact on how much runoff will result (Fig. 1). Runoff will increase at the expense of infiltration and evapotranspiration as the percentage of total impervious area is increased (Arnold and Gibbons, 1996; USEPA, 1993).

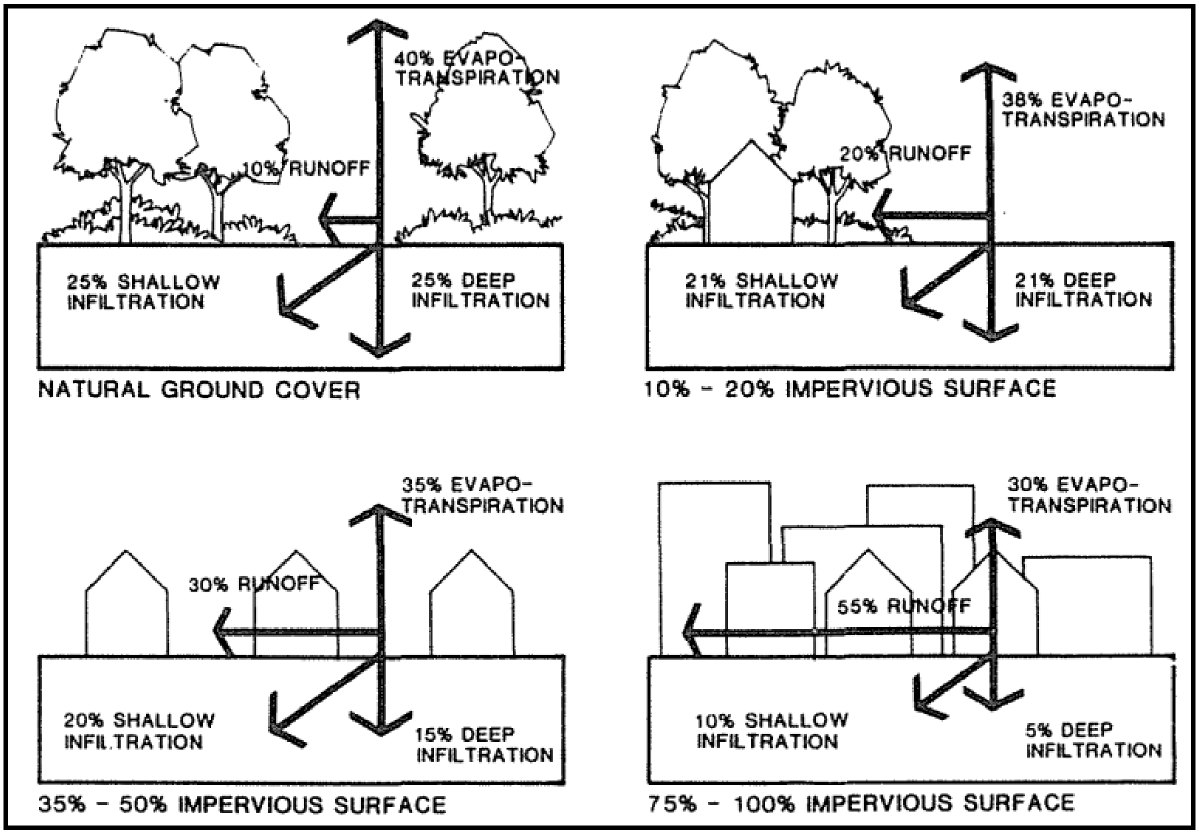

**Figure 1.** Changes in the hydrologic cycle with respect to impervious surface coverage (modified from USEPA, 1993).

With less natural groundcover for infiltration and storage, the majority of runoff is collected, transported, and discharged directly into nearby surface waters via engineered stormwater systems. Primarily, these systems are designed to quickly remove stormwater from streets and communities to protect human health and property, placing less of a priority on preserving the surrounding ecosystem. In areas without these systems, stormwater simply moves downgradient into nearby streams and other surficial water bodies. In both cases, intense or frequent precipitation events can rapidly discharge polluted stormwater into receiving waters, leading to a myriad of water quantity and water quality issues (Field and Pitt, 1990; Hall and Ellis, 1985; Noble et al. 2003; Pratt et al. 1981; Talbot, 2012).

Despite continued regulations and efforts at the federal, state, and local levels, coastal water quality continues to be a growing concern. In 2010, approximately 39% of the U.S. population lived within coastal shoreline counties and 52% lived within coastal watershed counties. Population density among coastal regions greatly exceeds the population density of the nation as a whole (Crosset et al. 2013). Coastal populations rely on their water resources to provide water supplies, recreational activities, and economic benefits from tourism and fisheries. Coastal waters also provide critical habitat to a variety of wildlife, including commercially important fish and shellfish species. With the expected future increases in population, coastal areas will continue to develop and unless significant steps are taken to mitigate or reverse the effects of urban stormwater runoff, this further development has the potential to exacerbate current issues of coastal water quality.

### 1.1 Stormwater Runoff: Impacts on Water Quantity and Quality

The effects of urbanization, impervious surfaces, and resulting stormwater runoff on coastal watersheds have been extensively documented (Brabec et al. 2002; Nagy et al. 2012; O'Driscoll et al. 2010). Runoff can affect stream hydrology and geomorphology by increasing peak flows and decreasing baseflow and lag times. Higher peak flows have been shown to increase erosion rates, increase channel incision and channel cross-sectional area, and alter sediment transport (Paul and Meyer, 2001). Flooding can also be a major issue for coastal regions of the eastern U.S. Severe storms such as hurricanes combined with the low elevations and the generally flat landscape can overwhelm stormwater systems that are outdated or insufficiently designed to handle large volumes of stormwater. Additionally, stormwater has been shown to contribute to the inundation of groundwater within the surficial aquifer in populated barrier islands, compounding the issue of coastal flooding (Manda et al. 2015).

Stormwater runoff has previously been identified as a primary conveyance for delivering contaminants to surface waters and a key contributor to degrading water quality (Cole et al. 1984; USEPA, 1983). These contaminants include any substances that can be suspended, dissolved, and readily transported in water. Runoff in a given area that is contaminated by various sources is the most common type of non-point source pollution. Sediment from active construction sites, heavy metals from automobile use, insecticides and herbicides from agriculture fields, nitrogen and phosphorus from agricultural and lawn fertilizers, and bacteria from human and animal waste are some of the most common examples of runoff contaminants contributing to the impairment of coastal waters (Islam and Tanaka, 2004; Strassler et al. 1999).

Suspended sediment limits the amount of light able to penetrate water, resulting in a reduction of photosynthesis and primary production by aquatic plants (Wood and Armitage, 1997). Heavy metals such as mercury, lead, and cadmium can accumulate in fish tissue and be harmful if consumed by humans and other wildlife (Soloman, 2008). Increased levels of pesticides in aquatic environments are associated with a wide variety of harmful effects to fish and other animals. These effects include cancer, tumors and lesions, reproductive inhibition or failure, and eventual death of the organism (Islam and Tanaka, 2004). Bacteria and other pathogens pose human health risks if ingested during recreational or occupational exposure, or by means of contaminated shellfish. In many cases, shellfish harvesting areas are temporarily closed after storm events to reduce risk of illness from consumption of contaminated shellfish (Cahoon et al. 2006; Coulliette and Noble, 2008; Stumpf et al. 2010).

## 1.2 Nutrient Pollution: Impacts and Sources

Nutrients, primarily in the form of nitrogen and phosphorus are vital for all living organisms, however excessive amounts can be detrimental to plant and animal life in aquatic ecosystems and can seriously degrade water quality, impairing its use for drinking, fishing, recreation, and other purposes. In addition, increased stormwater runoff, population growth and the expansion of residential, industrial, and agricultural land have also altered the global cycle of nutrients and significantly increased the transfer of anthropogenic nitrogen and phosphorus through rivers to estuarine systems and other coastal waters (Vitousek et al. 1997). In fact, anthropogenic nitrogen inputs to the U.S. doubled between 1961 and 1997, with the largest export being riverine flux to coastal waters (Howarth et al. 2002). A number of studies have shown nitrogen to be the major limiting nutrient that controls primary production in temperate coastal waters (D'Elia et al. 1986; Dugdale and Goering, 1967; Howarth and Marino, 2006; Ryther and Dunstan, 1971).

Consequently, increased nitrogen and phosphorus inputs to these waters can lead to over-enrichment, or eutrophication, and promote excessive primary production (Carpenter et al. 1998; Correll, 1998; Herbert, 1999; Nixon, 1995). This excessive primary production occurs in the form of suspended algal blooms that can dominate the water's surface and be potentially harmful or toxic (Anderson et al. 2002; Paerl, 1988, 1997). Decomposition of these algal blooms consumes dissolved oxygen, creating hypoxic or anoxic conditions that can lead to fish and shellfish kills (Paerl, 1998; Piontkovski, 2012; Smith et al. 1998). Davidson et al. (2014) estimates the economic effects of harmful algal blooms in the United States to be approximately $100 million per year, accrued from public health costs that include morbidities and mortalities, fish kills, commercial fish and shellfish closures, decreases in coastal tourism and recreation, and monitoring and management costs. Dodds et al. (2009) analyzed potential economic damages of eutrophication in U.S. freshwaters and estimated potential annual value losses at over $2 billion in recreational water usage, waterfront real estate, spending on recovery of threatened and endangered species, and drinking water.

Excess nutrient inputs entering surface waters come from a variety of point (single, identifiable source of discharge) and non-point sources. Point sources include wastewater discharge from centralized wastewater treatment facilities, combined and separate storm-sewer systems, and industrial operations. In urban areas of the U.S., point sources may account for >50% of nutrient inputs to rivers and streams (Carpenter et al. 1998), and their impacts have been shown to be even more significant downstream of the local discharge area (Carey, 2009). However, while point source discharges can contribute significant nutrient loads to receiving waters, they are relatively easier to regulate, and monitor compared to non-point sources.

Major non-point sources of nutrients to coastal waters include: agricultural and lawn fertilizers, atmospheric deposition from fossil fuel combustion, animal waste (manure) from livestock production, and human waste from onsite wastewater treatment (septic) systems. The production and use of synthetic or inorganic nitrogen fertilizer is the single largest anthropogenic alteration of the nitrogen cycle and is the dominant source of inputs in agricultural watersheds (Howarth, 2008; Vitousek et al. 1997). Approximately 30% of coastal nitrogen pollution is estimated to come from nitrogen emissions as a result of fossil fuel combustion (Howarth and Reilinger, 2003) therefore urban stormwater can also be a significant source of nitrogen

Animal manure from concentrated/confined animal feeding operations (CAFOs) produces a vast amount of nitrogen and phosphorus that can impact surface waters by surface or groundwater transport of wastewater-related nutrients. In addition, nitrogen in animal waste can volatilize, move with air currents, and eventually contribute nitrogen to adjacent surface waters via atmospheric deposition (Costanza et al. 2008). A study by Whitall et al. (2003) estimated that wet deposition of nitrogen could contribute up to 50% of the total externally supplied nitrogen flux to the Neuse River Estuary in North Carolina. Mallin and

Cahoon (2003) estimated 124,000 metric tons of nitrogen and 29,000 metric tons of phosphorus were generated by CAFOs annually in the North Carolina Coastal Plain.

In addition to animal waste, municipal and residential wastewater can also be a source of nutrients. Decentralized or onsite wastewater treatment systems (OWTS) have also been shown to contribute significant nutrient loads to surface waters via groundwater discharge (Humphrey et al. 2013; Iverson et al. 2015; O'Driscoll et al. 2014); however, malfunctioning or improperly designed and/or located systems may allow effluent to seep to the surface and be carried with runoff, particularly in coastal areas where groundwater inundation is known to occur.

### 1.3 Stormwater Runoff Mitigation Strategies

In order to reduce stormwater runoff and mitigate its effects on surface water quality and erosion, a combination of laws, public education and outreach, and stormwater control measures (SCMs) are being used. The Clean Water Act was established in 1972 and administered by the United States Environmental Protection Agency (EPA) to address declines in water quality. It required municipal and industrial wastewater treatment facilities to obtain National Pollutant Discharge Elimination System (NPDES) permits, limiting the amount of effluent that can be discharged to surface waters (Metcalf et al. 2002). However, these regulations only addressed point-sources of pollution. Several environmental studies subsequently conducted by the EPA, most notably the Nationwide Urban Runoff Program, indicated stormwater runoff as one of the primary causes of non-point pollution affecting the nation's watersheds (USEPA, 1983). In 1987 the NPDES was updated to include a stormwater program that required urban areas to also obtain permits for their stormwater discharges (Copeland, 1999).

State agencies and local governments have also realized the importance of reducing runoff to protect their water resources. In North Carolina, the NC Coastal Resource Commission issued the Coastal Area Management Act (CAMA) that requires permitting of new development in 20 coastal counties if the development may affect areas of environmental concern. Additionally, under the authority of the NC Environmental Management Commission, the State Stormwater Management Program specifically protects Outstanding Resource Waters and High-Quality Waters in the 20 CAMA coastal counties from runoff impacts induced by new development activity (NCDEQ, 2016). The EPA also provided state municipalities and local governments with programs, education, and grants in order to assist their communities with improving their water quality. Research on the effectiveness on these efforts has shown that media campaigns as well as intensive training sessions may produce positive results in residential neighborhoods (Dietz et al. 2004).

Perhaps the most recognized way to mitigate the impacts of runoff is through the use of SCMs (also commonly referred to as stormwater best management practices or BMPs). SCMs are defined by the EPA as "a technique, measure, or structural control that is used for a given set of conditions to manage the quantity and improve the quality of stormwater runoff in the most cost-effective manner” (Strassler et al. 1999). Non-structural SCMs are primarily focused on the prevention of stormwater runoff and can greatly reduce the need for down-gradient structural controls. Improved land use planning and site design that minimizes impervious cover, preservation of natural or forested area, and downspout disconnects are examples of nonstructural approaches in urban areas. Minimizing impervious cover and preserving natural vegetation directly prevent runoff in newly developed areas, while downspout disconnects can divert rooftop runoff into grassed areas for infiltration in previously developed areas. In rural areas, nonstructural SCMs include conservation cover, cover crops, and crop rotation which prevent runoff and erosion of bare soil, while proper nutrient management techniques and vegetative or riparian buffers can reduce nitrogen and phosphorus exports to surface waters (Dinnes, 2004).

Structural or engineered SCMs are designed to reduce runoff volumes and peak flows to surface waters by promoting storage and infiltration of runoff, while various physical, biological, and chemical processes aid in pollutant removal. Common structural SCMs in urban areas include detention/retention basins, bioretention areas or rain gardens, green roofs, pervious pavements, and vegetated swales. Where there are significant amounts of impervious cover, such as parking lots, detention and retention basins are often used to capture and hold large runoff volumes for extended periods, reducing peak flows, while still providing treatment through sedimentation and filtration. Bioretention areas, green roofs, and vegetated swales are generally smaller, onsite SCMs designed to capture and temporarily store runoff. Generally, these SCMs use a combination of plants and soil to facilitate pollutant removal through evapotranspiration, assimilation, biological degradation, and adsorption. Pervious pavement systems allow for the direct infiltration of stormwater, reducing runoff. In agricultural settings, controlled drainage systems that use flashboards, gates, or valves, can control the rate and volume of runoff discharged to surface waters (Gilliam et al. 1997).

The effectiveness of an SCM varies significantly depending on its design, operation, maintenance, and site conditions, but studies have shown their ability to reduce runoff and its associated contaminants. A literature review by Liu et al. (2017) provides an evaluation of the effectiveness of some of the urban and agricultural SCMs previously mentioned. A portion of these reviews and their results are summarized in Tables 1 and 2. All the studies reviewed showed that SCMs were effective to some degree in reducing pollutants; however, some examples also showed that the SCMs were temporarily a source of pollutants.

**Table 1.** Review studies of urban SCM effectiveness on reducing runoff and various pollutants including: nitrite ($NO_2$-N), nitrate ($NO_3$-N), nitrogen (N), ammonia nitrogen ($NH_3$-N), total Kjeldahl nitrogen (TKN), total nitrogen (TN), organic nitrogen (ON), phosphate ($PO_4$-P), and total phosphorus (TP) (modified from Liu et al. 2017).

| Literature citation | SCMs reviewed | Runoff and pollutant reduction efficiency | Number of studies reviewed |
|---|---|---|---|
| Ahiablame et al. (2012) | Bioretention/rain garden | Runoff (48 to 97%), TP (−3 to 99%), N (1 to 83%), $NH_3$-N (−65 to 82%), TKN (26 to 80%), TN (32 to 99%). | 17 |
| | Green roof | Runoff (23 to 100%). | 12 |
| | Permeable pavement | Runoff (50 to 93%), TP (10 to 78%), $NH_3$-N (75 to 85%), TKN (75 to 100%). | 10 |
| | Swale systems | TP (24 to 99%), TN (14 to 61%). | 5 |
| Dietz (2007) | Bioretention systems | N (13 to 75%), $NH_3$-N (−1 to 86%), TKN (−5 to 67%), TP (−240 to 87%), TN (40 to 59%), ON (41%). | 4 |
| | Green roofs | Runoff volume (38.6 to 70.7%). | 5 |
| | Permeable Concrete blocks | Runoff volume (72%). | 2 |
| | Pervious asphalt | Runoff volume (60 to 96.7%). | 2 |
| | Pervious concrete | TP (3%), N (66%), $NH_3$-N (85%), and TN (42%). | 1 |
| Simpson and Weammert (2009) | Dry detention basins | TN (−30 to 44%), $NO_3$-N (−11 to 64%), TP (−3 to 88%), $PO_4$-P (−47 to 74%). | 20 |
| Berndtsson (2010) | Green roof | Runoff volume (5 to 100%). | 9 |
| Davis et al. (2009) | Bioretention | TN (30 to 99%), TP (−240 to 99%). | 12 |
| Liu et al. (2014) | Bioretention | Peak flow (0 to 99%), runoff volume (0 to 100%), TN (−3 to 99%), TP (−240 to 100%). | 14 |

**Table 2.** Review studies of agricultural SCM effectiveness on reducing runoff and various pollutants including: nitrate ($NO_3$–N), nitrogen (N), ammonia nitrogen ($NH_3$–N), total Kjeldahl nitrogen (TKN), total nitrogen (TN), and total phosphorus (TP) (modified from Liu et al. 2017).

| Literature citation | SCMs reviewed | Runoff and pollutant reduction efficiency | Number of studies reviewed |
|---|---|---|---|
| Arora et al. (2010) | Buffer strip | Runoff volume (0 to 100%). | 54 |
| Simpson and Weammert (2009) | Drilled rye conservation tillage | N (57 to 75%). | 8 |
| | Dry detention basins | TN (25 to 31%), TP (19%). | 2 |
| | Riparian forest buffer | TN (32 to 95%), TP (20 to 96%). | 16 |
| Dinnes (2004) | Conservation tillage | TN (−90 to 95%), TP (25 to 90%). | 25 |
| | Cover crops | TN (−20 to 90%), TP (0 to 95%). | 26 |
| | In-field vegetative buffers | TN (−10 to 95%), TP (10 to 95%). | 19 |
| | Riparian buffers | TN (0 to 100%), TP (0 to 100%). | 14 |
| | Wetlands | TN (−10 to 100%), TP (−50 to 80%). | 11 |
| | Nutrient application techniques | TN (−100 to 90%), TP (−100 to 95%). | 21 |
| | Nutrient timing and rate management practices | TN (−50 to 90%), TP (−100 to 100%). | 33 |
| Hoffmann et al. (2009) | Buffer strip | TP (32 to 93%). | 9 |
| Cronk (1996) | Constructed wetlands | TKN (57 to 99%), $NH_3$-N (54 to 99%), TP (44 to 94%). | 8 |
| Dodd and Sharpley (2016) | Buffer strips/riparian zones | Runoff volume (−71 to 84%), TP (−37 to 95%). | 8 |
| | Constructed wetlands | TP (−54 to 80%). | 6 |
| Dorioz et al. (2006) | Grass buffer strips | N (47 to 100%), TP (−64 to 93%). | 11 |
| Gumiere et al. (2011) | Vegetated filters | Runoff volume (14.5 to 99.9%). | 48 |
| Kay et al. (2009) | Buffer zones | TN (−217 to 100%), $NO_3$-N (−232 to 100%), TP (−41 to 98%). | 11 |
| | Wetlands | TN (−7 to 100%), $NO_3$-N (−8 to 100%), TP (−6 to 72%). | 7 |
| Lacas et al. (2005) | Grassed strips | Runoff volume (0 to 100%). | 16 |

Ahiablame et al. (2012) showed that bioretention/rain gardens were able to reduce runoff by 48% to 97%, while reducing total nitrogen (TN) and total phosphorus (TP) up to 99%, but in some instances, they also became a source for TP and ammonia nitrogen ($NH_3$-N), indicated by the negative efficiency values (Table 1). Similarly, Dietz (2007) showed that bioretention systems reduced TN -5% to 59%, $NH_3$-N -1% to 86%, and TP -240% to 87%, with the negative values indicating that after the SCM was installed there was a release of nitrogen and phosphorus. Release of these pollutants can be explained by higher levels of nitrogen and phosphorus that were previously present within the sod and other soil media, as well as post fertilization of the SCM itself. Because they have shown to be effective in reducing stormwater runoff volumes and pollutants, SCMs can be used to address stormwater-related non-point source pollution in coastal areas.

### 1.4 Stormwater Runoff in the Lower White Oak River

Portions of estuarine areas along the coast of North Carolina are periodically or permanently closed for shellfishing due to degraded water quality. For example, waters within the White Oak River basin are nutrient-sensitive and in some areas impaired due to elevated concentrations of fecal indicator bacteria. Over the last few decades, the community of Cedar Point and land surrounding Boathouse Creek, a tributary of the lower White Oak River currently on the NC Division of Water Resources 303(d) list of impaired waters for exceeding fecal coliform bacteria standards, has experienced an increase in construction, land development, impervious surfaces, and runoff. In 2006, a previous watershed study funded via a grant from the EPA's 319 Nonpoint Source Program was performed by the NC Division of Water Quality, NC Department of Transportation, NC Coastal Federation, and the town of Cedar Point to determine pollution sources. That study found no obvious point-sources of pollution and concluded that urbanization and the altered landscape and resulting stormwater runoff was the primary source of non-point pollution in the lower White Oak River (Tursi, 2009). Since the mechanism of pollutant-transport has generally been determined to be stormwater-related, more efforts are needed to reduce stormwater runoff and its associated contaminants. A restoration plan was developed by the NC Coastal Federation which provided locations where stormwater runoff could be reduced and various SCMs that could be viable solutions. In an attempt to improve water quality and implement SCMs to reduce stormwater runoff, a second EPA 319 grant was provided to fund this study.

The specific objectives of this study were to: (1) characterize the water quality and hydrology of Boathouse Creek under baseflow and stormflow conditions, (2) determine if nutrient concentrations in Boathouse Creek were elevated during storm/runoff events, (3) identify the primary sources of nitrogen in the study area, (4) implement 12 or more SCMs that facilitate the infiltration of stormwater runoff, and (5) estimate runoff volumes and nutrient loads reduced by SCMs. The specific reduction goal set for the project was to reduce stormwater runoff by 200,000 L for the region's 1-year, 24-hour storm event. Efforts were also made to increase public awareness of the area's surface water quality issues.

Based on the literature review regarding the effects of urban and agricultural stormwater runoff on nearby surface waters, the use of SCMs to mitigate these effects, and preliminary analyses, it was hypothesized that: 1) Concentrations of nitrogen and phosphate in Boathouse Creek will be elevated during storm events; 2) Primary sources of nitrogen in the study area include human/animal waste and soil organic matter; and 3) Implementation of SCMs will reduce stormwater runoff volumes and nutrient loads to Boathouse Creek.

# CHAPTER 2: STUDY AREA

## 2.1 White Oak River Basin

The White Oak River Basin is located in southeastern North Carolina, within the outer coastal plain. The White Oak is bordered by the Cape Fear River Basin to the west and Neuse River Basin to the north. The NC Division of Water Quality divides the basin into five distinct sub-basins that include four separate rivers systems: the New River, White Oak River, Newport River, and North River, encompassing parts of Carteret, Onslow, Jones, and Craven counties (Fig. 2). The basin also contains Bogue, Back, and Core Sounds along with portions of the Outer Banks barrier islands. The New River watershed (03-05-02) is the largest and most populated of

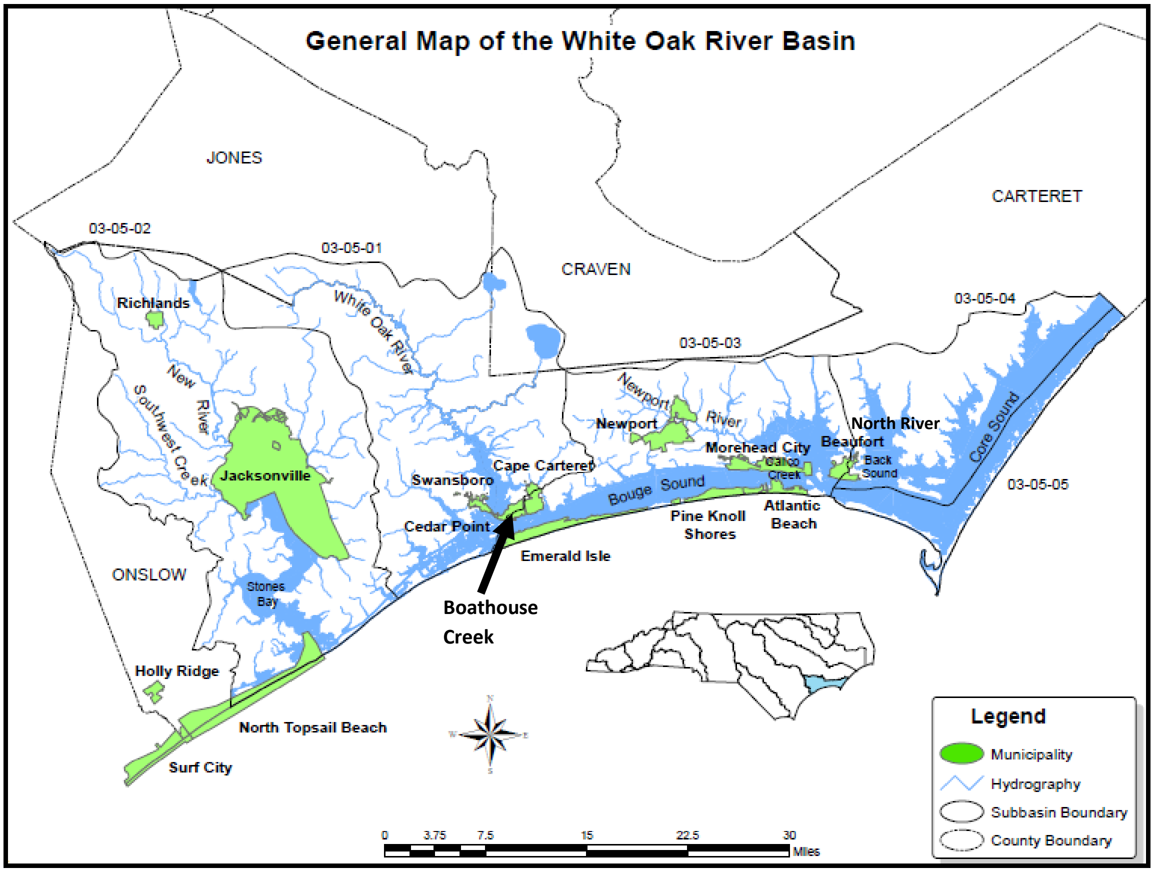

**Figure 2.** General map of the White Oak River Basin showing sub-basin and county boundaries, municipalities, and major water bodies (modified from NCDENR, 2007).

the five sub-basins. It lies entirely within Onslow County and includes the town of Richlands, the city of Jacksonville, and the Camp Lejeune Marine Corps Base which comprise the majority of developed land within the watershed. The New River and all of its tributaries, over 10,800 acres, are designated as being nutrient-sensitive waters, meaning they are either experiencing or are most susceptible to microscopic or macroscopic growths of vegetation (NCDENR, 2007). The Newport River watershed (03-05-03) lies within Carteret County and contains Bogue Sound, the city of Newport, Morehead City, Beaufort, and popular beach destinations such as Emerald Isle and Atlantic Beach. Sub-basin 03-05-04 also lies within Carteret County and includes the North River as well as the northern half of Back Sound and western half of Core Sound. A significant portion of land area within this sub-basin (approximately 23%) is used for crop production (NCDENR, 2007). Sub-basin 03-05-05 is the smallest of the five and is largely made up of estuarine waters from the southern half of Back Sound and eastern half of Core Sound, with the Shackleford Banks, Cape Lookout, and Core Banks barrier islands making up the land area.

This study was conducted within the White Oak River sub-basin (03-05-01) which is located east of the New River and contains over 4,400 acres of recreational water and over 11,000 acres shellfish harvesting waters, of which 62% is considered impaired (Fig. 2) (NCDENR, 2007). It includes the White Oak River and its tributaries, along with Great Lake and Catfish Lake, draining portions of all four counties. Municipalities include Maysville, Peletier, Swansboro, Cape Carteret, and Cedar Point. Headwaters begin from the inland wetlands of Hofmann Forest, flowing 40 miles generally to the southeast, forming the border between Onslow, Jones, and Carteret Counties, then draining into the Atlantic Ocean on the western end of Bogue Sound (Fig. 3). It also forms the western boundary of the Croatan National Forest which comprises the majority of land on the eastern half of the sub-basin.

**Figure 3.** The lower portion of the White Oak River sub-basin. Surrounding area includes the town of Cedar Point and Boathouse Creek.

The upper area of the sub-basin is primarily rural, with land being predominantly forest/wetlands or cleared for agricultural purposes. Agricultural practices in the area include CAFOs. As of 2016, there were seven permitted swine feeding operations (NCDEQ, 2017a), which potentially allow their runoff to drain into adjacent tributaries. With the exception of the town of Maysville, urban areas are concentrated toward the mouth of the river in the lower part of the sub-basin (Fig. 3). There are four minor wastewater treatment facilities with individual NPDES discharge permits serving the surrounding population, however, none of the facilities discharge within the Boathouse Creek watershed (NCDEQ, 2017b).

### 2.2 Boathouse Creek Watershed

Boathouse Creek is a low order stream that empties into the lower estuarine portion of the White Oak River. The watershed occupies 626 acres (approximately 2.5 km$^2$) of land within the lower part of the White Oak River sub-basin. It is located on the east side of the White Oak River in Carteret County, just west of Cape Carteret and includes portions of the town Cedar Point. The watershed is largely made up of the Ocean Spray and Marsh Harbor communities.

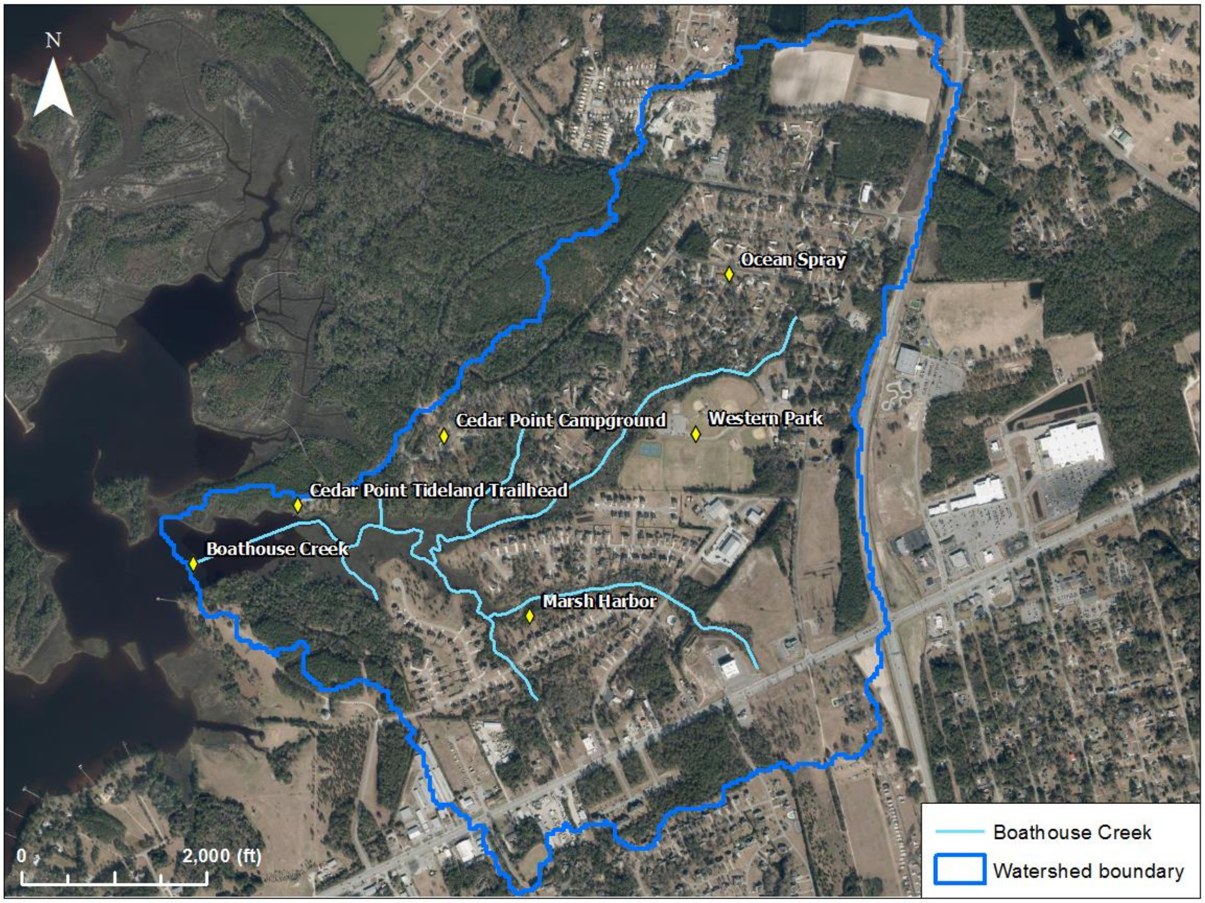

**Figure 4.** The Boathouse Creek watershed area. Notable sites include the Ocean Spray and Marsh Harbor communities, Western Park, Cedar Point Campground, and the Cedar Point Tideland Trailhead parking area and boat ramp.

Other notable locations include a park and recreation area (Western Park), the Cedar Point Campground, and the Cedar Point Tideland Trailhead parking area and boat ramp (Fig. 4). It also contains sections of highways NC 58 and 24. The mouth of the creek primarily drains forest, shrub, and grasslands, along with the trail parking area and boat ramp. Moving inland, the creek divides into multiple tributaries, with the northern tributaries primarily draining Ocean Spray and Western Park, while the southern tributaries drain Marsh Harbor.

**Figure 5.** The Marsh Harbor site predevelopment in 2003 (top) and the developing community in 2015 (bottom). Notice the decrease in forested area and increase in impervious surface coverage since development.

Population and land development within the watershed has been increasing over the last few decades. The Ocean Spray community was largely developed in the 1980s and continued to expand over the next twenty years. The Marsh Harbor community is more recent, with most of its development taking place over the last ten years. The land was forested prior to development, meaning approximately 75 acres of natural forest was converted to residential land (Fig. 5). The development of Marsh Harbor has decreased natural vegetation and increased the amount of impervious surface coverage (roofs, driveways, roads) in the watershed, contributing more stormwater runoff to Boathouse Creek and exacerbating the previously present water quality issues.

Based on data from the National Land Cover Database of 2011 (Homer et al. 2015), over 50% of the land within the Boathouse Creek watershed has been developed in some aspect, either as open space or as low, medium, or high-density development. However, this doesn't consider the more recent home additions (2012-2017) in Marsh Harbor which would increase the amount of developed land to over 60%. There are also a few small areas of cultivated/tilled crop land in the southeastern and northeastern portions of the watershed, accounting for 3% of the watershed area. The rest of the land is distributed fairly evenly between forest, shrub/scrub, grasslands, and wetlands.

Soils within the watershed consist largely of sands to sandy loams. The U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) assigns soils to a hydrologic soil group based on their runoff potential under similar storm and cover conditions. There are four

**Figure 6.** Soil map of the Boathouse Creek watershed (NRCS Web Soil Survey, 2016). Soils consist of predominantly sands to sandy loams. Explanation of unit symbols can be found in Table 3.

**Table 3.** Soil units, along with their hydrologic soil group and respective coverage area within the Boathouse Creek watershed (NRCS Web Soil Survey, 2016).

| Map Unit Symbol | Map Unit Name | Hydrologic Soil Group | Acres | Percent Area |
|---|---|---|---|---|
| Ag | Augusta loamy fine sand | B/D | 2.7 | 0.4% |
| Ap | Arapahoe fine sandy loam | A/D | 44.1 | 7.0% |
| ByB | Baymeade fine sand | A | 52.8 | 8.4% |
| HB | Hobucken mucky fine sandy loam | B/D | 26.0 | 4.2% |
| KuB | Kureb sand | A | 88.4 | 14.1% |
| Ln | Leon sand | A/D | 86.9 | 13.9% |
| Se | Seabrook fine sand | A | 61.6 | 9.8% |
| WaB | Wando fine sand | A | 252.9 | 40.5% |
| W | Water | | 10.3 | 1.7% |
| **Total** | | | **625.7** | **100.0%** |

hydrologic soil groups, A, B, C, and D, along with three dual groups, A/D, B/D, and C/D. Soils in group A have the lowest runoff potential when thoroughly wet (high infiltration rate) while group D has the highest runoff potential when thoroughly wet (very low infiltration rate). Dual groups are reserved for soils in which the seasonal-high water table is within 60 centimeters of the surface but can be adequately drained. The first letter applies to drained conditions and the second to undrained conditions.

A soil map of the Boathouse Creek watershed can be found in Figure 6, with soil names and characteristics in Table 3 (NRCS Web Soil Survey, 2016). Group A soils make up most of the area in the Ocean Spray and Marsh Harbor communities, Western Park, and the campground (Fig. 6). Overall, group A soils account for 73% of the soils within the watershed, while group A/D soils account for another 21% (Table 3). Remaining soils belong to the B/D group and are found in and immediately adjacent to Boathouse Creek and its tributaries (Fig. 6).

Based on NOAA's 1981-2010 Climate Normals data from nearby weather stations (Atlantic Beach and Hofmann Forest) the area averages between 50 and 60 inches of rain, annually (Arguez et al. 2010). This precipitation varies seasonally and is greatest and most variable in the summer months due to thunderstorms, with the wettest months typically being July and August. Fall months bring the second highest precipitation averages, while winter and spring have the lowest average precipitation (Arguez et al. 2010). The area is also subject to severe tropical storms and hurricanes during the summer and fall seasons, which contributes to their higher averages.

Due to Boathouse Creek's proximity to the Atlantic Ocean (Fig. 3), it is tidally influenced and brackish, especially within the main channel and lower portions of the two main tributaries. The longest flow path in the watershed begins above the Ocean Spray community and travels approximately two miles before entering the main river channel of the White Oak. Compared to the southern tributary, the northern tributary drains a larger area and discharges more water to the main channel. Flow varies seasonally and within each tributary, with some of the smaller tributaries showing very little flow during the summer months. Lower flows during summer are common in this region due to higher associated evapotranspiration rates (Sun et al. 2002). Prolonged precipitation as well as short, intense events can rapidly raise water levels and cause flooding within these tributaries due to their urbanized setting and relatively small cross-sectional areas.

Because the Boathouse Creek watershed is largely suburban, there are no CAFOs or livestock within or immediately around it that could be a potential source of nutrient pollution. There are also no point source discharges from wastewater treatment plants or industrial facilities within the watershed. The Marsh Harbor community and homes in Ocean Spray use onsite wastewater treatment systems which could contribute to nutrient loading in Boathouse Creek. Inorganic fertilizers are also a possible source, being used on residential lawns, the Western Park ball fields, and the small portions of cultivated land.

Despite the lack of CAFOs and continued urbanization of the area, animal waste could still be a nutrient source. The remaining forest, grasslands, and wetlands provide habitat for an abundance of wildlife (birds, raccoons, deer, etc.). Finally, atmospheric deposition of nitrogen is prominent in the North Carolina coastal plain because of CAFOs (Costanza et al. 2008), with deposition totals being some of the highest in the United States (Fig. 7). According to the National Atmospheric Deposition Program, Hofmann forest, which is approximately 20 miles northwest of Boathouse Creek, received nearly 5 kg-N/ha from precipitation alone in 2016 (NADP, 2017). In association with precipitation, atmospheric deposition varies seasonally, with the highest totals occurring during the summer and the lowest totals during the fall and winter.

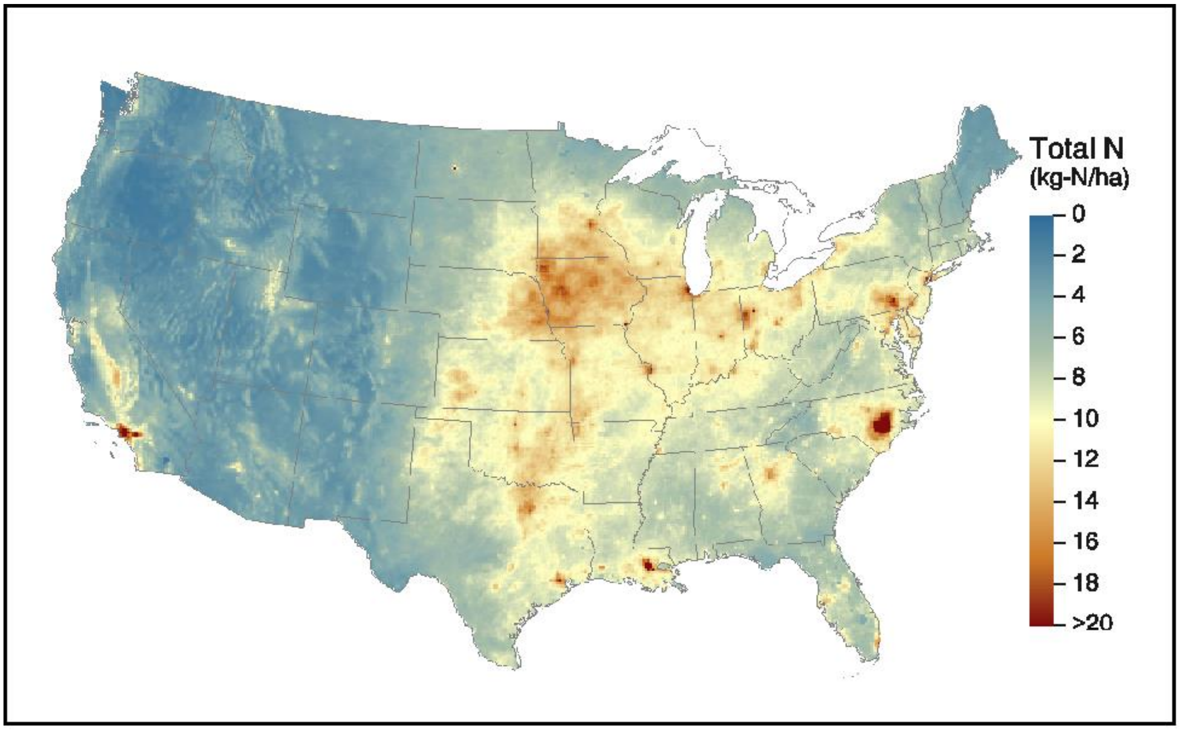

**Figure 7.** Total atmospheric nitrogen deposition from precipitation and air/wind (wet + dry) for the contiguous United States in 2015 (NADP, 2016). The North Carolina coastal plain had some of the highest deposition totals in the country.

# CHAPTER 3: MATERIALS AND METHODS

## 3.1 Monitoring Sites and Equipment

Eight locations were selected for routine monitoring and sampling of Boathouse Creek (Fig. 8). Sites WO-1 to WO-3 are located along the northern tributaries in the more heavily wooded areas that drain the Ocean Spray community, Western Park, and the campground. Stream staff gauges were installed at these sites along with HOBO water-level loggers that record the pressure resulting from the overlying water column and convert it to a water stage measurement (Fig. 9). A similar logger was installed at site WO-3 to capture air pressure data.

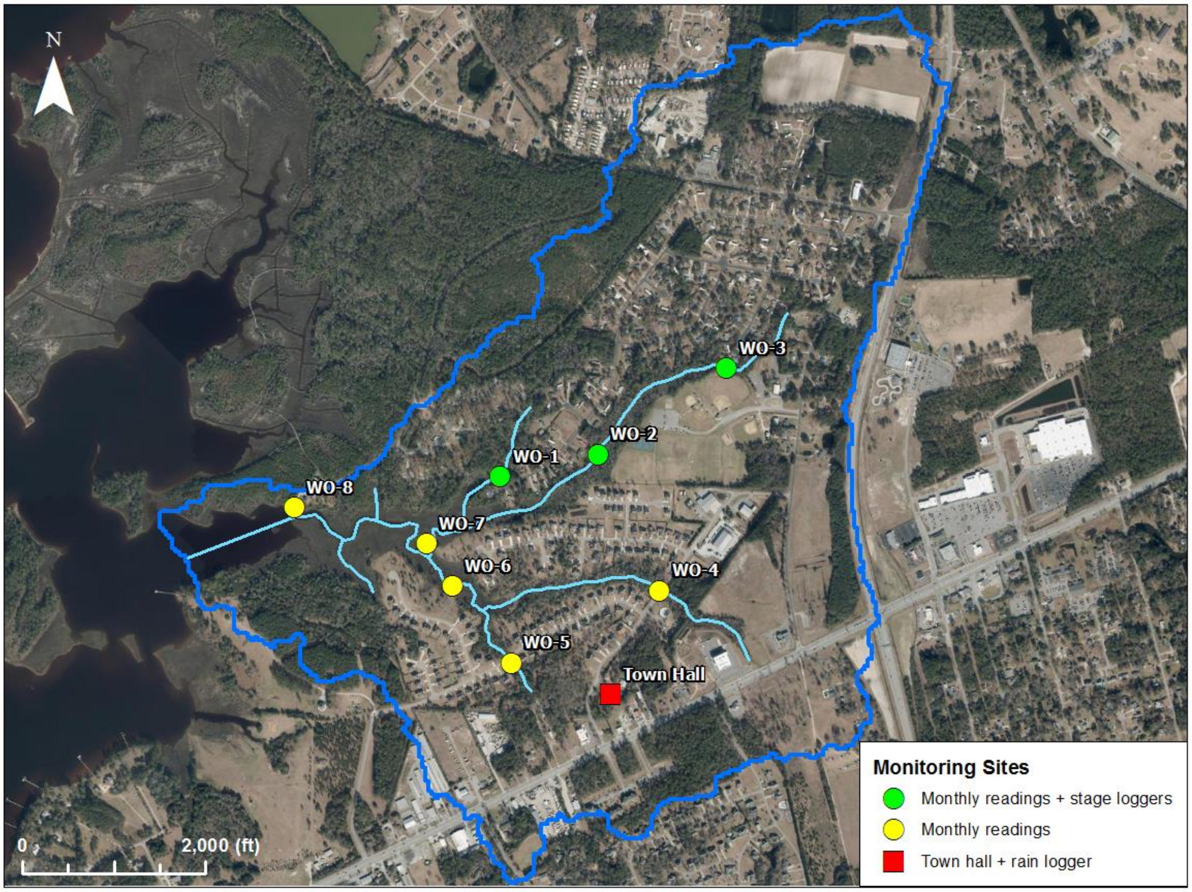

**Figure 8.** Locations of monitoring sites within the Boathouse Creek watershed. Water level and air pressure data loggers were installed at sites 1-3. A rain data logger was also installed at the Cedar Point Town Hall.

At the Cedar Point Town Hall, a rain-data logger was installed to monitor precipitation. Sites WO-4 to WO-6 are located along the southern tributaries, surrounded by the Marsh Harbor community. Sites WO-4 and WO-5 are street adjacent, near drainage culverts that underlie the road. Sites WO-6 and WO-7 are situated within the tidally influenced herbaceous wetlands. Site WO-8 is located at the Cedar Point Tideland Trailhead parking area and boat ramp (Fig. 9).

**Figure 9.** Monitoring sites 1, 5, 7, and 8 in the Boathouse Creek watershed. Stream staff gauge and automated water level data logger are pictured at site 1 (top-left).

## 3.2 Water Quality Monitoring

Monitoring of surface waters began in May 2015 and continued for approximately one year. Monitoring was halted during the summer months of 2016 while SCMs were being constructed and implemented, and it resumed in September and continued until March 2017. Monitoring was performed under baseflow and stormflow conditions, with the baseflow monitoring performed approximately once per month. A total of six storm events were observed, with two occurring before and four after SCM implementation.

**Table 4.** Baseflow water quality monitoring plan.

| Parameter | Frequency | Events Completed |
|---|---|---|
| Physical/Chemical | Monthly | 18 |
| Nutrient species | Quarterly | 8 |
| Stable Isotopes ($NO_3$-N) | Twice | 2 |

**Table 5.** Stormflow water quality monitoring plan.

| Parameter | Events Completed |
|---|---|
| Physical/Chemical | 6 |
| Nutrient species | 6 |
| Stable Isotopes ($NO_3$-N) | 2 |

Physical and chemical characteristics including pH, temperature, dissolved oxygen, oxidation/reduction potential, specific conductance, and turbidity were measured at each of the eight monitoring sites using a calibrated YSI 556 Multiprobe System meter and HACH turbidity meter. Physical measurements of stream stage, active channel width, average stream depth, and stream velocity were recorded at sites 1-5 in order to calculate flow. Average stream depth was calculated based on multiple depth measurements across the active channel. Initially, stream velocity was determined using a Global Water Flow Probe, but baseflow conditions at some sites were too low for the meter to measure velocity. Therefore, the floating object method (WVDEP, 2013) and/or tracer dye were used to estimate velocity for the remainder of the study period. The floating object and tracer dye methods were conducted at least three times and the average velocity from these three readings was used to estimate stream velocity. Stage was also measured at sites 7 and 8, but flow was not calculated at sites 6-8 due to channel size and tidal influence. A summary of the water quality monitoring plan can be found in Tables 4 and 5.

### 3.3 Water Sampling

Sampling of surface waters at each of the eight monitoring sites was performed for nutrient analyses. Samples were collected quarterly under baseflow conditions. Additionally, surface water samples were collected under stormflow conditions six times during the study period. Stormwater runoff samples were also collected at or near SCM sites during storm events. Samples were collected using either newly opened and sterile plastic flasks or previously sanitized and rinsed Nalgene 250mL plastic bottles. Sample bottles were rinsed with stream water or stormwater at each location prior to sample collection. All samples were placed in an iced cooler during transport back to East Carolina Unversity. If anlayses could not be performed within 24 hours, samples were either refrigerated or frozen until analyses could be performed.

### 3.4 Nutrient Analyses

Frozen samples were thawed and then transported to the ECU Environmental Research Laboratory where they were immediately filtered. The filtering process entailed the use of 1.5µm and 0.7µm glass microfiber filters in order to remove sediment and organic matter. Using similar procedures, concentrations of ammonium ($NH_4$-N), nitrate + nitrite ($NO_3$-N + $NO_2$-N), phosphate ($PO_4$-P), and chloride (Cl) in each filtered water sample were analyzed simultaneously with a Automated SmartChem 200 discrete analyzer (Westco, 2007, 2008a, 2008b). Total dissolved nitrogen (TDN) and dissolved organic carbon (DOC) were determined using a Shimadzu TOCV-TNM1 analyzer (Shimadzu, 2010). Dissolved inorganic nitrogen (DIN) was estimated by summing concentrations of ammonium and nitrate + nitrite. Dissolved organic nitrogen (DON) was calculated by subtracting DIN from TDN.

### 3.5 Nitrogen Source Identification

Because various sources of nitrogen have distinct isotopic compositions, isotopic fractionation of $\delta^{15}N/\ \delta^{14}N$ and $\delta^{18}O/\ \delta^{16}O$ or the ratio of $\delta^{15}N$ to $\delta^{18}O$ in nitrate found in the sample can be used as a means for source identification (Kendall et al. 2008; Kendall and McDonnell, 1998; Silva et al. 2002; Spruill et al. 2002). Leftover filtrate from baseflow and stormflow samples were frozen and sent to the Stable Isotope Facility at the University of

California at Davis for analysis of $\delta^{15}N$ to $\delta^{18}O$ in nitrate via bacterial denitrification. Isotope ratios were measured using a ThermoFinnigan GasBench + PreCon trace gas concentration system interfaced to a ThermoScientific Delta V Plus isotope-ratio mass spectrometer (Casciotti et al. 2002; Granger and Sigman 2009; Sigman et al. 2001).

### 3.6 Statistical Analyses

Physical/chemical and nutrient data sets were subjected to summary statistical analysis (mean, median, standard deviation, etc.) using Microsoft Excel. Minitab 17 statistical software was used to test data sets for normality via the Ryan-Joiner normality test (similar to Shapiro-Wilk). The Mann-Whitney non-parametric test was performed to determine if statistically significant differences existed between nutrient concentrations from samples taken under baseflow and stormflow conditions.

### 3.7 Implementation of SCMs

After approximately one year of monitoring and sampling, implementation of SCMs took place during the summer months of 2016 and was completed in September 2016. A variety of SCMs were used to facilitate the infiltration of stormwater runoff in the Boathouse Creek watershed and included the use of water control structures in drainage culverts, enhancement and stabilization of grassed swales, rock check dams, runoff diversion to forested areas, and a rain garden (Table 6). SCM types, implementation methods, and their respective locations are described in further detail below.

### Water Control Structures

Several water control structures were installed in drainage culverts within the Ocean Spray community. These structures are a type of controlled drainage technique commonly used for agricultural fields in eastern North Carolina (Gilliam et al. 1997; O'Driscoll, 2012). Here, they are scaled down to use in neighborhood drainage swales, but still function the same way. The water control structure is inserted into the drainage culvert and wooden boards are added within the frame in order to dam or hold back stormwater runoff, thereby reducing the velocity and volume of stormwater discharging from the swale (Fig. 10).

**Figure 10.** Installation of water control structures in Ocean Spray drainage culverts. Soil around the culvert was removed to allow placement of the structure. Wooden boards were placed within the frame in order to reduce velocity and volume of runoff discharging from the swale (bottom-right).

By reducing discharge, peak flows during storms are limited, residence time is increased, and infiltration is increased, allowing pollutant treatment by various mechanisms before reaching surface waters. Approximately twenty sites were selected for possible placement of these structures; however, some drainage culverts did not meet the required diameter to accomodate the control structures and property owner permission was needed before installation could occur. Ultimately, only five sites met the required size and were given permission for installation (Fig. 11).

**Figure 11.** Locations of the five water control structures in the Ocean Spray community.

### Swale Stabilization and Enhancement

Often placed along roadways and residential areas, swales are vegetated, shallow depressions or channels designed to collect stormwater runoff and reduce flow velocity, promoting infiltration and pollutant removal (USEPA, 1999). In many locations in the Ocean Spray community, grass and soil along the edge of the road had grown higher than the pavement (Fig. 12), impeding stormwater runoff from entering the drainage swales and directing it along the roadway to enter down-gradient swales where the water table is closer to the surface, causing erosion and minimizing opportunity for infiltration and treatment.

**Figure 12.** Swale stabilization and enhancement process in the Ocean Spray community. Grass and soil along the edge of the road was excavated, graded, resodded, and watered, allowing runoff to enter swales more effectively and promoting infiltration.

**Figure 13.** Locations of swale stabilization and enhancement in the Ocean Spray community. Enhancement location dimensions shown are approximated.

In order to ameliorate this issue, grass and soil were excavated from the road's edge and the area was graded for better drainage (Fig. 12). Fresh sod was then installed and thoroughly watered to establish roots and stabilize the soil. Sod was also installed in areas with bare soil to reduce erosion. Overall, over a dozen locations were selected for stabilization and enhancement (Fig. 13). These improvements will allow stormwater runoff to enter swales more effectively in many locations, promoting infiltration and pollutant removal, and reducing erosion.

### Rock Check Dams

Rock check dams are a common type of SCM placed in drainage ditches and swales to reduce the velocity of stormwater runoff, increase residence time, and disrupt flow by effectively reducing or flattening out the slope of the channel. Typical construction consists of using larger riprap stone sizes (approximately 5 to 12 inches) for the overall structure, while the upstream side is lined with smaller aggregate (1/2 to 1 inch in size). Height is kept below two feet and stone is extended beyond the channel to prevent flow around the dam.

**Figure 14.** Installation of rock check dams in drainage swale along Croatan Forest Road, near the Cedar Point Campground. Check dams reduce runoff velocity and allow temporary ponding of water behind them, encouraging infiltration and pollutant treatment (bottom-right).

In order to reduce runoff velocity more effectively, check dams are spaced such that the crest of the downstream dam is at equal elevation to the toe of the upstream dam. Proper construction and spacing allow for temporary ponding of water behind the dam, providing opportunity for infiltration (Fig. 14). Overtime, sedimentation behind dams can also act as a trap for pollutants as stormwater runoff flows through. A series of four check dams were installed near the Cedar Point Campground to reduce stormwater runoff from Croatan Forest Road discharging to Boathouse Creek (Fig. 15).

**Figure 15.** Locations of rock check dams installed along Croatan Forest Road, near the Cedar Point Campground.

### Stormwater Runoff Diversion

Diversion of stormwater runoff away from areas of concern is another conventional technique used in stormwater management. In urban areas, stormwater runoff from roads, sidewalks, and parking lots is primarily diverted through engineered stormwater systems and discharged directly to surface waters. A similar approach can be used to divert stormwater runoff to vegetated or forested areas where it can infiltrate before reaching surface waters.

**Figure 16.** Construction of the new walkway at the Cedar Point Tideland Trailhead parking area and boat ramp. Walkway edge was made level with parking lot and graded to divert runoff toward forested area for infiltration, as shown by the tracer dye (bottom-right).

At the Cedar Point Tideland Trailhead area there is approximately a half acre of impervious surface contributing runoff to Boathouse Creek. A gap between the asphalt parking lot and the concrete walkway with a slightly raised lip was causing runoff to flow along the lot's edge and down to the boat ramp, where unfiltered stormwater runoff was discharging directly to the creek. In order to resolve this issue, a large section of the walkway was removed and replaced (Fig. 16). The new walkway's edge was made level with the parking lot and graded to divert runoff away from Boathouse Creek and allow it to flow toward the adjacent forested area (Fig. 17). Although soil at this location is classified as a B/D group (loamy fine sand to sandy loam), it should still accommodate infiltration of runoff and provide treatment.

**Figure 17.** Locations of the new concrete walkway and rain garden at the Cedar Point Tideland Trailhead parking area and boat ramp.

## Rain Garden

As previously mentioned, rain gardens are a popular type of SCM commonly used in urban and residential areas. In general, a rain garden is a constructed vegetated depression designed to capture and temporarily store stormwater runoff from impervious areas until it can be infiltrated. Various soils, grasses, and other drought tolerant, native vegetation are used to provide pollutant treatment through various physical, biological, chemical processes, such as filtration, evapotranspiration, assimilation, biological degradation (nitrification and denitrification), and adsorption. Due to the significant amount of impervious area at the Cedar Point Tideland Trailhead, a rain garden was also installed at the end of the parking lot to capture stormwater runoff and prevent it from directly entering Boathouse Creek (Fig. 17).

**Figure 18.** Rain garden construction at the Cedar Point Tideland Trailhead parking area and boat ramp. Rain garden is shown storing runoff from a storm shortly after installation (bottom-right).

Soil was excavated and removed from the site to create the depression. Because ground water is relatively shallow at this location, depth was limited to approximately 10 inches (25 cm) in order to allow for infiltration and prevent long-term ponding. A slight berm was also built up on the down-slope end to help increase storage capacity and encourage infiltration. After excavation was completed, fresh sod was installed and thoroughly watered to establish roots and stabilize the soil. Soon after completion, the rain garden was tested and filled with runoff after a storm (Fig. 18).

**Table 6.** Stormwater control measures and their locations within the study area, along with their primary methods for reducing runoff and increasing infiltration.

| SCM | Location | Reduction Method(s) |
|---|---|---|
| **Control Structures** | Ocean Spray | Decrease flow velocity/ increase residence time |
| **Enhanced Swales** | Ocean Spray | Capture/storage |
| **Rock Check Dams** | Croatan Forest Rd | Decrease flow velocity/ increase residence time |
| **Walkway** | Boat ramp | Diversion |
| **Rain Garden** | Boat ramp | Capture/storage |

### 3.8 Estimating Stormwater Runoff and Nutrient Load Reductions

Variations of the Simple Method (Schueler, 1987) were used to estimate the volume of stormwater runoff draining to each SCM location resulting from a design storm event, as well as an annual runoff volume and annual nutrient load (Table 7). This method utilizes the total drainage area for each SCM, percent of impervious surface within that area, and a design storm or rainfall depth to estimate storm-based runoff volume. The Simple Method was developed by measuring runoff from various watersheds where percent impervious coverage was previously calculated and curve-fitting a relationship between percent impervious area and the portion of precipitation converted to runoff, known as the runoff coefficient (NCDENR, 2009). The equation for runoff coefficient and its variables is:

$$R_V = 0.05 + (0.9 * I_A)$$

Where: $R_V$ = Runoff coefficient [runoff depth (in)/design storm depth (in)], unitless

$I_A$ = Percent imperviousness [impervious portion of drainage area (ac)/total drainage area (ac)], unitless

Once the runoff coefficient is calculated, the volume of runoff produced by the design storm draining to each site can be estimated using the following equation:

$$V = 3630 * R_D * R_V * A$$

Where: $V$ = Volume of runoff produced by design storm (ft$^3$)

$R_D$ = Design storm rainfall depth (in)

$R_V$ = Runoff coefficient

$A$ = Total drainage area (ac)

$3630$ = Unit conversion factor

The runoff coefficient is also used to estimate the annual runoff volume (NYSDEC, 2001; CWP & CSN, 2008) draining to each site using the following equation:

$$R_A = 3630 * P * P_I * R_V * A$$

Where: $R_A$= Annual runoff volume (ft$^3$)

$P$ = Annual rainfall (in)

$P_I$ = Fraction of annual rainfall events that produce runoff (usually 0.9)

$R_V$ = Runoff coefficient

$A$ = Total drainage area (ac)

$3630$ = Unit conversion factor

Additionally, the Simple Method can be used to estimate annual nutrient loads (NYSDEC, 2001; CWP & CSN, 2008) as a product of the annual runoff volume and average nutrient concentration, as:

$$L = (2.83 * 10^{-5}) * R_A * C$$

Where: $L$ = Annual load (kg)

$R_A$ = Annual runoff volume (ft$^3$)

$C$ = Nutrient concentration (mg/L)

$2.83 * 10^{-5}$ = Unit conversion factor

**Table 7.** Variations of the Simple Method (Schueler, 1987) used to estimate stormwater runoff volumes and nutrient loads draining to SCM sites.

| Application | Description | Source(s) |
|---|---|---|
| Storm Runoff Volume | $V = 3630 * R_D * R_V * A$<br>Where: $V$ = Volume of runoff produced by design storm (ft$^3$)<br>$R_D$ = Design storm rainfall depth (in)<br>$R_V$ = Runoff coefficient<br>$A$ = Total drainage area (ac)<br>$3630$ = Unit conversion factor | NCDENR (2009) |
| Annual Runoff Volume | $R_A = 3630 * P * P_I * R_V * A$<br>Where: $R_A$ = Annual runoff volume (ft$^3$)<br>$P$ = Annual rainfall (in)<br>$P_I$ = Fraction of annual rainfall events that produce runoff (usually 0.9)<br>$R_V$ = Runoff coefficient<br>$A$ = Total drainage area (ac)<br>$3630$ = Unit conversion factor | NYSDEC (2001)<br>CWP & CSN (2008) |
| Annual Nutrient Load | $L = (2.83 * 10^{-5}) * R_A * C$<br>Where: $L$ = Annual load (kg)<br>$R_A$ = Annual runoff volume (ft$^3$)<br>$C$ = Nutrient concentration (mg/L)<br>$2.83 * 10^{-5}$ = Unit conversion factor | NYSDEC (2001)<br>CWP & CSN (2008) |

Total drainage area for each SCM was estimated based on topography and in-field observations during storm events, while impervious surface coverage was calculated using satellite imagery. Per the project's goals, a 1-year, 24-hour design storm event with a rainfall depth of 3.66 inches (9.3 cm) was used to determine storm-based runoff volumes at each location (NOAA, 2017). An annual rainfall of 60 inches (152.4 cm) was used to estimate annual runoff, based on rain gauge data and previous year totals. Average nutrient concentrations found in runoff sampled at or near SCM sites were used to estimate annual nutrient loads.

Because SCMs such as the water control structures and check dams are primarily designed to reduce velocity and increase residence time, runoff volume and nutrient load reductions were estimated based on volume reduction efficiencies from previous studies (Table 8). Water control structures that used flashboards for controlled drainage in North Carolina agricultural fields reduced drainage outflow by approximately 20-40% (Amatya et al. 1996; Evans et al. 1992; Wesström et al. 2001; Wright et al. 2006). Battiata et al. (2009) found that based on average rainfall in the Virginia Piedmont, runoff was reduced 40 to 60% by dry swales, while wet swales showed no reduction. In a review of studies by Davis et al. (2012), mean volume reduction by roadside grassed swales ranged from 30 to 47%. A study performed on two check dams (comparable to those used here) within a grassed swale in eastern North Carolina showed a volume reduction of 53% for small (<19 mm of rainfall) storm events and 22% for moderate (19 to 38 mm) storm events (Winston et al. 2018). Davis et al. (2011) also found that grassed check dams used adjacent to a Maryland highway reduced runoff volume by 27% during moderate storm events. Based on these values, a conservative volume reduction estimate of 30% was used for the water control structures and enhanced swales, while a 37%

volume reduction estimate was used for the check dams. Runoff captured by the rain garden and diverted by the walkway was estimated to be fully accommodated (100% volume reduction efficiency) for storm events ≤ the regional 1-year, 24-hour storm of 3.66 inches, based on SCM design and field observations during intense storms. Although there were three storm events larger than the regional 1-year, 24-hour storm of 3.66 inches (Appendix B), annual runoff reduction estimates assume all storm events are ≤ the regional 1-year, 24-hour storm.

**Table 8.** Estimated volume reduction for each SCM based on available sources and conservative estimate used for this study. Estimates for the walkway and rain garden are based on SCM design and field observations during intense storms.

| SCM | Estimated Volume Reduction | Source(s) |
|---|---|---|
| **Control Structures** | 20-40%<br>(30%)[1] | Amatya et al. (1996)<br>Evans et al. (1992)<br>Wesström et al. (2001)<br>Wright et al. (2006) |
| **Enhanced Swales** | 0-60%<br>(30%)[1] | Battiata et al. (2010)<br>Davis et al. (2011) |
| **Rock Check Dams** | 22-52%<br>(37%)[1] | Davis et al. (2011)<br>Winston et al. (2018) |
| **Walkway** | 100%[2] | |
| **Rain Garden** | 100%[2] | |

[1] Conservative volume reduction estimate used for this study.

[2] Based on SCM design and field observations during intense storms.

# CHAPTER 4: RESULTS

## 4.1 Water Quality and Flow

Surface water temperatures ranged from 2.2 to 36.3 °C, both of which occurred at monitoring site WO-8. The mean temperature for all locations under baseflow conditions was 20.5 °C. Temperatures under stormflow conditions averaged 18.8 °C; however, it should be noted that storm events were recorded primarily in the cooler months during fall and winter. Temperatures at sites WO-6 to WO-8 were noticeably warmer in the summer months compared to sites WO-1 to WO-5 (Fig. 19). Mean surface water temperatures generally increased moving downstream, with site WO-1 having the lowest (18.6 °C) and site WO-8 having the highest (22.5 °C).

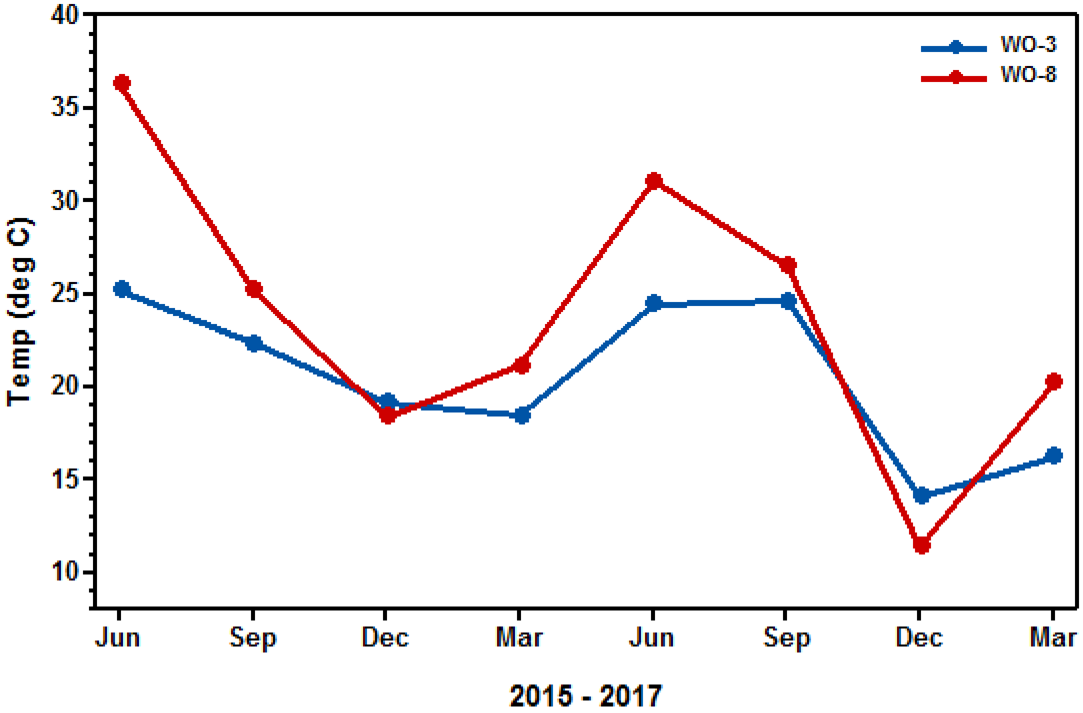

**Figure 19.** Seasonal surface water temperatures for monitoring sites WO-3 and WO-8 during the study period. Site WO-8 was noticeably warmer in June and colder in December compared to site WO-3.

Specific conductance (SC) was relatively low at monitoring sites WO-1 to WO-5 (mean values 311 to 647 µS/cm) during baseflow and stormflow conditions, indicative of freshwater streams. SC was higher at monitoring sites WO-6 to WO-8 (mean values 14,703 to 29,364 µS/cm) indicating brackish waters. However, SC did reach 11,490 µS/cm at site WO-1 during one baseflow event (January 2017), suggesting that brackish water could be pushed further inland under certain conditions. When compared to baseflow conditions, mean SC values were slightly lower during storms at each location (Tables 9 and 10).

Oxidation/reduction potential (ORP) values ranged from -123 to 156 mV under baseflow and stormflow conditions. Site WO-1 averaged 14.6mV and was the most varied (-123 to 144 mV). Sites WO-2, WO-3, and WO-7 had similar averages to site WO-1, and values were more often than not positive, while sites WO-4 and WO-5 were largely negative, averaging -16.8 and -27.5 mV, respectively. Overall, ORP values were highest at site WO-8, with a mean of 48.7 mV. Turbidity was relatively low at all locations under baseflow and stormflow conditions.

Under baseflow conditions, mean turbidity at each location ranged from 2.1 NTU at site WO-2 to 17.5 NTU at site WO-8 (Table 9), while stormflow conditions ranged from 4.2 NTU at site WO-1 to 13.2 NTU at site WO-5 (Table 10). Turbidity was typically highest at site WO-8 and higher at brackish water sites (WO-6 to WO-8) compared to freshwater sites (WO-1 to WO-5). However, site WO-8 is located at a public boat ramp, so some turbidity readings could have been elevated because of human activity. Of the 72 total samples taken at brackish water sites, only 7 (approximately 10%) were above the EPA/North Carolina standard of ≤ 25 NTU that is recommended for aquatic life and secondary recreation in salt waters. The state standard for turbidity for freshwater streams (≤ 50 NTU) was not exceeded at sites WO-1 to WO-5 under baseflow or stormflow conditions (Fig. 20).

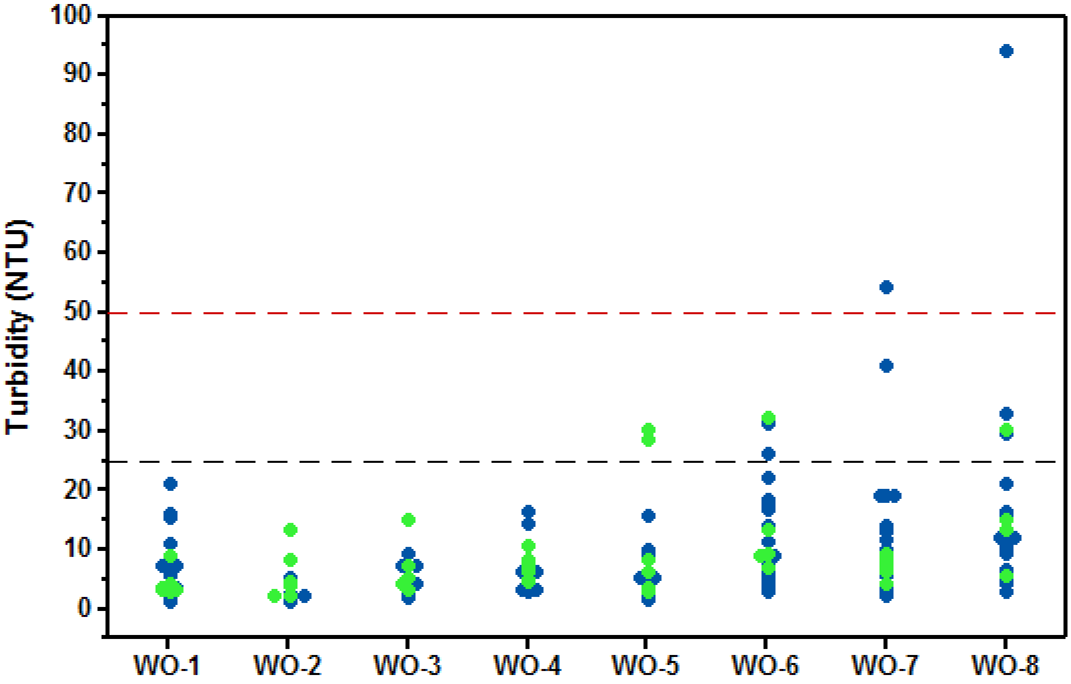

**Figure 20.** Individual value plots of turbidity during baseflow (blue) and stormflow (green) conditions for monitoring sites 1-8. The black dashed reference line indicates the state saltwater standard for turbidity (≤ 25 NTU), while the red reference line indicates the state standard for freshwater streams (≤ 50 NTU).

Under baseflow conditions, mean pH values at each location ranged from 7.15 (WO-2) to 7.42 (WO-7). Storm conditions showed similar results, with mean values ranging from 7.13 (WO-3) to 7.52 (WO-2). Site WO-1 was the most varied, with pH values as low as 5.12 and as high as 9.28, while site WO-5 was the most consistent (6.84 to 7.73). There were only three instances in which pH at sites did not meet the state standard of 6.0 to 9.0 for freshwaters. At sites WO-6 to WO-8 where water is brackish, there were six instances in which the state standard for saltwater (6.8 to 8.5) was not met.

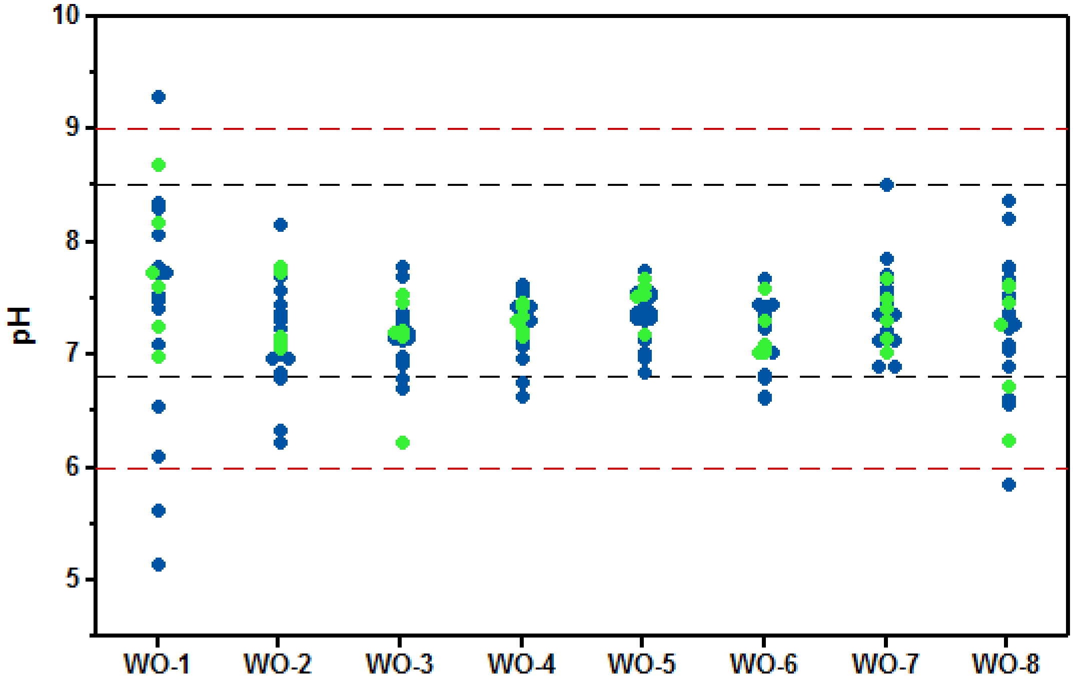

**Figure 21.** Individual value plots of pH during baseflow (blue) and stormflow (green) conditions for monitoring sites 1-8. Red dashed reference lines indicate the state standard pH range (6.0-9.0) for freshwaters, while black reference lines indicate the saltwater standard (6.8-8.5).

Dissolved oxygen (DO) concentrations ranged from 2.0 to 11.5 mg/L under baseflow and stormflow conditions. DO was lowest at sites WO-1, and WO-3 to WO-5, with similar mean concentrations between 5.1 and 5.3 mg/L, slightly above the state standard daily average of ≥5.0 mg/L (Fig. 22). Sites WO-6 to WO-8, and WO-2 were higher, averaging between 6.9 to 7.1 mg/L. DO concentrations at the eight monitoring sites were below standard on 30% of the occasions sampled. Hypoxic conditions (< 2 mg/L) were most prevalent during the warmest months (May – September) where higher water temperatures limit the solubility of oxygen and enhanced organic matter decomposition may also take up oxygen.

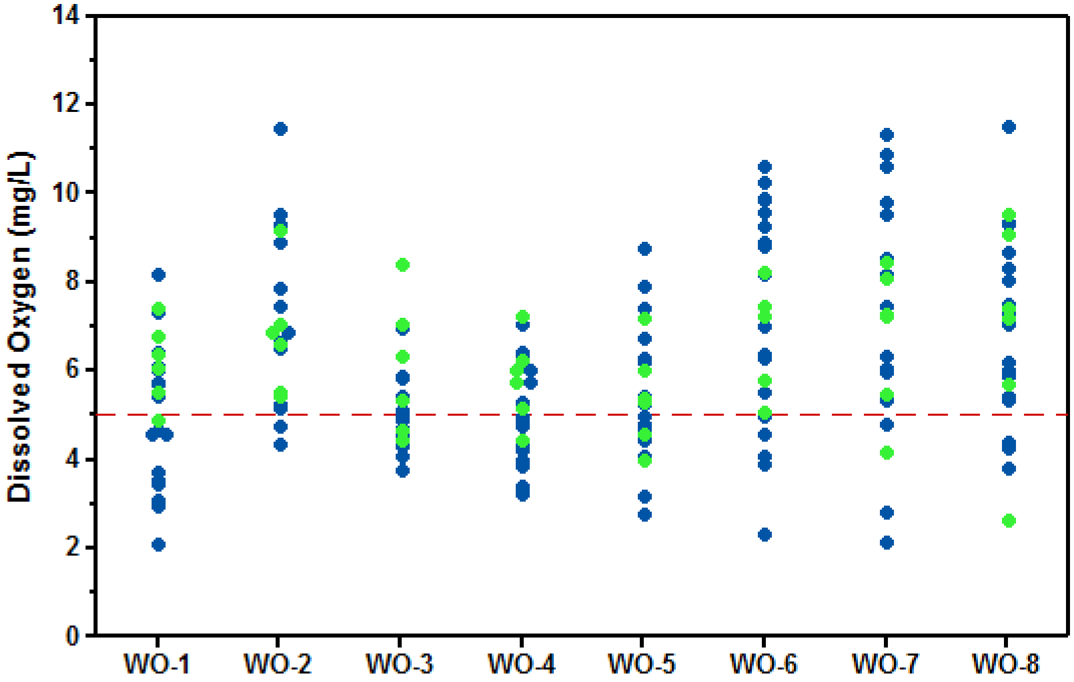

**Figure 22.** Individual value plots of dissolved oxygen concentrations during baseflow (blue) and stormflow (green) conditions for monitoring sites 1-8. Dashed reference line indicates the dissolved oxygen state standard (≥5.0 mg/L daily average) for freshwater and saltwater aquatic life.

This was most observable at site WO-1, in which the lowest recorded water temperature (6.7°C) had the highest concentration of DO (8.1 mg/L) and the highest recorded water temperature (25.7°C) had the lowest DO concentration (2.1 mg/L). Hypoxic conditions did not occur until water temperature reached above 20°C (Fig. 23). Discharge also declined during warmer months, which likely contributed to the lower DO concentrations at some sites. Flowing water tends to have higher DO levels compared to more stagnant water due to turbulence and mixing at the air-water interface. In addition, flowing water may have lower algal growth. Of all the occasions in which DO was substandard, 68% occurred during these warmer months.

**Table 9.** Average environmental parameters for monitoring sites 1-8 during baseflow conditions.

| Site | Temp ($^oC$) | DO (mg/L) | pH | Turbidity (NTU) | SC (µS/cm) | ORP (mV) | Stage (cm) | Discharge (L/s) |
|---|---|---|---|---|---|---|---|---|
| **WO-1** | 18.6 | 4.8 | 7.4 | 7.0 | 1208 | 17 | 6.3 | 3.4 |
| **WO-2** | 18.9 | 7.0 | 7.1 | 2.1 | 327 | 18 | 32.3 | 17.8 |
| **WO-3** | 19.6 | 5.1 | 7.2 | 3.8 | 358 | 14 | 9.1 | 8.2 |
| **WO-4** | 20.1 | 5.1 | 7.3 | 5.8 | 425 | -18 | | 13.6 |
| **WO-5** | 20.1 | 5.3 | 7.3 | 4.7 | 343 | -27 | | 9.3 |
| **WO-6** | 22.0 | 7.2 | 7.2 | 12.4 | 14841 | -4 | | |
| **WO-7** | 22.3 | 7.2 | 7.4 | 13.8 | 18897 | 5 | | |
| **WO-8** | 22.4 | 7.0 | 7.3 | 17.5 | 30211 | 45 | | |

**Table 10.** Average environmental parameters for monitoring sites 1-8 during stormflow conditions.

| Site | Temp ($^oC$) | DO (mg/L) | pH | Turbidity (NTU) | SC (µS/cm) | ORP (mV) | Stage (cm) | Discharge (L/s) |
|---|---|---|---|---|---|---|---|---|
| **WO-1** | 18.9 | 6.1 | 7.7 | 4.2 | 630 | 8 | 9.9 | 11.3 |
| **WO-2** | 18.0 | 6.7 | 7.3 | 5.7 | 266 | 11 | 42.1 | 51.2 |
| **WO-3** | 18.7 | 6.0 | 7.1 | 6.2 | 270 | 13 | 12.2 | 17.3 |
| **WO-4** | 18.9 | 5.8 | 7.3 | 6.9 | 365 | -9 | | 36.0 |
| **WO-5** | 18.8 | 5.4 | 7.5 | 13.2 | 279 | -29 | | 17.5 |
| **WO-6** | 19.0 | 6.8 | 7.2 | 12.4 | 14287 | 16 | | |
| **WO-7** | 19.0 | 6.8 | 7.3 | 6.9 | 17033 | 25 | | |
| **WO-8** | 19.0 | 6.9 | 7.1 | 12.6 | 26820 | 60 | | |

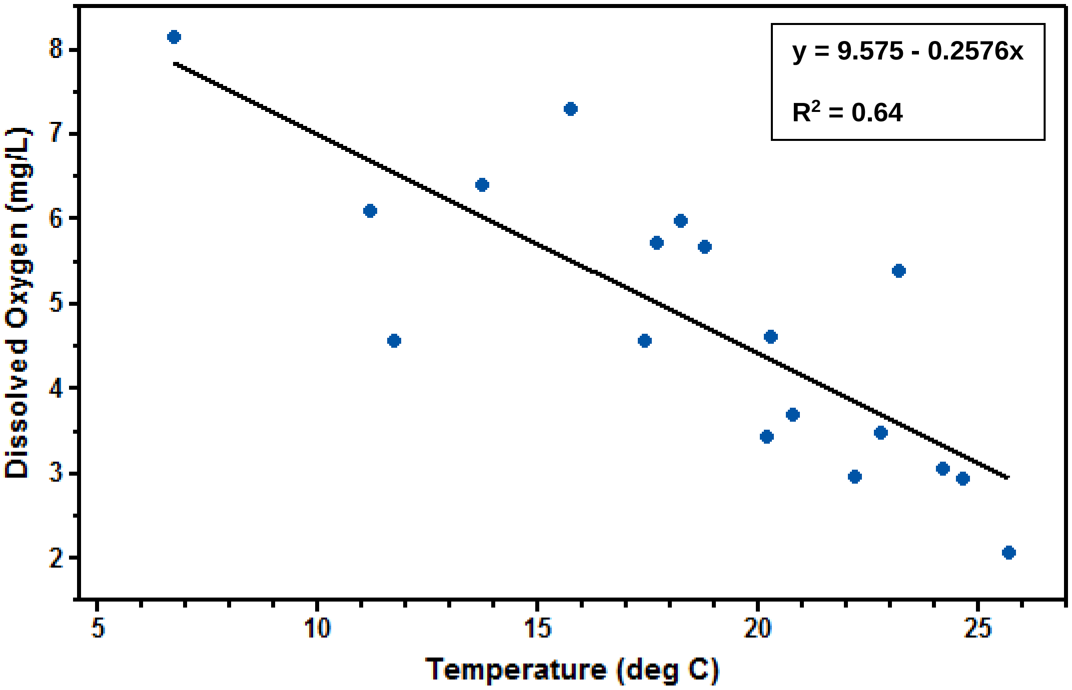

**Figure 23.** Dissolved oxygen vs. water temperature under baseflow conditions for monitoring site WO-1. WO-1 illustrates the negative correlation between the two variables. Hypoxic conditions did not occur until water temperature reached above 20°C.

Stream discharge varied seasonally at sites WO-1 to WO-5, with the highest values occurring in the non-growing season (winter and early spring) and lower values in the summer and fall. Discharge was consistently lowest at site WO-1, under both baseflow and stormflow conditions. During the summer months, site WO-1 exhibited little to almost no flow on some occasions. Discharge was highest at site WO-2, with a mean value of 17.8 L/s during baseflow and 51.3 L/s during storms. With the exception of site WO-5, average stormflow discharge was at least two times higher than baseflow at each location (Tables 9-10). Stream discharge for the northern tributaries (sum of WO-1 and WO-2) was similar to the discharge for the southern tributaries (sum of WO-4 and WO-5) during baseflow and stormflow conditions (Tables 9-10, and Fig. 8).

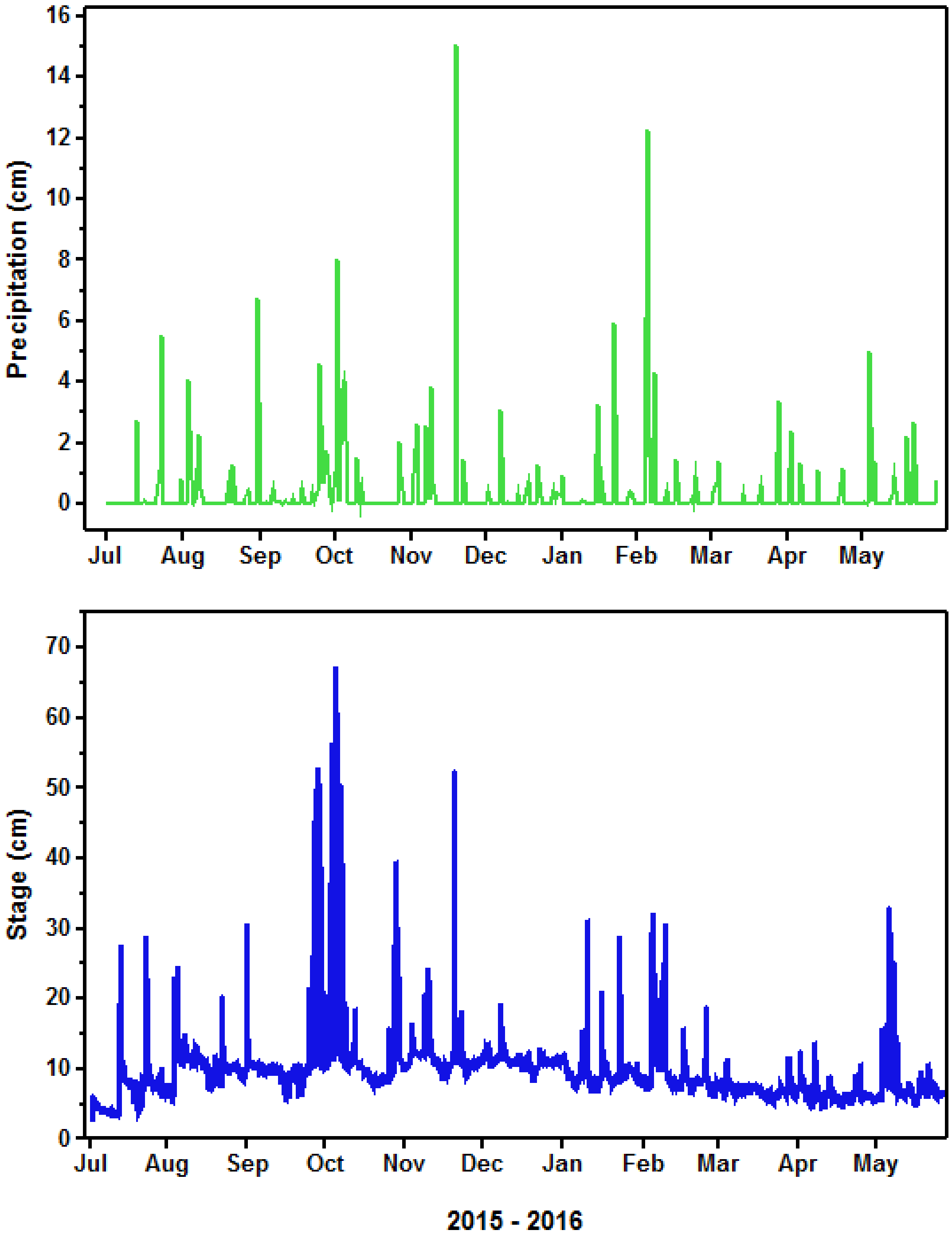

**Figure 24.** Time series plots of precipitation (top) and stream stage at monitoring site WO-1 (bottom) from July 2015 through May 2016. Storm events are easily identified by the rapid increase and decrease in stage over a relatively short period.

Based on the stream stage data from monitoring sites WO-1 through WO-3, they exhibit the typical behavior of streams in urbanizing areas (O'Driscoll et al. 2010). Stream stage hydrographs are flashy (high peak flows, short lag times, and steep rising/falling limbs) and characterized by extreme events in which stage is increased by 200% or greater over median stage levels (Fig. 24). During one event, approximately 9 cm of precipitation over a 16-hour period increased stage at site WO-1 from 11.0 to 52.5 cm (377% increase) and stage at site WO-2 increased from 32.4 to 90.3 cm (179% increase).

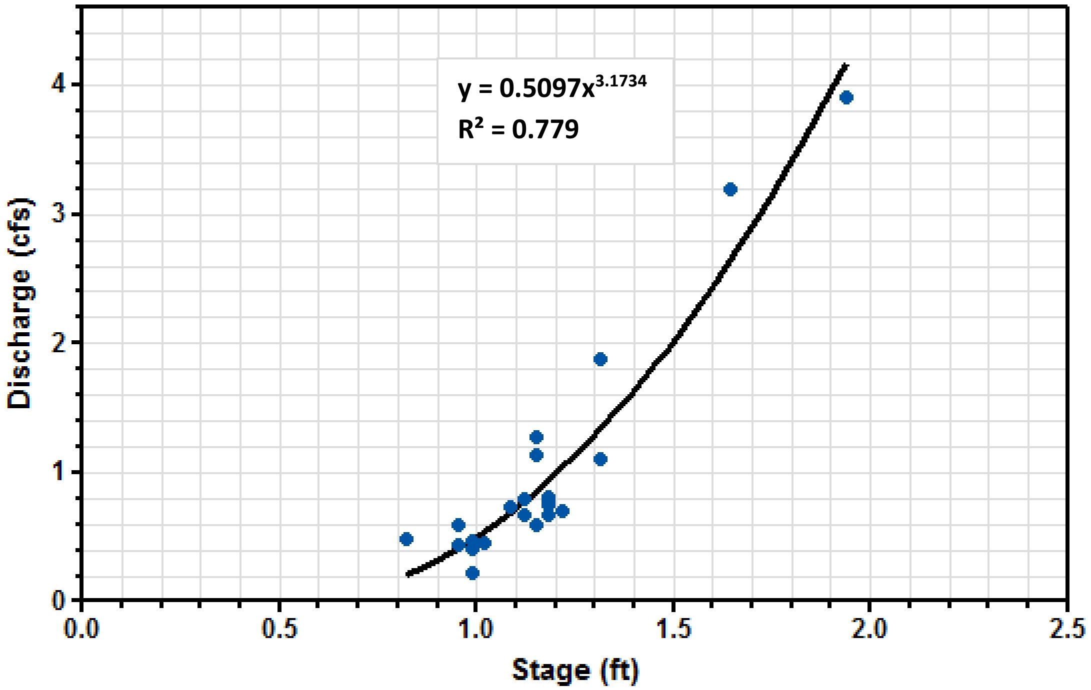

**Figure 25.** Stage-discharge rating curve for Boathouse Creek tributary located at monitoring site WO-2.

Monitoring site WO-2 was the only site with a large enough upstream drainage area to provide a sufficient record (July 2015 – May 2016) of stage and measured discharge data in order to develop a stage-discharge rating curve (Fig. 25). Air pressure data from the logger at WO-3 was subtracted from the water pressure data at site WO-2 to determine the stage measurement. Additionally, the offset between the stage logger and stream bed was corrected for by comparing logger data with visual measurements from the staff gauge (Fig. 9) to improve accuracy. A power regression model was used as a best fit for the rating curve and discharge was estimated for each stage measurement using the predictive stage-discharge equation.

Daily average discharge was calculated for site WO-2 and the Web-based Hydrograph Analysis Tool (WHAT) was used to separate the baseflow component from the direct runoff component (Lim et al. 2005). Average discharge over the eleven-month period was estimated at 20.4 L/s. Results from the hydrograph analysis showed a baseflow index (BFI) value (the ratio of baseflow to total stream flow) of 0.762, indicating that groundwater contributions accounted for approximately 76% of stream flow, while stormwater runoff accounted for approximately 24% of stream flow over the eleven-month period. Based on average discharge and the watershed area upstream of site WO-2, annual runoff was estimated at 28 in/yr (71 cm/yr), while precipitation for the 2015 – 2016 year was measured at 68 inches (172.7 cm) (Appendix B).

## 4.2 Nutrient Analyses

### Chloride

Chloride concentrations were low at the freshwater sites (WO-1 to WO-5); averaging between 20 and 47 mg/L during baseflow (Table 11), well below the state standard of 230 mg/L for freshwater aquatic life. Chloride concentrations were higher at brackish water sites (WO-6 to WO-8), with mean values of approximately 3,400 to 8,000 mg/L during baseflow (Table 12). In some cases, concentrations were too high to be measured (out of range) so subsequent samples were diluted. These brackish water, tidally influenced sites were also much more variable, concentrations at site WO-6 ranged from 15 to 8,323 mg/L during baseflow and 365 to 18,990 mg/L during storms. With the exception of site WO-8, mean concentrations at each site were similar under baseflow and stormflow conditions. Chloride concentrations at site WO-8 were consistently lower during storms, likely as a result of dilution from direct precipitation and runoff from upstream areas flowing down the boat ramp.

### Dissolved Organic Carbon

Concentrations of dissolved organic carbon (DOC) ranged from 3.1 to 44 mg/L across all sites and conditions. In general, baseflow concentrations increased during the study period. A substantial increase was observable during the winter (December) and spring (March) months of 2015 – 2016, where average concentrations more than doubled from 9.5 to 20 mg/L (Fig. 26). Mean concentrations of DOC at sites ranged from 11.8 to 19.0 mg/L during baseflow, while storms ranged from 18.8 to 26.4 mg/L. However, the majority of storms were sampled after the substantial increase in baseflow concentrations, indicating that stormwater wasn't solely responsible for the higher mean concentrations. Site WO-5 was lowest under both conditions.

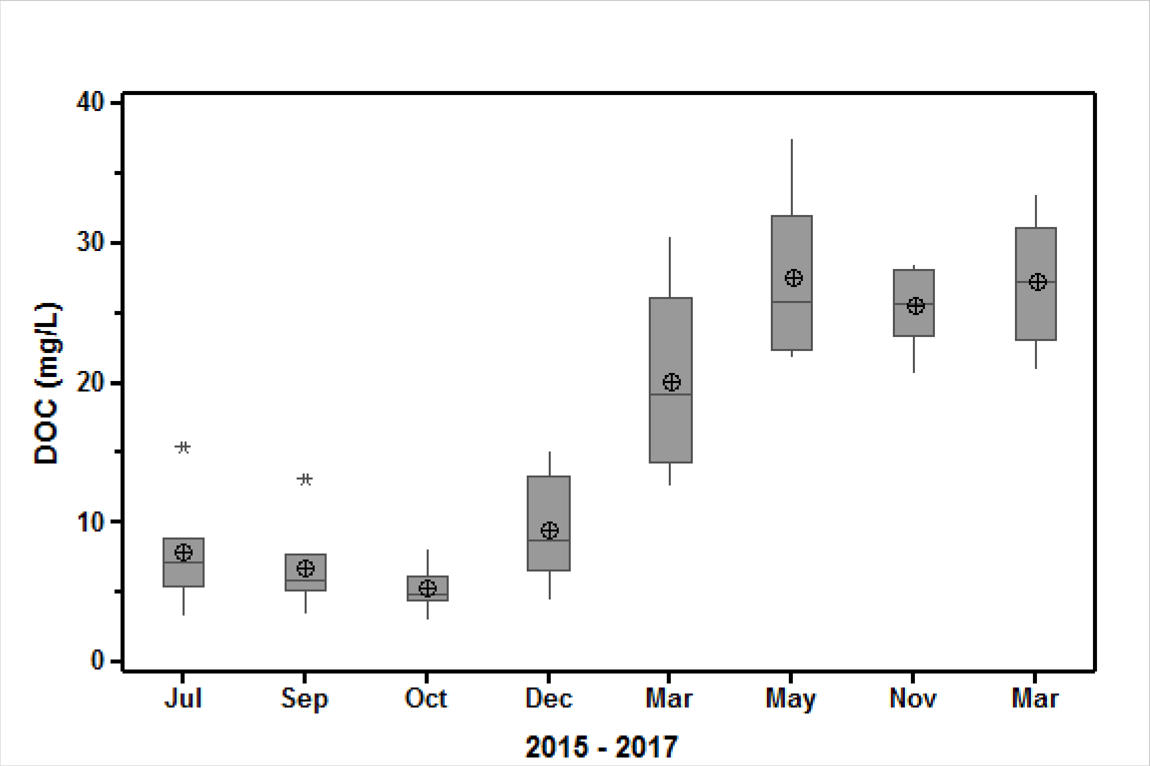

**Figure 26.** Seasonal baseflow concentrations of dissolved organic carbon. Concentrations increased substantially from December (2015) to May (2016).

### Phosphate

Phosphate ($PO_4$-P) concentrations were low and, in several instances, (23%) below the method detection limit. Mean baseflow concentrations ranged from 0.01 to 0.02 mg/L (Table 11), while stormflow concentrations averaged 0.01 to 0.04 mg/L (Table 12). Downstream sites typically showed higher concentrations compared to sites located further upstream. Comparison of baseflow to stormflow mean phosphate concentrations at each site exhibited mixed results, with three sites (WO-1, WO-6, and WO-7) showing an increase during storms, four sites (WO-2, WO-3, WO-5, and WO-7) decreased during storms, and one site (WO-4) remained relatively unchanged (Fig. 27). Differences in median concentrations of phosphate between baseflow and stormflow conditions were insignificant (p = 0.87 at the 0.05 significance level), indicating that phosphate concentrations in Boathouse Creek were not significantly elevated during storm events.

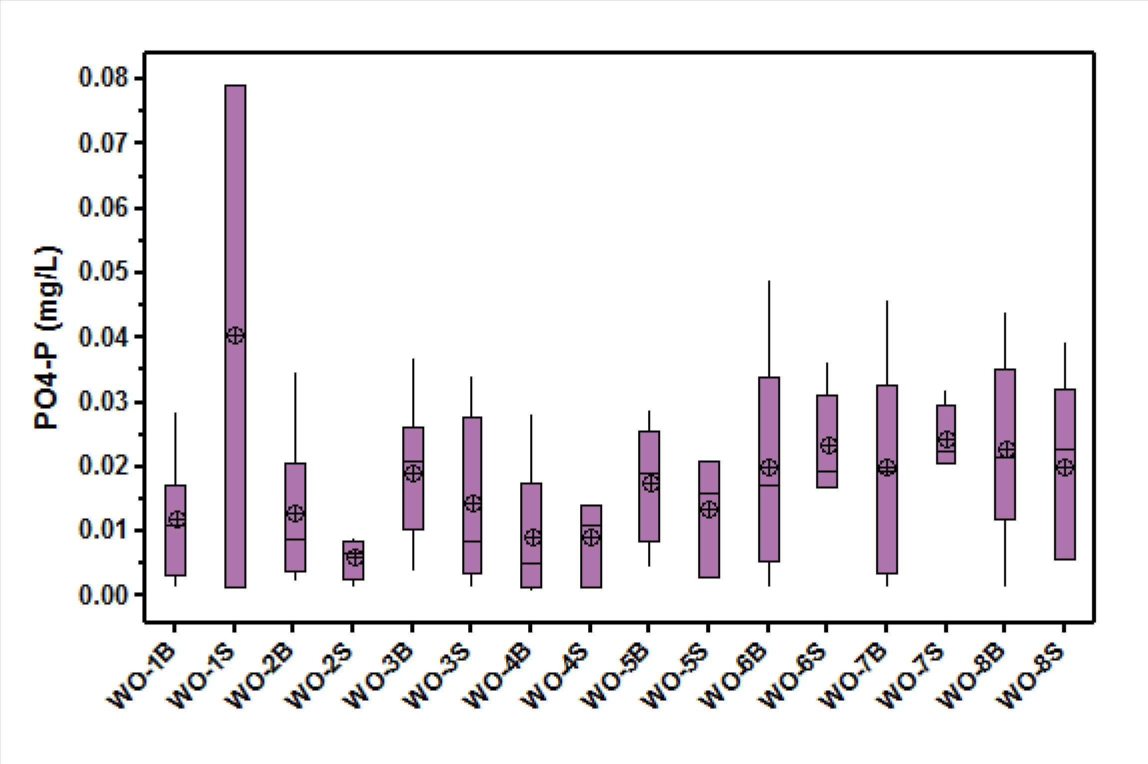

**Figure 27.** Phosphate concentrations under baseflow (B) and stormflow (S) conditions for monitoring sites 1-8. Comparison of baseflow to stormflow concentrations exhibited mixed results, with some sites showing an increase, while others showed a decrease during storms.

### Total Dissolved Nitrogen

Concentrations of total dissolved nitrogen (TDN) in natural waters consist of inorganic nitrogen (nitrite, nitrate, and ammonium) and organic nitrogen. Baseflow concentrations of TDN ranged from 0.46 to 1.56 mg/L, with mean concentrations between 0.9 to 1.0 mg/L at each site. Stormflow concentrations ranged from 0.75 to 1.61 mg/L, and similarly to baseflow, mean concentrations were consistent, between 1.28 to 1.35 mg/L. Under stormflow conditions, concentrations of TDN were elevated relative to baseflow at all eight sites (Fig. 28).

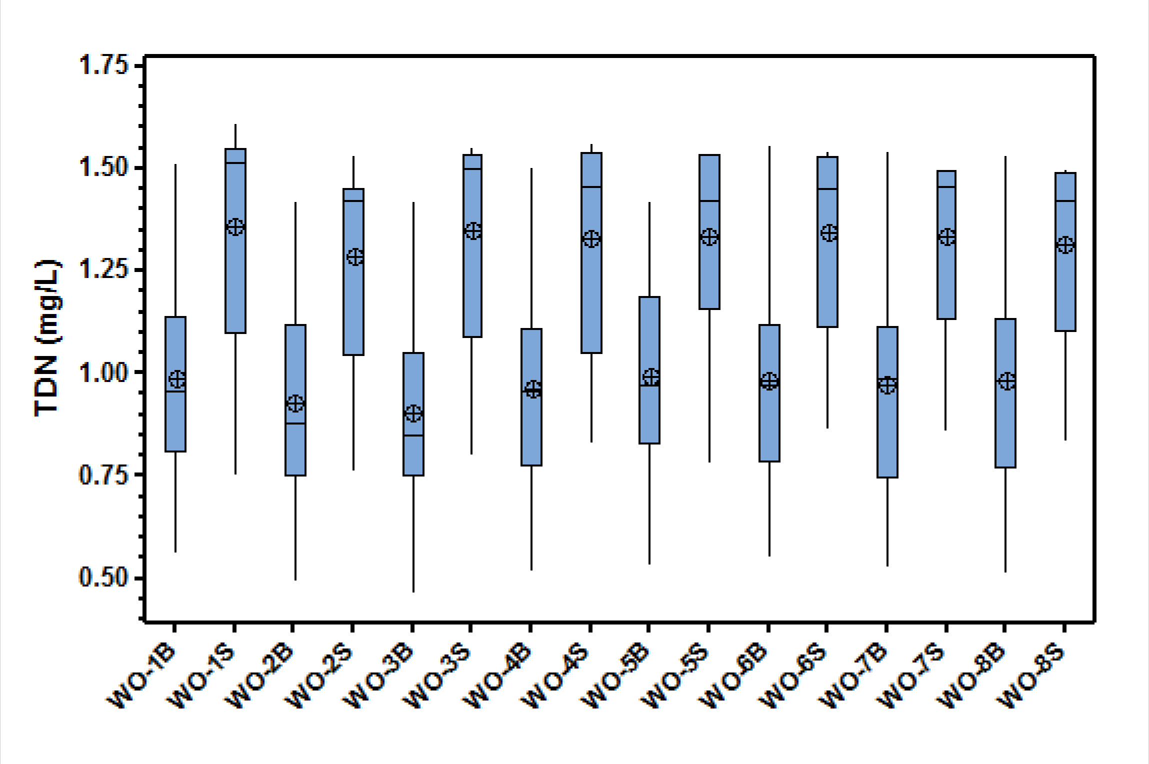

**Figure 28.** Total dissolved nitrogen (TDN) concentrations under baseflow and stormflow conditions for monitoring sites 1-8. Stormflow concentrations of TDN were elevated compared to baseflow concentrations at all eight sites.

The differences in median concentrations of TDN between baseflow and stormflow conditions were found to be significant ($p < 0.001$ at the 0.05 significance level), indicating that TDN concentrations in Boathouse Creek were significantly elevated during storm events, potentially due to runoff contributions.  Baseflow TDN levels increased over the course of the study period.  Mean concentrations increased nearly 1 mg/L from July 2015 to March 2017 (Fig. 29).

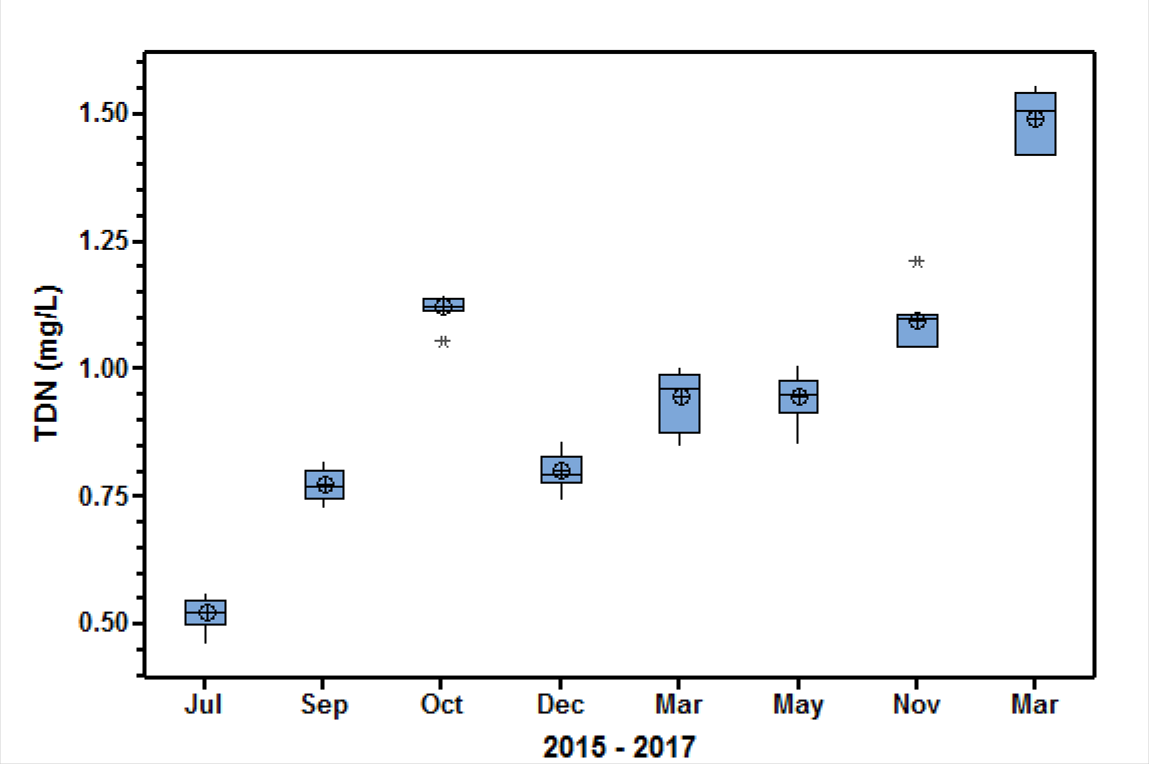

**Figure 29.** Seasonal baseflow concentrations of total dissolved nitrogen (TDN).  TDN increased steadily over the course of the study period.

### Nitrate plus Nitrite

Because it is typically present in such small concentrations relative to nitrate ($NO_3$-N), nitrite ($NO_2$-N) concentrations were not analyzed separately.  For the purposes of this study, concentrations of nitrate plus nitrite were considered to represent nitrate.  Nitrate concentrations were generally low, with mean concentrations at sites ranging from 0.013 to 0.22 mg/L.  On average, nitrate accounted for approximately 36% of dissolved inorganic nitrogen (DIN) and only 7% of TDN under baseflow conditions. During storms, nitrate accounted for approximately 22% of DIN and 7% of TDN. Sites within the Marsh Harbor community, particularly site WO-5, showed higher nitrate concentrations compared to other locations. Average concentrations also seemed to decrease as sites progressed downstream from freshwater toward brackish water (WO-3 to WO-1, WO-5 to WO-7) (Fig. 30). Although minor, concentrations typically increased during storms at each site.

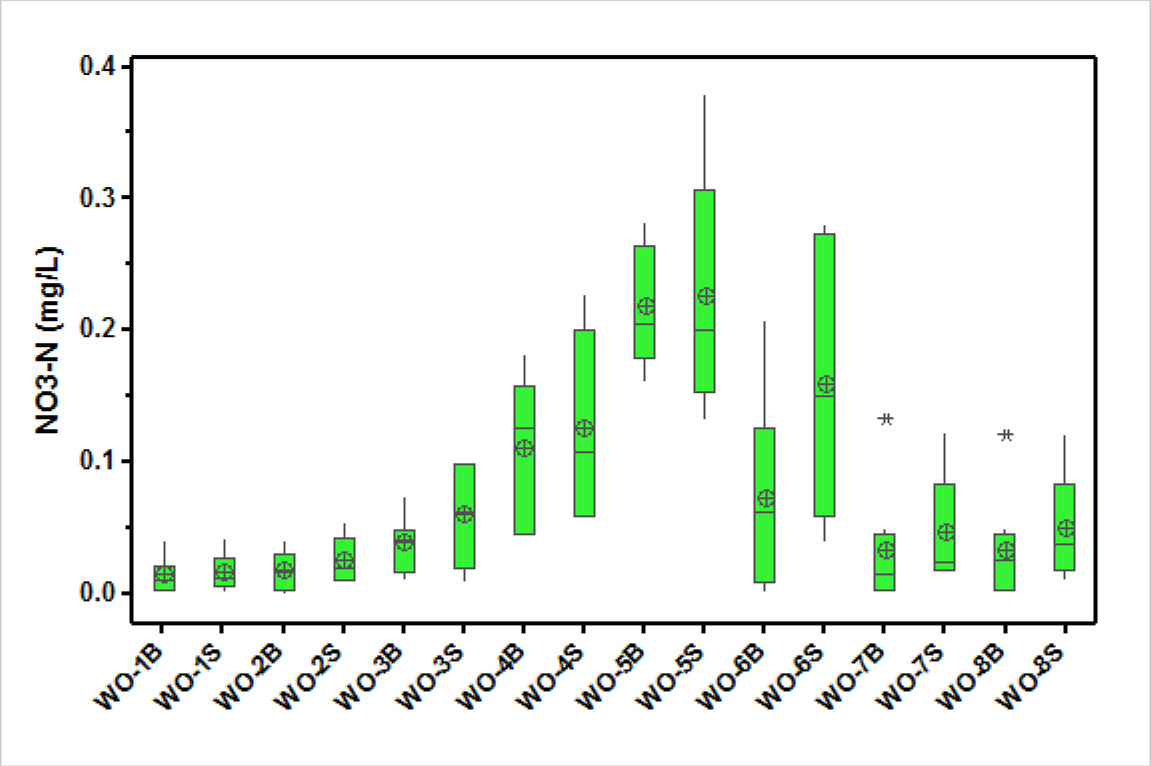

**Figure 30.** Nitrate concentrations under baseflow and stormflow conditions for monitoring sites 1-8. Sites within the Marsh Harbor community (WO-4 to WO-6) showed higher concentrations compared to other locations.

### Ammonium

Ammonium ($NH_4$-N) concentrations were also generally low, especially under baseflow conditions. Mean baseflow concentrations ranged from 0.09 to 0.2 mg/L (Table 11) while mean stormflow concentrations ranged from 0.16 to 0.48 mg/L (Table 12). Although the difference was minor at site WO-3, when compared to baseflow, ammonium was elevated and generally more variable during storms at each location (Fig. 31). Concentrations at sites WO-5 and WO-6 were the most variable during storms, while site WO-8 had the highest mean concentrations among sites under both conditions. On average, ammonium accounted for approximately 64% of DIN and 9% of TDN during baseflow conditions. During storms, ammonium accounted for approximately 78% of DIN and 23% of TDN.

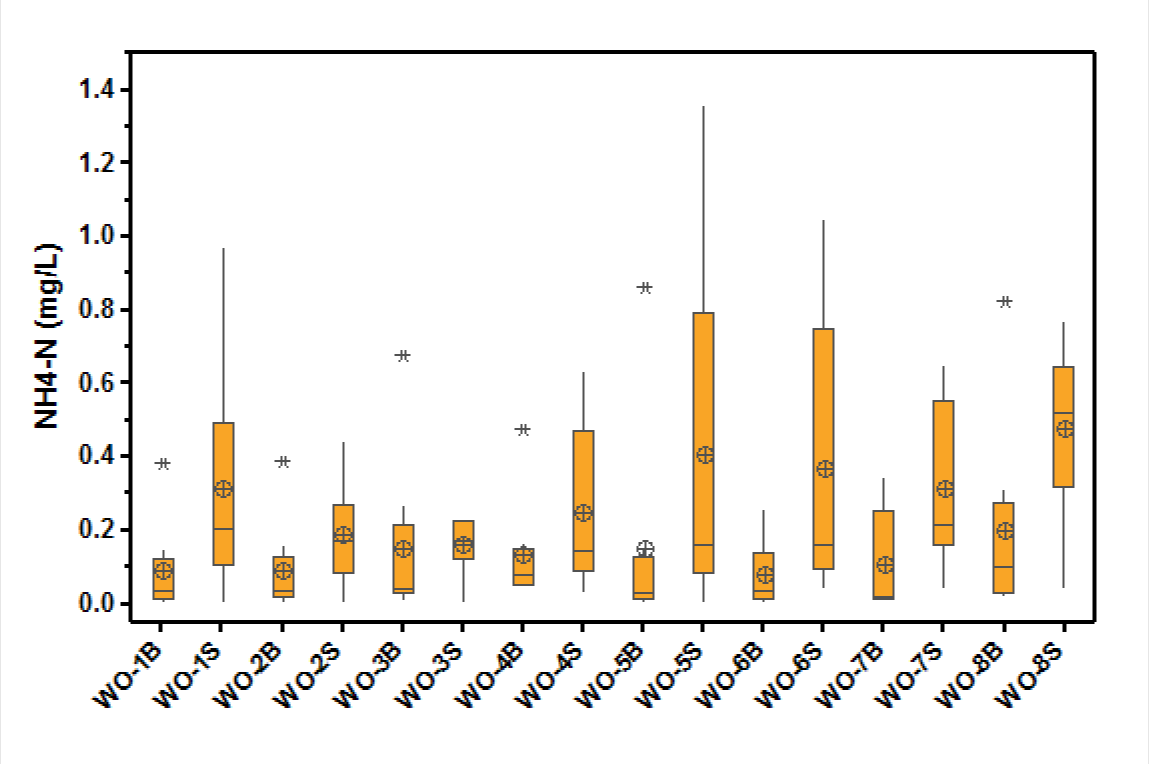

**Figure 31.** Ammonium concentrations under baseflow and stormflow conditions for monitoring sites 1-8. Concentrations during storms were typically higher and more variable compared to baseflow.

### Dissolved Organic Nitrogen

Dissolved organic nitrogen (DON) was the dominant species of nitrogen found at each monitoring site within Boathouse Creek. On average, DON accounted for 80% of TDN concentrations during baseflow and 70% during storms. Baseflow concentrations of DON ranged from 0.25 to 1.36 mg/L, with mean concentrations between 0.62 to 0.88 mg/L at each site. Stormflow concentrations ranged from 0.61 to 1.46 mg/L, with mean concentrations between 0.7 to 1.13 mg/L. Because DON was the dominant nitrogen species, it showed similar trends to TDN. Stormflow concentrations were elevated at sites compared to baseflow concentrations (Fig. 32), and concentrations increased steadily throughout the study period. DON also seemed to increase as sites progressed downstream from freshwater to brackish water (WO-3 to WO-1, WO-5 to WO-6).

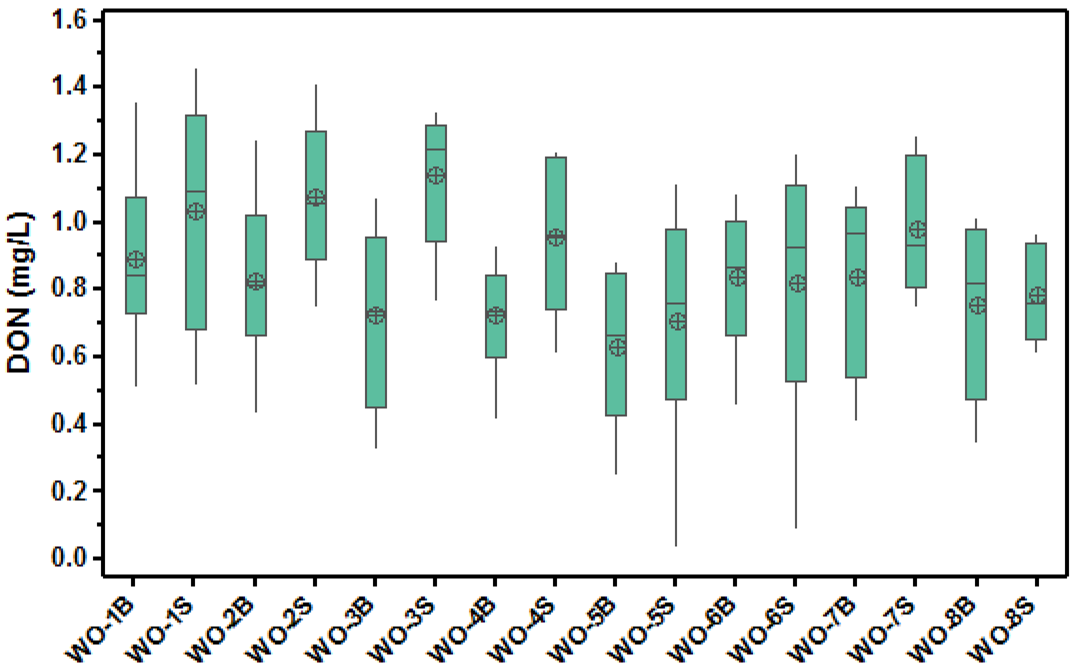

**Figure 32.** Dissolved organic nitrogen (DON) concentrations under baseflow and stormflow conditions for monitoring sites 1-8. Stormflow concentrations of DON were typically higher compared to baseflow concentrations at all eight sites.

**Table 11.** Average baseflow concentrations of chloride (Cl), dissolved organic carbon (DOC), phosphate ($PO_4$-P), total dissolved nitrogen (TDN), nitrate plus nitrite ($NO_3$-N), ammonium ($NH_4$-N), and dissolved organic nitrogen (DON) for monitoring sites 1-8. Concentrations are listed in milligrams per liter.

| Site | Cl | DOC | $PO_4$-P | TDN | $NO_3$-N | $NH_4$-N | DON |
|---|---|---|---|---|---|---|---|
| **WO-1** | 44 | 16.9 | 0.01 | 0.98 | 0.01 | 0.09 | 0.88 |
| **WO-2** | 27 | 16.3 | 0.01 | 0.92 | 0.02 | 0.09 | 0.82 |
| **WO-3** | 36 | 14.0 | 0.02 | 0.90 | 0.04 | 0.14 | 0.72 |
| **WO-4** | 22 | 16.9 | 0.01 | 0.96 | 0.11 | 0.13 | 0.72 |
| **WO-5** | 20 | 11.8 | 0.1 | 0.99 | 0.22 | 0.14 | 0.62 |
| **WO-6** | 3413 | 17.1 | 0.02 | 0.98 | 0.07 | 0.08 | 0.83 |
| **WO-7** | 4665 | 19.0 | 0.02 | 0.97 | 0.03 | 0.10 | 0.83 |
| **WO-8** | 7993 | 17.6 | 0.02 | 0.98 | 0.03 | 0.20 | 0.75 |

**Table 12.** Average stormflow concentrations of chloride (Cl), dissolved organic carbon (DOC), phosphate ($PO_4$-P), total dissolved nitrogen (TDN), nitrate plus nitrite ($NO_3$-N), ammonium ($NH_4$-N), and dissolved organic nitrogen (DON) for monitoring sites 1-8. Concentrations are listed in milligrams per liter.

| Site | Cl | DOC | $PO_4$-P | TDN | $NO_3$-N | $NH_4$-N | DON |
|---|---|---|---|---|---|---|---|
| **WO-1** | 32 | 22.4 | 0.04 | 1.35 | 0.02 | 0.31 | 1.03 |
| **WO-2** | 42 | 20.9 | 0.01 | 1.28 | 0.02 | 0.18 | 1.07 |
| **WO-3** | 28 | 22.3 | 0.01 | 1.34 | 0.06 | 0.16 | 1.13 |
| **WO-4** | 25 | 26.4 | 0.01 | 1.32 | 0.13 | 0.25 | 0.95 |
| **WO-5** | 26 | 18.8 | 0.01 | 1.33 | 0.23 | 0.40 | 0.70 |
| **WO-6** | 5297 | 25.8 | 0.02 | 1.34 | 0.16 | 0.36 | 0.82 |
| **WO-7** | 4180 | 25.7 | 0.02 | 1.33 | 0.05 | 0.31 | 0.98 |
| **WO-8** | 2345 | 21.6 | 0.02 | 1.31 | 0.05 | 0.48 | 0.78 |

### 4.3 Nitrate Source Identification

Samples from all eight monitoring locations were sent to the Stable Isotope Facility at the University of California at Davis; however, only sites WO-4 to WO-6 in the Marsh Harbor community had sufficient nitrate concentrations for reliable stable isotopic analyses of nitrate. Isotopic values of $\delta^{15}N$ and $\delta^{18}O$ in surface water samples collected from Boathouse Creek are indicative of a mixing of nitrogen from multiple sources within the watershed. Of the twelve total data points, six plotted within the field of nitrogen originating from animal or human waste, including all four data points from monitoring site WO-5 and two data points from WO-6 (Fig. 33).

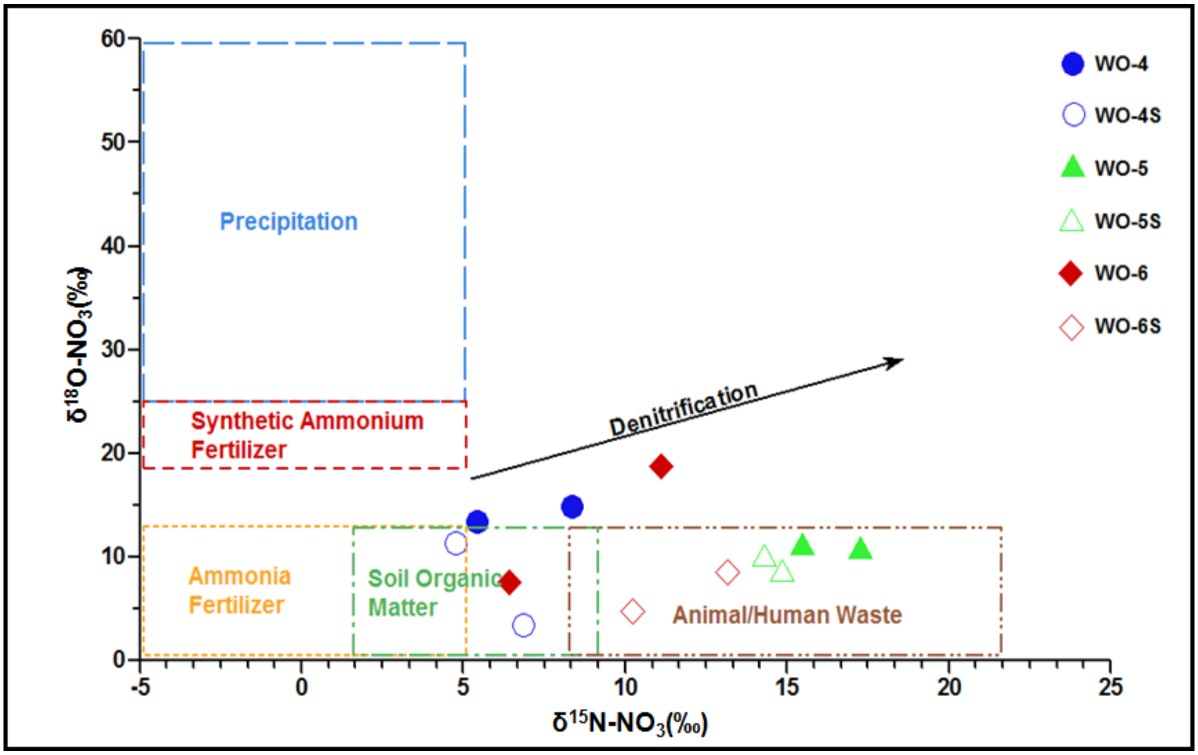

**Figure 33.** $\delta^{15}N$ and $\delta^{18}O$ compositions of nitrate in baseflow and stormflow(S) surface water samples collected from monitoring sites WO-4 to WO-6. The black arrow indicates the enrichment trend of $\delta^{15}N$ and $\delta^{18}O$ due to denitrification.

Five of the data points, including all from monitoring site WO-4, fell within or just outside the typical range of nitrogen originating from soil, with one overlapping into the nitrogen from ammonium fertilizers field. None of the points plotted near or within the typical ranges of $\delta^{18}O$ values for nitrate found in precipitation or synthetic ammonium fertilizer, indicating they were not a predominant source of nitrogen when the streams were sampled. $\delta^{18}O$ values found in nitrate in storm samples were reduced relative to baseflow values for each site.

## 4.4 Runoff and Nutrient Load Reductions

### Water Control Structures

The total drainage area for water control structure 1 (CS-1) consists of 2.9 acres, generally bounded by the crown of the roadway (Ocean Spray Dr.) to the south and the roof ridges from housing to the north (Fig. 34). The total impervious area includes 0.78 acres of road, driveways, sidewalks, and roofs, making the total drainage area approximately 27% impervious. The total drainage area for CS-2 consists of 1.46 acres, with similar boundaries as CS-1. Impervious coverage is slightly less, at 23%. One driveway in each drainage area consisted primarily of bare soil and grass and, therefore, was not considered impervious.

Drainage areas for the remaining control structures are smaller, at 0.45 acres for CS-3 and 0.3 acres each for CS-4 and CS-5 (Fig. 35 and 36). Percent imperviousness was highest at CS-5, at 37%. Stormwater runoff sampled in drainage swales located adjacent to water control structures showed average TDN concentrations of 1.60 mg/L, and $PO_4$-P concentrations of 0.064 mg/L. Runoff coefficient, storm-based runoff volumes, annual runoff volumes, and annual nutrient load calculations using variations of the Simple Method (CWP & CSN, 2008;

NYSDEC, 2001; Schueler, 1987) are presented in Appendix E for each of the water control structures. Drainage area information, estimated storm and annual runoff volumes, and nutrient loads draining to each SCM are summarized in Table 13 (stormwater runoff volumes were converted from cubic feet to liters). Values were then multiplied by the associated volume reduction efficiency (Table 8) to obtain the estimated reductions (Table 14).

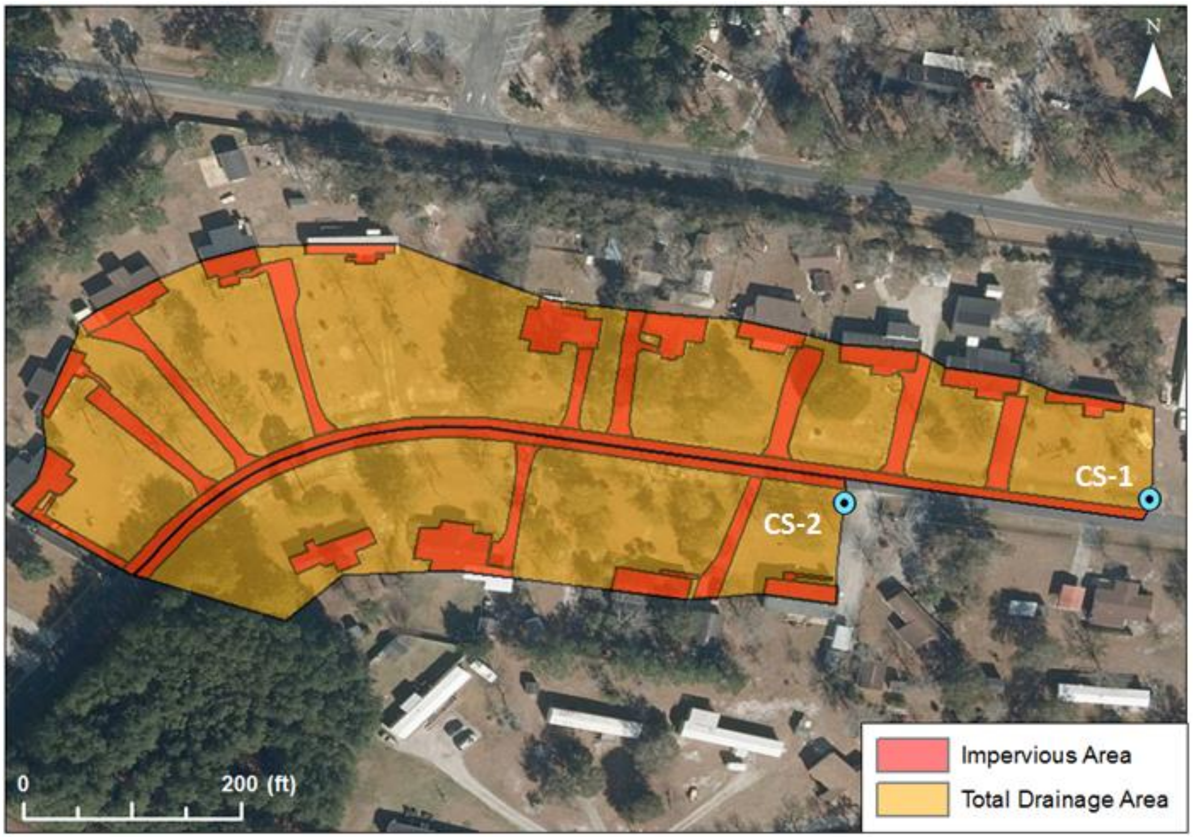

**Figure 34.** Total drainage area and impervious surface area for water control structures 1 and 2 in the Ocean Spray community. One driveway in each drainage area consisted of primarily bare soil or grass and, therefore, not considered impervious.

**Figure 35.** Total drainage area and impervious surface area for water control structures 3 and 4 in the Ocean Spray community.

**Figure 36.** Total drainage area and impervious surface area for water control structure 5 in the Ocean Spray community.

### Enhanced and Stabilized Swales

The sum of the areas draining to the enhanced and stabilized swales locations equal 0.13 acres. Enhanced swales that were located within the water control structure drainage areas were not included. Because the swales primarily drain the road surface, impervious area was considered equal to the total drainage area, making the impervious surface coverage 100% (Fig. 37). Stormwater runoff sampled in drainage swales within the Ocean Spray community showed average TDN concentrations of 1.50 mg/L and $PO_4$-P concentrations of 0.036 mg/L. Runoff coefficient, storm-based runoff volume, annual runoff, and annual nutrient load calculations for the sum of the enhanced swale drainage areas are presented in Appendix E.

**Figure 37.** A portion of the enhanced swale drainage areas found within the Ocean Spray community.

### Rock Check Dams

The total drainage area for the rock check dams consisted of 0.10 acres of impervious surface from Croatan Forest Rd., making impervious surface coverage 100% (Fig. 38). Stormwater runoff sampled above the check dams showed average TDN concentrations of 1.46 mg/L and $PO_4$-P concentrations of 0.007 mg/L. Runoff coefficient, storm-based runoff volume, annual runoff volume, and annual nutrient load calculations for the area draining to the check dams are presented in Appendix E.

**Figure 38.** Drainage area for the rock check dams installed along Croatan Forest Road, near the Cedar Point Campground.

### Walkway and Rain Garden

The areas draining to the newly constructed walkway and rain garden are approximately the same size at 0.08 acres each and consist entirely of the parking lot pavement (Fig. 39). Stormwater runoff sampled entering the rain garden showed average TDN concentrations of 1.55 mg/L and $PO_4$-P concentrations of 0.092mg/L. Runoff coefficient, storm-based runoff volume, annual runoff volume, and annual nutrient load calculations for the areas draining to the renovated walkway and rain garden are presented in Appendix E.

**Figure 39.** Drainage areas for the newly constructed walkway and rain garden at the Cedar Point Tideland Trailhead parking area and boat ramp.

**Table 13.** Drainage area information, estimated storm and annual runoff volumes, and estimated annual TDN and $PO_4$-P loads for the water control structures (CS), swales (SWL), check dams (CD), walkway (WLK), and rain garden (RG).

| SCM | Drainage Area (ac) | Percent Impervious (%) | Storm Volume[1] (L) | Annual Volume[2] (L) | TDN Load (kg-N/yr) | $PO_4$-P Load (kg-$PO_4$-P/yr) |
|---|---|---|---|---|---|---|
| **CS-1** | 2.91 | 27 | 320,773 | 4,732,680 | 7.57 | 0.30 |
| **CS-2** | 1.46 | 23 | 141,160 | 2,082,732 | 3.33 | 0.13 |
| **CS-3** | 0.45 | 27 | 49,611 | 731,849 | 1.17 | 0.05 |
| **CS-4** | 0.31 | 19 | 24,919 | 368,006 | 0.59 | 0.02 |
| **CS-5** | 0.30 | 37 | 44,656 | 659,018 | 1.05 | 0.04 |
| **SWL** | 0.13 | 100 | 46,468 | 685,494 | 1.03 | 0.02 |
| **CD** | 0.10 | 100 | 35,736 | 527,288 | 0.77 | 0.004 |
| **WLK** | 0.08 | 100 | 28,600 | 421,836 | 0.65 | 0.04 |
| **RG** | 0.08 | 100 | 28,600 | 421,836 | 0.65 | 0.04 |
| **Total** | **5.82** | | **720,523** | **10,630,739** | **16.81** | **0.64** |

[1] Storm runoff volumes are based on the regional 1-year, 24-hour storm of 3.66 inches (NOAA, 2017).
[2] Annual runoff volumes are based on an average annual precipitation of 60 inches.

**Table 14.** Estimated runoff volume and nutrient load reductions for the water control structures (CS), swales (SW), check dams (CD), walkway (WLK), and rain garden (RG).

| SCM | Storm Volume (L) | Annual Volume (L) | TDN Load (kg-N/yr) | $PO_4$-P Load (kg-$PO_4$-P/yr) | Reduction |
|---|---|---|---|---|---|
| **CS-1** | 96,221 | 1,419,807 | 2.27 | 0.09 | 30% |
| **CS-2** | 42,362 | 624,811 | 1.00 | 0.04 | 30% |
| **CS-3** | 14,895 | 219,569 | 0.35 | 0.015 | 30% |
| **CS-4** | 7,476 | 110,407 | 0.18 | 0.006 | 30% |
| **CS-5** | 13,394 | 197,708 | 0.32 | 0.012 | 30% |
| **SWL** | 13,932 | 205,637 | 0.31 | 0.006 | 30% |
| **CD** | 13,222 | 195,097 | 0.28 | 0.001 | 37% |
| **WLK** | 28,600 | 421,836 | 0.65 | 0.04 | 100% |
| **RG** | 28,600 | 421,836 | 0.65 | 0.04 | 100% |
| **Total** | **258,702** | **3,816,708** | **6.01** | **0.25** | **36%** |
| **Error[1]** | **±77,400** | **±1,140,00** | **±1.80** | **±0.06** | |

[1] Based on estimated volume reduction ranges from literature (Table 8).

# CHAPTER 5: DISCUSSION

## 5.1 Water Quality and Flow

Based on the results of the physical and chemical water quality parameters observed during this study, water quality at the eight monitoring sites throughout Boathouse Creek can be characterized as generally meeting NC surface water quality standards. Turbidity remained below the state standard for freshwater streams (≤ 50 NTU) on 100% of baseflow and stormflow occasions at freshwater sites, indicating that even during storms, sediment and other suspended particulate matter were not significantly impacting water quality. However, it is possible that with more intense stormwater sampling more elevated turbidity values could be observed, particularly during the first flush period. Similarly, pH at freshwater monitoring sites remained within the state standard pH range (6.0 to 9.0) on over 97% of the instances sampled. If adhering to the slightly more stringent saltwater pH range (6.0 to 8.5) for brackish water sites, pH remained within state standard over 98% of the instances sampled.

Dissolved oxygen concentrations were less ideal, with approximately 70% of occasions being above the state standard (≥5.0 mg/L daily average). However, because Boathouse Creek is considered a wetland system, it may fall under the NC Division of Water Resources' supplemental "Swamp Waters" classification, which allows for lower DO standards. Concentrations observed in this study are likely conservative and not fully representative of the daily average. This is because readings were generally taken in the late morning to early afternoon (9:00 AM to 2:00 PM), when DO concentrations are typically higher, while lower concentrations generally occur at night due to the absence of photosynthesis (Wang, 2003). As a result, the lowest daily concentrations were likely missed due to the sampling schedule.

DO concentrations also fluctuated seasonally; standards were more commonly violated and hypoxic conditions were more prevalent during the warm summer months. Due to the effects of climate change, future projections of warmer and longer summers could pose a problem for some aquatic organisms in Boathouse Creek and the lower White Oak River (Ficke et al. 2007; Hansen et al. 2012; Levin et al. 2009). The combined effect of higher temperatures and lower dissolved oxygen availability means that environmental conditions may become stressful for many species in these and similar shallow estuarine waters. If increased water temperatures cause dissolved oxygen levels to drop below some species requirements for prolonged periods, it would eventually result in forced migration of the species or weakening through reduced rates of survival, growth, and reproduction. For example, Breitburg et al. (2015) found that shallow water hypoxia reduced growth and increased the acquisition and progression of disease causing infections in the eastern oyster (*Crassostrea virginica*), which inhabit tidal creeks along the Atlantic coast, including the lower portions of Boathouse Creek.

Climate change may also impact water quality in Boathouse Creek by reducing flow. More frequent and prolonged droughts during summer months are another likely effect of climate change (Whitehead et al. 2009). Extended periods of dry weather combined with already higher temperatures and evapotranspiration rates associated with summer would significantly reduce baseflow and could result in “headwater-drying”, especially in the smaller tributaries of Boathouse Creek. On some occasions, monitoring site WO-1 showed little to almost no discharge during summer, while average discharge at site WO-2 was reduced by more than half during the warmest months (May – September) compared to the rest of the year. Lower flows in tidal creeks decrease the availability of nursery areas important to juvenile fish species that travel between the open estuary and salt marsh-tidal creek habitats. Ross (2003) showed that juvenile spot (*Leiostomus xanthurus*) and Atlantic croaker (*Micropogonias undulates*) from upriver oligohaline creeks exhibited lower mortality rates than fish from downstream polyhaline creeks within the Cape Fear River estuary and Pamlico Sound system, indicating that upstream habitats may provide better conditions for survival.

Drought induced low flows would exacerbate the issue of dissolved oxygen and water temperature previously mentioned. As stream stage and discharge decrease, velocity is reduced, mixing at the air-water interface is reduced, temperature is increased, and as a result, dissolved oxygen concentrations decrease. If other factors were held constant, baseflow pollutant concentrations would increase due to less water being available for dilution; meanwhile storms that terminate drought periods would flush excess nutrients and other pollutants into Boathouse Creek, further increasing concentrations during storms. Lower flows, reduced velocities and, therefore, higher stream water residence times, along with increased nutrient concentrations would also enhance the potential for algal blooms (Paerl, 1998; Paerl and Huisman, 2009). Lastly, the combined effects of lower flows with global sea-level rise could result in saline water migrating further upstream, threatening flora and fauna that are dependent on brackish or freshwater habitat.

In terms of water quality for human use and recreation, the NCDWR classifies Boathouse Creek as a “Class SA” water body, which include tidal salt waters used for commercial shellfishing purposes. Additionally, it is classified as “Class SC”, which includes “all tidal salt waters protected for secondary recreation such as fishing, boating, and other activities involving minimal skin contact; fish and noncommercial shellfish consumption; aquatic life propagation and survival; and wildlife.” However, shellfish harvesting within Boathouse Creek has been permanently closed by the NC Division of Marine Fisheries due to the presence of elevated concentrations of fecal indicator bacteria. A study by Lyons (2017) evaluated fecal indicator bacteria within the study area and found that enterococci concentrations exceeded standards in approximately 45% of samples taken at monitoring sites WO-6 and WO-7. Consequently, primary recreation is not recommended in Boathouse Creek and it remains on the state’s 303(d) list of impaired waters because its designated use (shellfish harvesting) is not being achieved.

### 5.2 Nutrients and Dissolved Organic Carbon

Concentrations of DOC in Boathouse Creek fell within the range of 0.5 to 50 mg/L that is typical for most stream and river systems (Findlay and Sinsabaugh, 2002); however, it is unclear why mean baseflow concentrations more than tripled from the 2015 to 2016 year (Fig. 26). Several studies have shown that stream DOC concentrations can be highly influenced by the flow path of water across the landscape, channel slope, and the presence of wetlands in the catchment area. Generally, streams draining landscapes in which the dominant flow paths are shallow, occurring at or near the surface (runoff) and in contact with litter layers and organic rich soils, have higher DOC concentrations than those receiving inputs from deeper flow paths. Studies by Eckhardt and Moore (1990), Gergel et al. (1999), and Gorham et al. (1998), found that the percentage of drainage area consisting of wetlands was the best predictor of DOC concentrations and their variability. Mulholland (1997) found that average channel slope explained approximately 44% of the variation in DOC. Although wetland percentage was not considered as a predictor, his results indicated that higher concentrations (>12 mg/L) were found in watersheds with low slopes, broad floodplains, and sizable riparian wetlands, which included streams within the southeastern Coastal Plain, draining wetlands in North Carolina and Georgia. DOC concentrations are not regulated in surface waters, but similar to nitrogen and phosphorus, excess DOC can increase biochemical oxygen demand, resulting in reduced DO concentrations and increased potential for hypoxic conditions (Wallace et al. 2014).

When baseflow and stormflow DOC concentrations were compared at sites during similar time periods (≤ 30 days), sites sometimes showed increases while in other cases concentrations decreased as a result of storms. In forested watersheds, increased DOC during stormflow can be explained by flushing of upper soil and litter horizons in riparian areas. In more urbanized watersheds, lower DOC concentrations can be expected during storms due to increased impervious area that may divert water away from soils, combined with the decreased availability of vegetation and riparian area (Hook and Yeakley, 2005). This may explain why stormflow DOC concentrations in Boathouse Creek fluctuated with respect to baseflow between sites. Sites more heavily surrounded by riparian area and receiving less runoff may initially increase in DOC, whereas sites draining less vegetated areas with more impervious cover may result in concentrations becoming more quickly diluted.

Although there are currently no state numerical standards for nutrient species in North Carolina surface waters, phosphate concentrations found in Boathouse Creek were generally low, within the natural background levels (0.01 – 0.03 mg/L) found in uncontaminated water bodies. Phosphate concentrations above 0.025 mg/L are typically associated with the overstimulation of plant growth, while concentrations above 0.1 mg/L are known to accelerate eutrophication and lead to harmful conditions for aquatic life (Wimalawansa, 2015). In 2000, the EPA provided nutrient criteria recommendations for rivers and streams within the NC Coastal Plain (Nutrient Ecoregion XIV). Based on the medians of all the 25th percentile seasonal data over a nine-year period, they recommend total phosphorus concentrations between 0.0068 and 0.052 mg/L in order to minimize human impact and protect aquatic life (USEPA, 2000). Stormflow concentrations of phosphate in Boathouse Creek were not elevated with respect to baseflow, with the majority of sites showing a decrease in concentration during storms, likely as a result of dilution. On several instances, baseflow and stormflow concentrations found in samples were below the method detection limit, indicating that Boathouse Creek may be phosphorus-limited under some conditions. It is important to note that although dissolved phosphate concentrations were not elevated, particulate phosphate may be elevated during storms.

Baseflow and stormflow TDN concentrations increased throughout the study period. TDN concentrations during baseflow were above the EPA recommended background range (0.48 - 0.87 mg/L) for the region on approximately 58% of the occasions sampled, with 40% of samples having concentrations >1.0 mg/L. Stormflow TDN concentrations were significantly elevated with respect to baseflow, with concentrations exceeding 1 mg/L on 83% of the occasions sampled. These elevated baseflow and stormflow concentrations pose more of a problem downstream where they contribute to nitrogen loading within the lower White Oak River and Bogue Sound estuarine waters where nitrogen is typically the limiting nutrient, and concentrations over 1 mg/L are considered high due to the potential of nuisance and toxic algal bloom stimulation (NOAA, 1996). It is also important to note that stormflow concentrations of TDN and phosphate reported in this study could be underestimated due to the timing of sample collection during storms. Pollutant concentrations may have been higher during peak flows or when rain intensity was highest. Additionally, concentrations may have been elevated during the initial stages of a storm or runoff event, known as the “first flush effect” (Maestre and Pitt, 2005).

DON was the dominant species of nitrogen found throughout Boathouse Creek and was the primary cause for elevated TDN concentrations during storms. DON showed similar trends to DOC, with baseflow concentrations more than doubling over the course of the study period. A possible explanation for these increases in dissolved organic matter could be the higher baseflow discharges when the samples were taken (Lehrter, 2006). Carbon: Nitrogen ratio values from storm samples generally averaged between 15 and 20, indicating that the probable sources of organic matter include a combination of terrestrial derived plant material (leaf litter) and organic rich soils due to runoff (Kendall et al. 2001; Rostad et al. 1998). Elevated DON concentrations in Boathouse Creek could also be attributed to wastewater from OWTS found throughout the Ocean Spray and Marsh Harbor communities. A study by O’Driscoll et al. (2014) performed adjacent to the Pamlico River Estuary in the NC Coastal Plain found that DON originating from OWTS was mobile and contributed to surface water nitrogen loading through groundwater discharge, most notably during periods of frequent precipitation. Recognition of elevated DON concentrations in nutrient-sensitive, coastal waters is becoming increasingly important. There is evidence to suggest that DON may often be the dominant form of nitrogen exported from coastal watersheds and it may play an active role in supplying nitrogen to phytoplankton and bacteria (Berman and Bronk, 2003; Kroeger et al. 2006).

Nitrate concentration patterns and the stable isotopic data support that OWTS are contributing nitrogen to nearby portions of Boathouse Creek. Nitrate concentrations were noticeably higher at monitoring site WO-5 which is located directly downstream from a high density OWTS area in Marsh Harbor. In addition, all four $\delta^{15}N$ and $\delta^{18}O$ data values from monitoring site WO-5 indicated animal or human (septic) waste as the nitrogen source. Lower nitrate concentrations at monitoring site WO-4 combined with $\delta^{15}N$ and $\delta^{18}O$ data values indicating soil as the nitrogen source can be explained by its location further upstream of the OWTS plumes. Further downstream from both sites, isotopic data from monitoring site WO-6 indicate a mixture of the previously mentioned sources. Nitrate concentrations were significantly lower at monitoring sites WO-1 to WO-3, possibly as a result of the wider riparian buffer zone where nitrogen can be more easily assimilated and soils are richer with organic matter, promoting denitrification (Fig. 8) (Osmond et al. 2002). Although elevated nutrient loads in the NC Coastal Plain region are often attributed to excess fertilizer runoff from agriculture or as a result of atmospheric deposition, the relatively low concentrations of nitrate and isotope data suggest that wastewater from OWTS or animal waste from wildlife and pets may play a more prominent role as sources in the Boathouse Creek watershed.

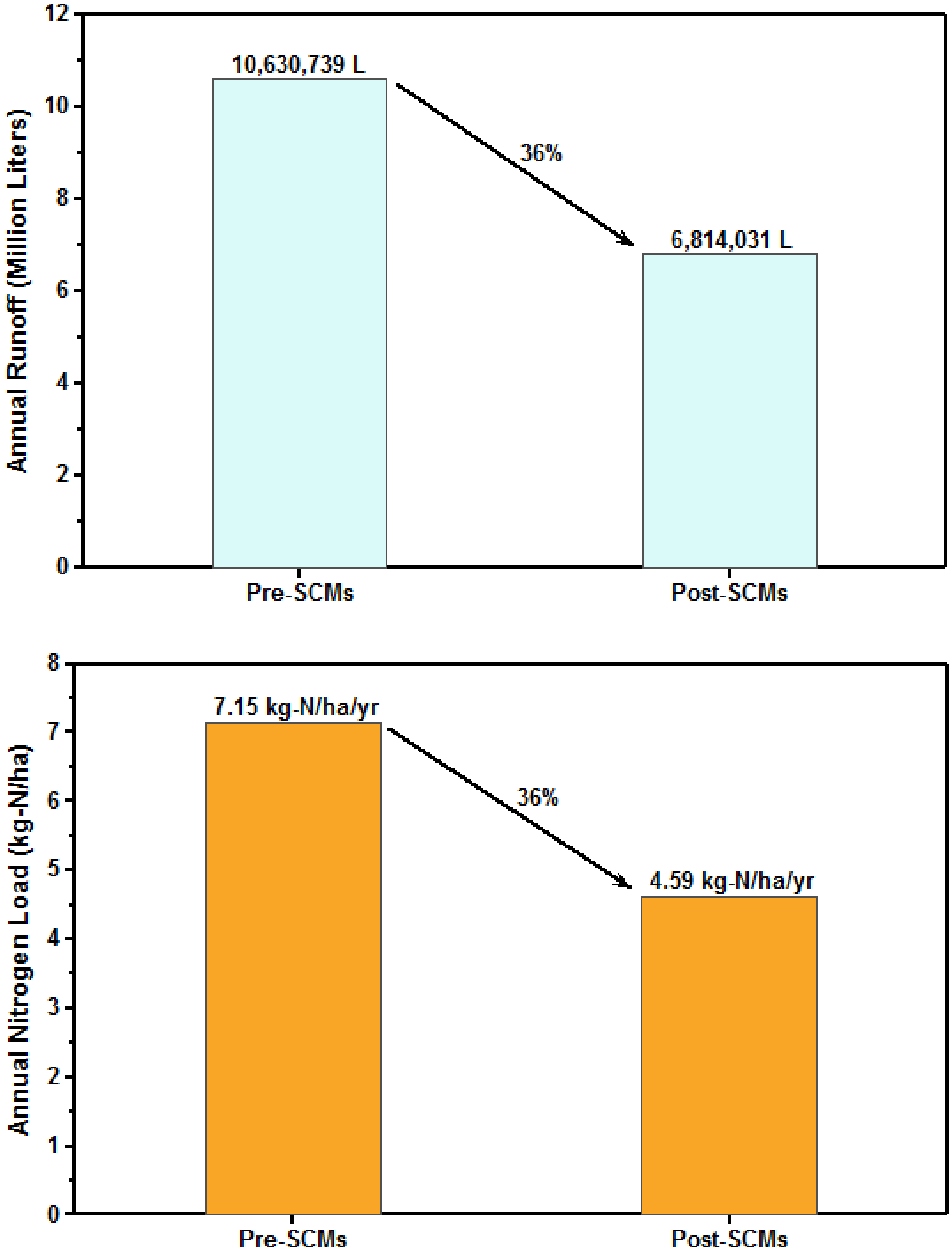

**Figure 40.** Annual estimates of stormwater runoff (top) and nitrogen loading (bottom) at SCM sites before and after implementation of SCMs. Stormwater runoff and nitrogen load reductions to Boathouse Creek were estimated to be 36%.

## 5.3 Runoff and Nutrient Load Reductions

Based on the methods used in this study, an estimated 258,000 L of stormwater runoff was reduced by SCMs in the Boathouse Creek watershed for the regional 1-year, 24-hour storm event, achieving the grant's goal of 200,000 L. Annually, it was estimated that approximately 3,800,000 L of runoff was collectively infiltrated by SCMs, equating to a 36% annual reduction in runoff when compared to pre-SCM site estimates (Fig. 40). Pre-SCM site estimates of nitrogen and phosphorus loading to Boathouse Creek were 7.15 kg-N/ha/yr and 0.27 kg-$PO_4$-P/ha/yr, respectively. It is estimated that SCMs reduced nitrogen loading by 2.56 kg-N/ha/yr (Fig. 40) and phosphorus loading by 0.11 kg-$PO_4$-P/ha/yr, equating to a 36% annual reduction when compared to pre-SCM site estimates. The largest estimated reductions occurred at water control structures 1 and 2 due to their larger drainage areas and moderate amounts of impervious area. Despite having the smallest drainage areas, significant reductions also occurred at the rain garden and renovated walkway due to their 100% impervious drainage areas and runoff reduction efficiencies (Tables 13 and 14).

Because there is a range of potential factors used for assessing SCM effectiveness, these estimations are based on conservative SCM volume reduction values cited in previous studies. Strecker et al. (2001) explain that inconsistent study methods, lack of associated design information, and reporting protocols all contribute in making wide-scale assessments of SCM effectiveness difficult. Also, many efficiency values reported in studies are based on short-term performance and may not consider reduced efficiencies overtime due to degradation or lack of maintenance (Liu et al. 2017). SCMs such as the enhanced swales in the Ocean Spray community may lose effectiveness overtime as sediment and grass accumulate near the roadway edge.  Similarly, excessive sediment and debris build up behind the check dams can reduce their ability to infiltrate and temporarily pond water.  Further research is needed on similar SCMs used in an NC Coastal Plain setting to better understand their performance, but future work could refine the estimates made in this study.  Future studies using a GIS-modeling framework approach, such as the EPA's System for Urban Stormwater Treatment and Analysis IntegratioN (SUSTAIN), could help optimize site locations for SCMs based on cost and effectiveness (Shoemaker et al. 2009).  Estimating stormwater reductions per SCM cost can allow for more effective placement of SCMs, increase the number of sites, and enhance overall stormwater reductions.  For example, the water control structures were the most cost-effective SCM used in this study, being relatively inexpensive to fabricate and install and accounting for 67% of the estimated stormwater reductions (Table 14).

Further efforts to reduce stormwater runoff were made shortly after monitoring ended. Adjacent to the installed check dams in the Cedar Point Campground, a damaged drainage culvert was replaced.  The previous drainage culvert had partially collapsed and was clogged with roots, forcing drainage to only one side of the road and the resulting runoff was contributing to erosion and flooding near the campground entrance.  The new drainage culvert diverted drainage to a wooded area adjacent to the road ditch.  Also, the NC Coastal Federation provided 42 rain barrels with a total combined storage capacity of 9,600 L, to homes primarily within the Marsh Harbor community.

Based on the nutrient analyses and isotopic data, it may also be beneficial to reduce groundwater associated nutrient loading from OWTS. Studies have shown that OWTS can be a significant source of nitrogen and phosphorus to nutrient-sensitive coastal surface waters and groundwater (Iverson et al. 2015; Humphrey et al. 2013; O'Driscoll et al. 2014). In future development, optimizing the location and placement of installed OWTS with respect to groundwater and adjacent surface waters may reduce nutrient loading. Maximizing the separation distance between the seasonal high groundwater table and drainfield trenches or elevating the drainfield using fill material could improve pollutant treatment efficiency. Extending the separation distance between the installed OWTS and nearby surface waters may also improve treatment (Humphrey et al. 2017; O'Driscoll et al. 2014).

Much of the riparian area that previously surrounded portions of Boathouse Creek was removed during the development of the Marsh Harbor community (Fig. 5). Although removal efficiencies vary widely among studies, riparian buffers have been shown to reduce nitrogen loads to surface waters (Christensen et al. 2013; Lowrance et al. 1997; Mayer et al. 2007; Vidon et al. 2010). Apart from small grasses and a sparse population of trees, stream banks are bare along the western-most portions of Marsh Harbor. Restoration of riparian areas along stream banks with more substantial vegetation (plants with root systems that penetrate the groundwater table) and aquatic plants that can be placed in the hyporheic zone could also enhance nitrogen reductions.

Although many of the SCM recommendations from the initial study have been implemented and expanded upon, there are still improvements that can be made to reduce stormwater runoff to Boathouse Creek and improve water quality so that its resources can be fully utilized. If further implementation of SCMs could reduce bacteria concentrations enough to re-establish usable shellfish area, the economic benefits would outweigh the cost of the SCMs. Lyons (2017) estimated bacteria reductions (*E. coli* and enterococci) at each of the SCM sites, with substantial reductions occurring at the parking area and boat ramp site. Grabowski et al. (2012) estimated the average annual ecosystem value of healthy shallow-water oyster beds at over $4,000 per acre and over $4,500 per acre when average annual harvest is included. At over 50 acres, the Boathouse Creek shellfish area could be valued at an estimated $225,000 annually, far more than the cost to install and maintain the SCMs used in this study.

### 5.4 Addressing Hypotheses

**Hypothesis 1:** Concentrations of nitrogen and phosphate in Boathouse Creek will be elevated during storm events.

The results of this study support that nitrogen concentrations during storms were elevated with respect to baseflow concentrations. Under stormflow conditions, concentrations of TDN were elevated relative to baseflow at all eight sites (Fig. 28). Results from the Mann-Whitney test indicated that the differences in median concentrations of TDN between baseflow and stormflow conditions were found to be significant ($p < 0.001$ at the 0.05 significance level), indicating that TDN concentrations in Boathouse Creek were significantly elevated during storm events, potentially due to stormwater runoff contributions.

However, the results do not support that phosphate concentrations were also elevated during storms relative to baseflow. Comparison of baseflow to stormflow mean phosphate concentrations at each site exhibited mixed results, with three sites (WO-1, WO-6, and WO-7) exhibiting an increase during storms, four sites (WO-2, WO-3, WO-5, and WO-7) exhibiting a decrease during storms, and one site (WO-4) remained relatively unchanged (Fig. 27). Results from the Mann-Whitney test indicated that differences in median concentrations of phosphate between baseflow and stormflow conditions were insignificant ($p = 0.87$ at the 0.05 significance level), indicating that phosphate concentrations in Boathouse Creek were not significantly elevated during storm events. Although elevated nitrogen concentrations during storms were supported, elevated phosphate concentrations during storms were not supported, thus Hypothesis 1 cannot be fully supported. However, it is possible that particulate phosphorus was elevated during storms but that was not sampled.

**Hypothesis 2:** Primary sources of nitrogen in the study area include human/animal waste and soil organic matter.

Although nitrate concentrations from samples taken in Boathouse Creek at five of the eight monitoring sites were too low for reliable stable isotopic analyses of $\delta^{15}N$ and $\delta^{18}O$, the remaining sites (WO-4 to WO-6) in the Marsh Harbor community had sufficient concentrations. Isotopic values of $\delta^{15}N$ and $\delta^{18}O$ from these sites indicated a combination of nitrogen sources. Of the twelve total data points, 50% plotted within the field of nitrogen originating from animal or human waste, including all four data points from monitoring site WO-5 and two data points from WO-6 (Fig. 33). Values from monitoring site WO-4 fell within or just outside the typical range of those originating from organic soils, with one overlapping into the nitrogen from ammonium fertilizers field. No data points plotted near or within the typical ranges of $\delta^{18}O$

values for nitrate found in precipitation or synthetic ammonium fertilizer, indicating they were not a source of nitrate when the streams were sampled. These results suggest that the dominant nitrate-nitrogen source at monitoring site WO-4 is from organic soils, while the dominant nitrate-nitrogen source at WO-5 is from animal or human waste. Downstream from these sites at WO-6, isotopic values indicate a mixing between the two previously mentioned sources, supporting Hypothesis 2.

**Hypothesis 3:** Implementation of SCMs will reduce stormwater runoff volumes and nutrient loads to Boathouse Creek and the lower White Oak River.

Based on visual evidence during storms, as well as the methods used in this study to quantify reductions, stormwater runoff volumes and nutrient loads discharging to Boathouse Creek were reduced at SCM sites, thus supporting Hypothesis 3. Approximately 258,000 L of runoff was reduced by SCMs in the Boathouse Creek watershed for the regional 1-year, 24-hour storm event, while approximately 3,800,000 L of runoff was prevented from entering Boathouse Creek, annually. Compared to pre-SCM site estimates, SCMs reduced nitrogen and phosphorus loading to Boathouse Creek by 2.56 kg-N/ha/yr and 0.11 kg-$PO_4$-P/ha/yr, respectively. Overall, it was estimated that annual stormwater runoff volume and nutrient loads from SCM sites were reduced by approximately 36%.

# CHAPTER 6: CONCLUSIONS

Due to increased urban development, stormwater runoff has been identified as the primary contributor of non-point source pollution to Boathouse Creek and the lower White Oak River. The specific goals of this study were to: (1) characterize the overall water quality and hydrology of Boathouse Creek under baseflow and stormflow conditions through monthly monitoring and sampling, (2) determine if nutrient concentrations are elevated during storm/runoff events, (3) identify the primary sources of nitrogen in the study area, (4) implement SCMs that will facilitate the infiltration of stormwater runoff, and (5) estimate potential runoff volume and nutrient loads reduced by SCMs.

Water quality and hydrology were characterized through monthly monitoring and sampling at eight sites. Of the surface water environmental parameters measured, DO concentrations pose the greatest concern in Boathouse Creek, especially with future projections of warmer and longer summers due to climate change. Reduced flows during warm, dry periods could result in habitat loss in the smaller tributaries and exacerbate low dissolved oxygen levels. Nutrient analyses from water samples showed relatively low concentrations of phosphate, but TDN concentrations did increase significantly over the study period and were elevated during storms. DON was found to be the dominant form of nitrogen in Boathouse Creek and the primary cause for elevated storm TDN concentrations. Although elevated nutrient loads in the region are often attributed to agricultural runoff or as a result of atmospheric deposition, isotopic analyses of nitrate in water samples suggest that soil organic matter, human waste from OWTS and/or wildlife/pet waste were the primary sources of nitrogen in the Boathouse Creek watershed. SCMs were implemented and stormwater runoff and nutrient loads reductions were estimated at each SCM site. Further research is needed on similar SCMs used in an NC Coastal Plain setting to better understand their performance, and future work could help refine these estimates.

Much of the work in reducing non-point source pollution to coastal surface waters is constrained by individual land-use and management decisions by property owners and residents, highlighting the importance of educating the public on local water quality issues and encouraging them to cooperate with and support reduction efforts. Further efforts to reduce stormwater-related pollution are suggested to improve water quality in Boathouse Creek and the lower White Oak River. Additionally, because human and/or animal waste was identified as a nitrogen source in Boathouse Creek, future efforts should also focus on reducing waste-related nitrogen inputs, including loading from OWTS. Predicting the impacts of human activities and climate change in coastal ecosystems is critical for the effective management of coastal water resources. Loss of aquatic habitat and reduced biodiversity could have adverse ecological and socioeconomic effects in coastal areas that depend on their fisheries and aquaculture.

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# APPENDIX A: PHYSICAL/CHEMICAL WATER QUALITY DATA

## Baseflow

| **pH** | WO-1 | WO-2 | WO-3 | WO-4 | WO-5 | WO-6 | WO-7 | WO-8 |
|---|---|---|---|---|---|---|---|---|
| May-15 | 5.13 | 6.22 | 6.79 | 7.06 | 7.15 | 7.42 | 7.34 | 7.47 |
| Jun-15 | 6.1 | 6.83 | 6.96 | 6.62 | 7.12 | 7.27 | 8.5 | 8.2 |
| Jul-15 | 5.62 | 6.33 | 6.7 | 6.75 | 6.84 | 6.62 | 7.12 | 7.52 |
| Aug-15 | 7.47 | 7.44 | 7.69 | 7.56 | 7.32 | 6.79 | 6.89 | 7.08 |
| Sep-15 | 7.7 | 6.79 | 7.19 | 7.42 | 7.55 | 7.43 | 7.64 | 7.78 |
| Oct-15 | 7.78 | 7.43 | 6.91 | 6.95 | 7.02 | 6.6 | 7.11 | 7.26 |
| Nov-15 | 6.54 | 7.02 | 6.97 | 7.24 | 7.4 | 7.34 | 7.5 | 7.75 |
| Dec-15 | 7.71 | 7.3 | 7.36 | 7.3 | 7.36 | 7.43 | 7.85 | 7.36 |
| Jan-16 | 7.4 | 6.95 | 7.32 | 7.32 | 7.36 | 7.37 | 7.7 | 6.88 |
| Mar-16 | 7.72 | 7.22 | 7.25 | 7.27 | 7.32 | 7.39 | 7.46 | 7.25 |
| Apr-16 | 8.33 | 7.37 | 7.22 | 7.38 | 7.73 | 7.25 | 7.37 | 7.31 |
| May-16 | 8.28 | 7.31 | 7.11 | 7.62 | 7.30 | 7.66 | 6.89 | 7.66 |
| Jun-16 | 6.97 | 6.95 | 7.13 | 7.59 | 6.96 | 7.02 | 7.11 | 7.03 |
| Oct-16 | 7.08 | 7.0 | 6.98 | 7.08 | 7.31 | 7.05 | 7.2 | 6.6 |
| Nov-16 | 8.05 | 7.56 | 7.37 | 7.34 | 7.46 | 7.03 | 7.34 | 6.56 |
| Dec-16 | 7.52 | 7.13 | 7.13 | 7.11 | 7.34 | 6.81 | 7.42 | 5.84 |
| Jan-17 | 8.3 | 7.68 | 7.35 | 7.42 | 7.55 | 7.23 | 7.53 | 7.22 |
| Mar-17 | 9.28 | 8.15 | 7.78 | 7.52 | 7.5 | 7.33 | 7.57 | 8.35 |

## Stormflow

| **pH** | WO-1S | WO-2S | WO-3S | WO-4S | WO-5S | WO-6S | WO-7S | WO-8S |
|---|---|---|---|---|---|---|---|---|
| Oct-15 | 6.53 | 7.1 | 7.16 | 7.21 | 7.17 | 7.06 | 7.02 | 7.25 |
| Dec-15 | 7.24 | 7.04 | 7.20 | 7.30 | 7.50 | 7.30 | 7.40 | 7.60 |
| Feb-16 | 7.71 | 7.15 | 7.19 | 7.15 | 7.53 | 7.01 | 7.49 | 6.71 |
| Sep-16 | 7.59 | 7.12 | 6.22 | 7.33 | 7.6 | 7.09 | 7.13 | 6.24 |
| Jan-17 | 8.67 | 7.72 | 7.46 | 7.45 | 7.59 | 7.57 | 7.67 | 7.45 |
| Feb-17 | 8.16 | 7.78 | 7.52 | 7.41 | 7.67 | 7.02 | 7.3 | 7.62 |

### Baseflow

| DO (mg/L) | WO-1 | WO-2 | WO-3 | WO-4 | WO-5 | WO-6 | WO-7 | WO-8 |
|---|---|---|---|---|---|---|---|---|
| May-15 | 3.70 | 5.44 | 5.40 | 4.86 | 5.35 | 6.97 | 2.10 | 7.49 |
| Jun-15 | 2.06 | 5.14 | 4.58 | 3.20 | 4.42 | 3.87 | 10.87 | 7.30 |
| Jul-15 | 2.94 | 4.72 | 4.07 | 3.28 | 3.94 | 2.31 | 6.28 | 4.24 |
| Aug-15 | 5.40 | 4.32 | 4.70 | 4.17 | 4.04 | 4.05 | 2.80 | 4.35 |
| Sep-15 | 2.97 | 5.24 | 3.75 | 3.37 | 2.73 | 5.51 | 5.97 | 5.32 |
| Oct-15 | 4.56 | 6.49 | 4.95 | 4.93 | 4.96 | 4.55 | 4.79 | 5.39 |
| Nov-15 | 5.67 | 6.53 | 4.98 | 4.74 | 7.87 | 10.23 | 6.05 | 7.00 |
| Dec-15 | 5.98 | 6.57 | 5.10 | 3.81 | 4.75 | 8.86 | 7.42 | 5.99 |
| Jan-16 | 8.14 | 9.50 | 5.80 | 7.20 | 6.70 | 9.80 | 11.30 | 11.50 |
| Mar-16 | 5.71 | 9.27 | 5.00 | 6.30 | 6.26 | 8.13 | 8.47 | 7.34 |
| Apr-16 | 4.62 | 6.51 | 5.29 | 5.26 | 4.63 | 6.25 | 5.93 | 6.15 |
| May-16 | 3.49 | 6.60 | 4.47 | 4.28 | 4.02 | 9.53 | 9.49 | 5.83 |
| Jun-16 | 3.06 | 6.63 | 4.28 | 3.94 | 3.13 | 4.96 | 6.04 | 3.79 |
| Oct-16 | 3.43 | 7.41 | 6.32 | 7.04 | 8.75 | 6.34 | 5.31 | 9.27 |
| Nov-16 | 4.56 | 7.85 | 4.86 | 5.98 | 5.41 | 9.23 | 8.13 | 8.0 |
| Dec-16 | 6.09 | 6.85 | 5.38 | 5.73 | 5.23 | 8.78 | 8.5 | 8.65 |
| Jan-17 | 6.41 | 8.87 | 5.83 | 7.0 | 6.18 | 9.84 | 10.6 | 9.31 |
| Mar-17 | 7.3 | 11.45 | 6.95 | 6.4 | 7.38 | 10.56 | 9.75 | 8.28 |

### Stormflow

| DO (mg/L) | WO-1S | WO-2S | WO-3S | WO-4S | WO-5S | WO-6S | WO-7S | WO-8s |
|---|---|---|---|---|---|---|---|---|
| Oct-15 | 6.05 | 6.85 | 7.04 | 5.98 | 5.37 | 7.45 | 7.27 | 7.15 |
| Dec-15 | 4.87 | 5.48 | 4.63 | 5.73 | 5.27 | 5.04 | 5.45 | 5.65 |
| Feb-16 | 6.35 | 7.03 | 6.30 | 5.11 | 5.98 | 7.19 | 7.19 | 7.37 |
| Sep-16 | 5.49 | 5.38 | 4.42 | 4.39 | 3.97 | 5.75 | 4.15 | 2.59 |
| Jan-17 | 6.75 | 6.55 | 5.3 | 6.21 | 4.53 | 7.22 | 8.06 | 9.52 |
| Feb-17 | 7.38 | 9.16 | 8.36 | 7.22 | 7.15 | 8.21 | 8.43 | 9.04 |

## Baseflow

| **Temp (°C)** | WO-1 | WO-2 | WO-3 | WO-4 | WO-5 | WO-6 | WO-7 | WO-8 |
|---|---|---|---|---|---|---|---|---|
| May-15 | 20.7 | 20.1 | 20.5 | 22.5 | 22.3 | 30.4 | 30.2 | 31.1 |
| Jun-15 | 25.7 | 25.1 | 25.2 | 26.5 | 25.2 | 33.3 | 35.3 | 36.3 |
| Jul-15 | 24.7 | 23.9 | 23.3 | 25.3 | 22.6 | 28.8 | 27.4 | 28.2 |
| Aug-15 | 23.2 | 23.6 | 23.2 | 24.4 | 22.3 | 26.3 | 27.2 | 29.6 |
| Sep-15 | 22.2 | 22.1 | 22.4 | 22.9 | 23.8 | 26.2 | 25.8 | 25.2 |
| Oct-15 | 17.4 | 17.9 | 18.9 | 18.9 | 19.0 | 20.1 | 20.4 | 20.6 |
| Nov-15 | 18.8 | 18.5 | 19.0 | 19.2 | 20.2 | 19.0 | 18.7 | 18.5 |
| Dec-15 | 18.2 | 18.7 | 19.2 | 19.9 | 18.7 | 18.8 | 18.7 | 18.4 |
| Jan-16 | 6.7 | 8.0 | 10.0 | 9.0 | 9.8 | 8.7 | 7.0 | 2.2 |
| Mar-16 | 17.7 | 20.3 | 18.5 | 19.3 | 20.5 | 21.2 | 21.4 | 21.2 |
| Apr-16 | 20.3 | 20.0 | 23.1 | 23.5 | 21.3 | 26.9 | 27.0 | 25.6 |
| May-16 | 22.8 | 21.3 | 22.0 | 24.7 | 25.6 | 28.6 | 30.5 | 30.2 |
| Jun-16 | 24.2 | 24.0 | 24.4 | 25.8 | 25.3 | 30.1 | 31.3 | 31.1 |
| Oct-16 | 20.2 | 20.1 | 20.7 | 20.8 | 21.4 | 22.8 | 22.8 | 23.0 |
| Nov-16 | 11.71 | 12.59 | 15.21 | 14.06 | 15.45 | 12.4 | 12.33 | 13.5 |
| Dec-16 | 11.13 | 12.22 | 14.11 | 13.36 | 14.63 | 11.25 | 11.58 | 11.4 |
| Jan-17 | 13.7 | 16.5 | 16.7 | 15.3 | 16.2 | 15.1 | 16.4 | 17.7 |
| Mar-17 | 15.7 | 15.9 | 16.3 | 17.0 | 16.7 | 16.9 | 17.8 | 20.3 |

## Stormflow

| **Temp (°C)** | WO-1S | WO-2S | WO-3S | WO-4S | WO-5S | WO-6S | WO-7S | WO-8S |
|---|---|---|---|---|---|---|---|---|
| Oct-15 | 28.67 | 21.17 | 21.33 | 21.5 | 20.7 | 20.7 | 20.88 | 21.9 |
| Dec-15 | 17.6 | 18.1 | 18.6 | 18.2 | 18.5 | 18.5 | 18.3 | 18.4 |
| Feb-16 | 15.6 | 16.9 | 17.5 | 18.1 | 18.3 | 17.5 | 17.2 | 18.5 |
| Sep-16 | 24.4 | 24.3 | 24.6 | 25.1 | 23.7 | 27.1 | 27.4 | 26.5 |
| Jan-17 | 14.7 | 15.4 | 17.3 | 16.9 | 18.3 | 17.9 | 18.0 | 15.6 |
| Feb-17 | 12.3 | 12.4 | 13.0 | 13.7 | 13.1 | 12.3 | 11.9 | 13.1 |

### Baseflow

| SC (µS/cm) | WO-1 | WO-2 | WO-3 | WO-4 | WO-5 | WO-6 | WO-7 | WO-8 |
|---|---|---|---|---|---|---|---|---|
| May-15 | 237 | 355 | 400 | 407 | 353 | 1409 | 8770 | 31380 |
| Jun-15 | 260 | 347 | 388 | 395 | 235 | 1305 | 5855 | 24568 |
| Jul-15 | 156 | 285 | 357 | 309 | 317 | 35716 | 16046 | 45186 |
| Aug-15 | 293 | 206 | 285 | 363 | 419 | 6956 | 19654 | 32266 |
| Sep-15 | 268 | 359 | 384 | 391 | 488 | 43259 | 47603 | 48555 |
| Oct-15 | 264 | 311 | 332 | 397 | 317 | 38672 | 40482 | 41530 |
| Nov-15 | 211 | 284 | 300 | 388 | 211 | 284 | 300 | 388 |
| Dec-15 | 717 | 282 | 286 | 19 | 287 | 36560 | 36320 | 16730 |
| Jan-16 | 223 | 283 | 301 | 393 | 318 | 1189 | 1570 | 3633 |
| Mar-16 | 616 | 304 | 344 | 406 | 318 | 1822 | 3751 | 17280 |
| Apr-16 | 704 | 341 | 385 | 441 | 325 | 16240 | 19770 | 30930 |
| May-16 | 537 | 332 | 370 | 579 | 343 | 2745 | 9975 | 30990 |
| Jun-16 | 995 | 446 | 453 | 950 | 430 | 10540 | 21816 | 45986 |
| Oct-16 | 1249 | 372 | 378 | 472 | 433 | 4153 | 27286 | 31712 |
| Nov-16 | 1439 | 384 | 408 | 454 | 356 | 18100 | 27200 | 45400 |
| Dec-16 | 1352 | 319 | 327 | 407 | 362 | 40120 | 42530 | 42850 |
| Jan-17 | 11490 | 325 | 368 | 440 | 317 | 6064 | 9179 | 26520 |
| Mar-17 | 729 | 344 | 382 | 447 | 340 | 2012 | 2034 | 27900 |

### Stormflow

| SC (µS/cm) | WO-1S | WO-2S | WO-3S | WO-4S | WO-5S | WO-6S | WO-7S | WO-8S |
|---|---|---|---|---|---|---|---|---|
| Oct-15 | 379 | 276 | 270 | 300 | 295 | 25180 | 31270 | 35370 |
| Dec-15 | 345 | 252 | 270 | 326 | 280 | 2685 | 5267 | 10260 |
| Feb-16 | 589 | 245 | 262 | 398 | 260 | 34950 | 37720 | 22880 |
| Sep-16 | 574 | 283 | 268 | 365 | 294 | 7184 | 1700 | 25070 |
| Jan-17 | 663 | 294 | 301 | 401 | 330 | 1270 | 5545 | 25870 |
| Feb-17 | 1227 | 245 | 249 | 398 | 217 | 14450 | 20700 | 41470 |

## Baseflow

| ORP (mV) | WO-1 | WO-2 | WO-3 | WO-4 | WO-5 | WO-6 | WO-7 | WO-8 |
|---|---|---|---|---|---|---|---|---|
| May-15 | 52 | 11.5 | -11 | -2.5 | 8.1 | -32 | -10 | 13.1 |
| Jun-15 | 23.7 | 43.4 | 36.0 | 13.0 | -3.0 | 6.7 | -2.5 | -14.9 |
| Jul-15 | 144 | 146 | 135 | -8 | -31 | 4 | 18 | -11 |
| Aug-15 | -25.9 | -73.0 | -30.9 | -48.0 | -25.0 | -16.2 | 51.0 | -4.6 |
| Sep-15 | -36 | -25 | -27 | -26 | -26 | -13 | -23 | -21 |
| Oct-15 | -123 | -34 | -25 | -23 | -55 | -13 | -16 | -8 |
| Nov-15 | -29 | -3 | -13 | -12 | -60 | -32 | 24 | 32 |
| Dec-15 | 39.4 | 30.7 | 36.2 | -28.7 | -42.0 | 28.5 | 33.4 | 119.6 |
| Jan-16 | 93 | 61 | 28 | -6 | 7 | -72 | -85 | 118 |
| Mar-16 | 56.4 | 13.2 | 30.2 | -28.5 | -25.8 | 21.8 | 23.7 | 27.8 |
| Apr-16 | 4.3 | 26.0 | 8.1 | -20.5 | -22.0 | 24.2 | 29.6 | 59.0 |
| May-16 | 30.5 | 13.9 | -7.5 | -51.2 | -21.5 | 6.2 | -21.4 | 28.3 |
| Jun-16 | YSI Meter with ORP not available | | | | | | | |
| Oct-16 | YSI Meter with ORP not available | | | | | | | |
| Nov-16 | 13.4 | 22.9 | 22.2 | -27.4 | -28 | 12.3 | 25.2 | 124.9 |
| Dec-16 | 59.4 | 42.4 | 22.3 | -2.6 | -41.2 | 20.7 | 21.9 | 158.9 |
| Jan-17 | -30.5 | -30.1 | -15.9 | -29.5 | -53.9 | -6.5 | 4.3 | 20.9 |
| Mar-17 | 4.1 | 36.8 | 33.4 | 10.1 | -8.1 | -1.5 | 10.9 | 72.1 |

## Stormflow

| ORP (mV) | WO-1S | WO-2S | WO-3S | WO-4S | WO-5S | WO-6S | WO-7S | WO-8S |
|---|---|---|---|---|---|---|---|---|
| Oct-15 | -23 | 25 | 24 | 12 | -36 | 24 | 5 | 44 |
| Dec-15 | -14 | -9 | 4 | -19 | -32 | 16 | 38 | 48 |
| Feb-16 | 78 | 50 | 54 | 9 | 6 | 38 | 50 | 122 |
| Sep-16 | 13.1 | -4.7 | -10.9 | -36.7 | -50.1 | 5.8 | 11.9 | 79.1 |
| Jan-17 | 13.8 | 1.7 | 0.5 | -10 | -42.1 | -4.4 | 15.1 | 22.2 |
| Feb-17 | -21.9 | 4.3 | 9.1 | -7.3 | -23.5 | 19 | 27.5 | 44.9 |

### Baseflow

| Turbidity (NTU) | WO-1 | WO-2 | WO-3 | WO-4 | WO-5 | WO-6 | WO-7 | WO-8 |
|---|---|---|---|---|---|---|---|---|
| May-15 | 7.42 | 5.03 | 1.84 | 14.10 | 2.17 | 31.10 | 40.80 | 32.70 |
| Jun-15 | 15.3 | 1.8 | 4.2 | 16.2 | 1.7 | 21.9 | 54.0 | 93.8 |
| Jul-15 | 2.3 | 1.3 | 5.0 | 6.0 | 5.0 | 14.0 | 19.0 | 12.0 |
| Aug-15 | 0.94 | 1.50 | 3.94 | 6.14 | 1.51 | 11.30 | 11.40 | 16.20 |
| Sep-15 | 6.26 | 1.00 | 1.83 | 5.76 | 1.78 | 17.60 | 19.10 | 10.20 |
| Oct-15 | 3.4 | 1.8 | 2.3 | 4.2 | 2.2 | 4.3 | 6.8 | 10.7 |
| Nov-15 | 16.0 | 2.3 | 4.0 | 3.2 | 15.7 | 6.2 | 5.4 | 6.6 |
| Dec-15 | 2.65 | 1.85 | 9.14 | 5.27 | 4.21 | 8.08 | 13.80 | 3.97 |
| Jan-16 | 7.0 | 1.7 | 2.7 | 3.2 | 1.9 | 7.0 | 3.5 | 10.0 |
| Mar-16 | 7.0 | 2.0 | 7.0 | 5.0 | 5.0 | 9.0 | 10.0 | 12.0 |
| Apr-16 | 3.5 | 3.9 | 3.5 | 6.6 | 4.4 | 8.0 | 6.6 | 11.5 |
| May-16 | 4 | 4 | 7 | 6 | 9 | 26 | 13 | 13 |
| Jun-16 | 11.00 | 1.71 | 3.25 | 5.66 | 4.19 | 18.40 | 19.10 | 15.30 |
| Oct-16 | 8.12 | 1.49 | 1.94 | 4.91 | 9.73 | 7.61 | 6.25 | 9.04 |
| Nov-16 | 5.53 | 1.08 | 3.34 | 3.52 | 1.41 | 2.67 | 2.71 | 4.19 |
| Dec-16 | 1.97 | 2.06 | 2.33 | 2.75 | 9.06 | 5.54 | 1.97 | 2.67 |
| Jan-17 | 21 | 2 | 2 | 2.68 | 3.48 | 16.7 | 7.68 | 21 |
| Mar-17 | 3.05 | 1.52 | 2.85 | 2.76 | 2.26 | 7.51 | 8 | 29.5 |

### Stormflow

| Turbidity (NTU) | WO-1S | WO-2S | WO-3S | WO-4S | WO-5S | WO-6S | WO-7S | WO-8S |
|---|---|---|---|---|---|---|---|---|
| Oct-15 | 3.1 | 2.2 | 2.99 | 4.8 | 30.2 | 6.7 | 6.7 | 30.2 |
| Dec-15 | 3.1 | 4.4 | 3.2 | 6.1 | 2.8 | 9.3 | 8.3 | 13.3 |
| Feb-16 | 4.1 | 8.3 | 4.0 | 7.2 | 6.3 | 3.9 | 4.2 | 5.3 |
| Sep-16 | 2.78 | 3.82 | 5.18 | 8.25 | 8.13 | 32.3 | 9.09 | 14.9 |
| Jan-17 | 3.4 | 2 | 14.9 | 4.5 | 3.3 | 9 | 6.2 | 6.55 |
| Feb-17 | 8.68 | 13.4 | 7.15 | 10.6 | 28.5 | 13.1 | 7.04 | 5.14 |

## APPENDIX B: PRECIPITATION, STREAM STAGE, AND STREAM DISCHARGE DATA

### Daily Precipitation (in)
### 2015 - 2016

| | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 0 | 0 | 0 | 0.41 | 0 | 0.02 | 0.37 | 0 | 0 | 0 | 0 | 0 |
| **2** | 0 | 0 | 0 | 3.16 | 0.39 | 0.15 | 0 | 0 | 0.16 | 0.93 | 0.03 | 0 |
| **3** | 0 | 1.61 | 0.03 | 0.02 | 1.04 | 0 | 0 | 0 | 0.27 | 0 | 0 | 0 |
| **4** | 0 | 0.33 | 0 | 1.48 | 0 | 0 | 0 | 4.82 | 0.55 | 0 | 1.96 | 0 |
| **5** | 0 | 0 | 0 | 1.61 | 0 | 0 | 0 | 0.62 | 0 | 0 | 0.03 | 2.56 |
| **6** | 0 | 0.05 | 0.2 | 0.03 | 0 | 0 | 0 | 0.01 | 0 | 0.53 | 0.55 | 0.64 |
| **7** | 0 | 0.89 | 0.04 | 0 | 1 | 1.21 | 0 | 1.69 | 0 | 0 | 0 | 0.44 |
| **8** | 0 | 0.19 | 0.03 | 0 | 0.05 | 0 | 0.02 | 0 | 0 | 0 | 0 | 0 |
| **9** | 0 | 0 | 0.02 | 0 | 1.51 | 0 | 0.05 | 0 | 0 | 0 | 0 | 0 |
| **10** | 0 | 0 | 0 | 0.59 | 0.27 | 0.02 | 0.02 | 0 | 0 | 0 | 0 | 0 |
| **11** | 0 | 0 | 0.04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **12** | 0 | 0 | 0 | 0.18 | 0 | 0 | 0 | 0.18 | 0 | 0 | 0 | 0.07 |
| **13** | 1.08 | 0 | 0.01 | 0 | 0 | 0 | 0 | 0 | 0 | 0.43 | 0.11 | 0.64 |
| **14** | 0 | 0 | 0.07 | 0 | 0 | 0.14 | 0 | 0 | 0.14 | 0 | 0.37 | 0 |
| **15** | 0 | 0 | 0 | 0 | 0 | 0.01 | 1.27 | 0.03 | 0 | 0 | 0 | 0.37 |
| **16** | 0.05 | 0 | 0 | 0 | 0 | 0.01 | 0 | 0.56 | 0 | 0 | 0 | 0 |
| **17** | 0 | 0 | 0 | 0 | 0 | 0.12 | 0.33 | 0 | 0 | 0 | 0 | 0 |
| **18** | 0 | 0 | 0.21 | 0 | 0 | 0.3 | 0 | 0 | 0 | 0 | 0 | 0.58 |
| **19** | 0 | 0.3 | 0 | 0 | 5.93 | 0 | 0 | 0 | 0 | 0 | 0.86 | 0 |
| **20** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.29 |
| **21** | 0.1 | 0.51 | 0 | 0 | 0 | 0 | 0 | 0 | 0.24 | 0 | 0 | 0.03 |
| **22** | 0.44 | 0 | 0.15 | 0 | 0.56 | 0.51 | 2.34 | 0.08 | 0 | 0.08 | 1.06 | 0 |
| **23** | 2.17 | 0 | 0.04 | 0 | 0 | 0.09 | 0.01 | 0.01 | 0 | 0.46 | 0 | 0 |
| **24** | 0 | 0 | 0.15 | 0 | 0 | 0.01 | 0 | 0.36 | 0 | 0.03 | 0 | 0 |
| **25** | 0 | 0 | 1.81 | 0 | 0 | 0 | 0 | 0.01 | 0 | 0 | 0 | 0 |
| **26** | 0 | 0.08 | 0.26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **27** | 0 | 0.18 | 0.66 | 0.8 | 0.01 | 0.01 | 0 | 0 | 0 | 0 | 0 | 0 |
| **28** | 0 | 0 | 0.66 | 0.36 | 0 | 0.19 | 0.15 | 0 | 1.33 | 0 | 0 | 0 |
| **29** | 0 | 0 | 0.1 | 0.01 | 0 | 0.07 | 0.14 | 0 | 0 | 0 | 0 | 0 |
| **30** | 0 | 0 | 0 | 0 | 0 | 0.14 | 0 | | 0 | 0 | 0 | 0.93 |
| **31** | 0.32 | 2.66 | | 0 | | 0.11 | 0 | | 0 | | 0.29 | |
| **Total** | 4.16 | 6.8 | 4.48 | 8.65 | 10.76 | 3.11 | 4.7 | 8.37 | 2.69 | 2.46 | 5.26 | 6.55 |
| **YTD** | **4.16** | **10.96** | **15.44** | **24.09** | **34.85** | **37.96** | **42.66** | **51.03** | **53.72** | **56.18** | **61.44** | **67.99** |

## Daily Precipitation (in)
## 2016 - 2017

| | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 0 | 1.26 | 0.03 | 1.03 | 0 | 0 | 0 | 0 | 0 | 0.98 | 0 | |
| **2** | 0 | 0.05 | 0.5 | 0.23 | 0 | 0 | 0 | 0 | 0.16 | 0 | 0.11 | |
| **3** | 0 | 1.44 | 4.79 | 0 | 0 | 0 | 1.14 | 0 | 0 | 0 | 0 | |
| **4** | 0 | 0.89 | 0 | 0 | 0 | 0 | 0.1 | 0.12 | 0 | 0.48 | 0.09 | |
| **5** | 0 | 0 | 0 | 0 | 0.29 | 2.56 | 0 | 0 | 0 | 0 | 1.12 | |
| **6** | 1.47 | 0 | 0 | 0 | 0 | 0.64 | 0 | 0 | 0 | 1.93 | 0 | |
| **7** | 0 | 0.15 | 0 | 0.23 | 0 | 0.44 | 0 | 0 | 0 | 0 | 0.12 | |
| **8** | 1.15 | 0 | 0 | 0 | 0 | 0 | 1.03 | 1.38 | 0 | 0 | 0 | |
| **9** | 0 | 0 | 0 | 2.13 | 0 | 0 | 0 | 0.23 | 0 | 0 | 0 | |
| **10** | 0.25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.18 | |
| **11** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.02 | 0 | 0 | |
| **12** | 0.05 | 0 | 0.35 | 0 | 0 | 0.07 | 0.02 | 0 | 0 | 0 | 0 | |
| **13** | 0.39 | 0 | 2.43 | 0 | 0 | 0.64 | 0 | 0 | 0.32 | 0 | 0.02 | |
| **14** | 0 | 0 | 0 | 0 | 0.86 | 0 | 0 | 0 | 1.55 | 0 | 0 | |
| **15** | 0 | 0 | 0 | 0 | 0 | 0.37 | 0 | 0 | 0 | 0 | 0 | |
| **16** | 0 | 0 | 0.23 | 0 | 0 | 0 | 0 | 0.79 | 0 | 0 | 0 | |
| **17** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| **18** | 0.31 | 0 | 0 | 0 | 0 | 0.58 | 0 | 0 | 0 | 0.05 | 0 | |
| **19** | 0 | 0.09 | 0.08 | 0 | 0 | 0 | 0.08 | 0 | 0.88 | 0 | 0 | |
| **20** | 1.3 | 2.89 | 0.83 | 0 | 0 | 0.29 | 0 | 0 | 0 | 0 | 0 | |
| **21** | 0.1 | 0.03 | 0.03 | 0 | 0 | 0.03 | 0 | 0 | 0 | 0 | 0 | |
| **22** | 0 | 0 | 0.23 | 0 | 0 | 0 | 0 | 0 | 0.12 | 0 | 0 | |
| **23** | 0 | 0 | 0.22 | 0 | 0 | 0 | 0.65 | 0 | 0 | 0.03 | 0.17 | |
| **24** | 0 | 0 | 0 | 0 | 0 | 0 | 0.25 | 0 | 0 | 0.31 | 0.91 | |
| **25** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.07 | 0.12 | |
| **26** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.02 | |
| **27** | 0 | 0 | 0.23 | 0 | 0 | 0 | 0.05 | 0 | 0 | 0 | 0.05 | |
| **28** | 0.09 | 0.03 | 0 | 0 | 0.16 | 0 | 0 | 0.18 | 0 | 0 | 0 | |
| **29** | 0 | 0.05 | 0 | 0 | 0 | 0 | 0 | | 0.38 | 0 | 0 | |
| **30** | 0 | 0 | 0.04 | 0 | 0 | 0.93 | 0 | | 0 | 0 | 0.95 | |
| **31** | 0.03 | 0.09 | | 0 | | 0 | 0 | | 0 | | 1.48 | |
| **Total** | 5.14 | 6.97 | 9.99 | 3.62 | 1.31 | 6.55 | 3.32 | 2.7 | 3.43 | 6.85 | 5.34 | |
| **YTD** | **5.14** | **12.11** | **22.1** | **25.72** | **27.03** | **33.58** | **36.9** | **39.6** | **43.03** | **49.88** | **55.22** | |

## Baseflow

| Stream Stage (cm) | WO-1 | WO-2 | WO-3 |
|---|---|---|---|
| Jul-15 | 3.8 | 25 | 6 |
| Aug-15 | 6 | 30 | 8 |
| Sep-15 | 5.5 | 29 | 8.5 |
| Oct-15 | 6 | 34 | 8.5 |
| Nov-15 | 8 | 35 | 10 |
| Dec-15 | 8 | 36 | 10 |
| Jan-16 | 7 | 33 | 10 |
| Apr-16 | 2 | 31 | 8 |
| May-16 | 2 | 30 | 8 |
| Jun-16 | 3 | 29 | 7 |
| Oct-16 | 9 | 30 | 10 |
| Nov-16 | 8 | 36 | 11 |
| Dec-16 | 10 | 36 | 10 |
| Jan-17 | 8 | 35 | 10 |
| Mar-17 | 7.5 | 36 | 12 |

## Stormflow

| Stream Stage (cm) | WO-1S | WO-2S | WO-3S |
|---|---|---|---|
| Oct-15 | 9 | 35 | 10 |
| Dec-15 | 9.5 | 40 | 10 |
| Feb-16 | 8.5 | 40 | 12 |
| Sep-16 | 6 | 34 | 10 |
| Jan-17 | 9 | 37 | 9.5 |
| Feb-17 | 12 | 50 | 16 |
| Apr-17 | 15 | 59 | 18 |

**Baseflow**

| Avg. Stream Depth (ft) | WO-1 | WO-2 | WO-3 | WO-4 | WO-5 | WO-6 | WO-7 | WO-8 |
|---|---|---|---|---|---|---|---|---|
| May-15 | 0.041 | 0.189 | 0.208 |  | 0.1 | 0.288 |  |  |
| Jun-15 | 0.013 | 0.123 | 0.143 | 0.18 | 0.142 | 0.48 |  |  |
| Jul-15 | 0.05 | 0.19 | 0.18 |  | 0.15 | 0.924 |  |  |
| Aug-15 | 0.19 | 0.18 | 0.25 | 0.15 | 0.19 | 0.77 |  |  |
| Sep-15 | 0.033 | 0.169 | 0.2 | 0.11 | 0.18 |  |  |  |
| Oct-15 | 0.14 | 0.28 | 0.25 | 0.15 | 0.19 |  |  |  |
| Nov-15 | 0.14 | 0.47 | 0.35 | 0.16 | 0.15 |  |  |  |
| Dec-15 | 0.24 | 0.33 | 0.56 | 0.872 | 0.21 |  |  |  |
| Jan-16 | 0.2 | 0.23 | 0.45 | 0.59 | 0.24 |  |  |  |
| Apr-16 | 0.12 | 0.328 | 0.38 | 0.396 | 0.205 |  | 1.5 | 2.1 |
| May-16 | 0.12 | 0.256 | 0.286 | 0.34 | 0.253 |  |  |  |
| Jun-16 | 0.126 | 0.48 | 0.32 | 0.654 | 0.464 |  | 1.5 |  |
| Oct-16 | 0.21 | 0.34 | 0.2 | 0.26 | 0.23 |  |  |  |
| Nov-16 | 0.225 | 0.54 | 0.275 | 0.45 | 0.172 |  |  |  |
| Dec-16 | 0.25 | 0.54 | 0.27 | 0.41 | 0.21 |  |  | 2.50 |
| Jan-17 | 0.163 | 0.508 | 0.198 | 0.358 | 0.229 |  |  | 1.4 |
| Mar-17 | 0.36 | 0.545 | 0.29 | 0.217 | 0.225 |  | 0.7 | 0.7 |

**Stormflow**

| Avg. Stream Depth (ft) | WO-1S | WO-2S | WO-3S | WO-4S | WO-5S | WO-6S | WO-7S | WO-8S |
|---|---|---|---|---|---|---|---|---|
| Oct-15 | 0.18 | 0.52 | 0.24 | 0.18 | 0.18 |  |  |  |
| Dec-15 | 0.26 | 0.48 | 0.56 | 0.86 | 0.23 |  |  |  |
| Feb-16 | 0.263 | 0.57 | 0.463 | 0.592 | 0.23 |  |  |  |
| Sep-16 | 0.216 | 0.397 | 0.283 | 0.3 | 0.208 |  |  |  |
| Jan-17 | 0.2 | 0.55 | 0.242 | 0.421 | 0.255 |  | 0.9 | 0.9 |
| Feb-17 | 0.27 | 0.91 | 0.363 | 0.76 | 0.292 |  | 1.6 | 1.9 |

### Baseflow

| Stream Width (ft) | WO-1 | WO-2 | WO-3 | WO-4 | WO-5 | WO-6 | WO-7 | WO-8 |
|---|---|---|---|---|---|---|---|---|
| May-15 | 0.8 | 5 | 1.6 |  | 1.5 | 4.3 |  |  |
| Jun-15 | 0.6 | 3.33 | 2 | 2.5 | 1.5 | 6.7 |  |  |
| Jul-15 | 0.9 | 2.6 | 1.1 |  | 1.7 | 8.4 |  |  |
| Aug-15 | 4.3 | 2.1 | 2.5 | 2.1 | 1.75 | 8.5 |  |  |
| Sep-15 | 0.9 | 3.7 | 2.4 | 2.1 | 1.8 | 9+ |  |  |
| Oct-15 | 1.2 | 4 | 2.1 | 2 | 1.8 |  |  |  |
| Nov-15 | 4.33 | 5 | 3 | 3 | 2.16 |  |  |  |
| Dec-15 | 3.6 | 5.3 | 3.1 | 3.9 | 3.4 |  |  |  |
| Jan-16 | 3.3 | 5.7 | 3.7 | 4.1 | 3.1 |  |  |  |
| Apr-16 | 2.1 | 4.2 | 3.4 | 4.4 | 4.6 |  |  |  |
| May-16 | 1.6 | 4.7 | 3.3 | 4.3 | 2.5 |  |  |  |
| Jun-16 | 2 | 5.2 | 3.3 | 4.7 | 2.4 |  |  |  |
| Oct-16 | 4.5 | 5.3 | 3.6 | 4.4 | 3.5 |  |  |  |
| Nov-16 | 3.8 | 5.8 | 4.1 | 4.8 | 3.2 |  |  |  |
| Dec-16 | 4.4 | 5.5 | 3.9 | 5.1 | 3.5 |  |  |  |
| Jan-17 | 3.3 | 5.5 | 3.8 | 5 | 3.4 |  |  |  |
| Mar-17 | 3.4 | 5.5 | 4 | 4.7 | 3.4 |  |  |  |

### Stormflow

| Stream Width (ft) | WO-1S | WO-2S | WO-3S | WO-4S | WO-5S | WO-6S | WO-7S | WO-8S |
|---|---|---|---|---|---|---|---|---|
| Oct-15 | 4.1 | 5.3 | 3.2 | 3.1 | 2.3 |  |  |  |
| Dec-15 | 3.9 | 5.5 | 3.6 | 4.12 | 4 |  |  |  |
| Feb-16 | 3.7 | 6.35 | 3.6 | 4.1 | 3.6 |  |  |  |
| Sep-16 | 3.17 | 6 | 3.58 | 4.33 | 3 |  |  |  |
| Jan-17 | 4.1 | 5.5 | 3.9 | 4.9 | 3.5 |  |  |  |
| Feb-17 | 5.2 | 6.42 | 4.6 | 6 | 4.5 |  |  |  |

## Baseflow

| Avg. Velocity (ft/s) | WO-1 | WO-2 | WO-3 | WO-4 | WO-5 | WO-6 | WO-7 | WO-8 |
|---|---|---|---|---|---|---|---|---|
| May-15 | 0.18 | 0.15 | 0.1 |  | 0.6 | 0.3 |  |  |
| Jun-15 | 0.18 | 0.84 | 0.62 | 0.92 | 0.98 |  |  |  |
| Jul-15 | 0.73 | 0.97 | 0.51 |  | 0.95 |  |  |  |
| Aug-15 | 0.1 | 0.58 | 0.3 | 0.6 | 0.6 |  |  |  |
| Sep-15 | 0.37 | 0.69 | 0.35 | 0.55 | 1 |  |  |  |
| Oct-15 | 0.51 | 0.6 | 0.4 | 0.6 | 0.6 |  |  |  |
| Nov-15 | 0.01 | 0.45 | 0.46 | 0.86 | 0.79 |  |  |  |
| Dec-15 | 0.19 | 0.44 | 0.32 | 0.32 | 0.56 |  |  |  |
| Jan-16 | 0.27 | 0.56 | 0.33 | 0.33 | 0.48 |  |  |  |
| Apr-16 | 0.42 | 0.33 | 0.4 | 0.228 | 0.75 |  |  |  |
| May-16 | 0.43 | 0.33 | 0.44 | 0.25 | 0.392 |  |  |  |
| Jun-16 | 0.078 | 0.235 | 0.336 | 0.19 | 0.4 |  |  |  |
| Oct-16 | 0.14 | 0.26 | 0.25 | 0.33 | 0.625 |  |  |  |
| Nov-16 | 0.16 | 0.258 | 0.256 | 0.105 | 0.741 |  |  |  |
| Dec-16 | 0.180 | 0.247 | 0.301 | 0.260 | 0.444 |  |  |  |
| Jan-17 | 0.229 | 0.211 | 0.235 | 0.182 | 0.421 |  |  |  |
| Mar-17 | 0.381 | 0.225 | 0.197 | 0.443 | 0.571 |  |  |  |

## Stormflow

| Avg. Velocity (ft/s) | WO-1S | WO-2S | WO-3S | WO-4S | WO-5S | WO-6S | WO-7S | WO-8S |
|---|---|---|---|---|---|---|---|---|
| Oct-15 | 0.52 | 0.41 | 0.8 | 1.14 | 1.14 |  |  |  |
| Dec-15 | 0.334 | 0.418 | 0.29 | 0.51 | 0.73 |  |  |  |
| Feb-16 | 0.523 | 0.516 | 0.519 | 0.546 | 1 |  |  |  |
| Sep-16 | 0.476 | 0.333 | 0.465 | 0.454 | 0.702 |  |  |  |
| Jan-17 | 0.331 | 0.229 | 0.333 | 0.294 | 0.465 |  |  |  |
| Feb-17 | 0.396 | 0.546 | 0.471 | 0.580 | 0.702 |  |  |  |

## Baseflow

| Discharge (ft$^3$/s) | WO-1 | WO-2 | WO-3 | WO-4 | WO-5 | WO-6 | WO-7 | WO-8 |
|---|---|---|---|---|---|---|---|---|
| May-15 | 0.006 | 0.142 | 0.033 | 0.069 | 0.090 | 0.372 | | |
| Jun-15 | 0.001 | 0.344 | 0.177 | 0.420 | 0.209 | | | |
| Jul-15 | 0.033 | 0.479 | 0.101 | 0.240 | 0.242 | | | |
| Aug-15 | 0.082 | 0.219 | 0.188 | 0.189 | 0.200 | | | |
| Sep-15 | 0.011 | 0.431 | 0.168 | 0.127 | 0.324 | | | |
| Oct-15 | 0.251 | 0.672 | 0.210 | 0.180 | 0.205 | | | |
| Nov-15 | 0.006 | 1.269 | 0.483 | 0.413 | 0.256 | | | |
| Dec-15 | 0.164 | 0.770 | 0.556 | 1.088 | 0.400 | | | |
| Jan-16 | 0.178 | 0.734 | 0.549 | 0.798 | 0.357 | | | |
| Apr-16 | 0.106 | 0.455 | 0.517 | 0.397 | 0.707 | | | |
| May-16 | 0.083 | 0.397 | 0.415 | 0.366 | 0.248 | | | |
| Jun-16 | 0.020 | 0.587 | 0.355 | 0.584 | 0.445 | | | |
| Oct-16 | 0.132 | 0.469 | 0.180 | 0.378 | 0.503 | | | |
| Nov-16 | 0.137 | 0.808 | 0.289 | 0.227 | 0.407 | | | |
| Dec-16 | 0.198 | 0.738 | 0.313 | 0.544 | 0.331 | | | |
| Jan-17 | 0.123 | 0.589 | 0.177 | 0.326 | 0.328 | | | |
| Mar-17 | 0.466 | 0.674 | 0.229 | 0.451 | 0.437 | | | |

## Stormflow

| Discharge (ft$^3$/s) | WO-1S | WO-2S | WO-3S | WO-4S | WO-5S | WO-6S | WO-7S | WO-8S |
|---|---|---|---|---|---|---|---|---|
| Oct-15 | 0.384 | 1.130 | 0.614 | 0.636 | 0.472 | | | |
| Dec-15 | 0.339 | 1.104 | 0.585 | 1.807 | 0.672 | | | |
| Feb-16 | 0.509 | 1.868 | 0.865 | 1.325 | 0.828 | | | |
| Sep-16 | 0.326 | 0.793 | 0.471 | 0.590 | 0.438 | | | |
| Jan-17 | 0.271 | 0.691 | 0.314 | 0.606 | 0.415 | | | |
| Feb-17 | 0.556 | 3.188 | 0.785 | 2.643 | 0.921 | | | |

## Appendix C:  Nutrient Concentration Data Tables

### Baseflow

| **$NH_4$ (mg/L)** | WO-1 | WO-2 | WO-3 | WO-4 | WO-5 | WO-6 | WO-7 | WO-8 |
|---|---|---|---|---|---|---|---|---|
| Jul-15 | 0.032 | 0.032 | 0.049 | 0.056 | 0.029 | 0.016 | 0.012 | 0.152 |
| Sep-15 | 0.043 | 0.041 | 0.040 | 0.046 | 0.027 | 0.148 | 0.346 | 0.316 |
| Oct-15 | 0.010 | 0.020 | 0.010 | 0.100 | 0.010 | 0.020 | 0.020 | 0.110 |
| Dec-15 | 0.003 | 0.003 | 0.040 | 0.060 | 0.000 | 0.003 | 0.010 | 0.030 |
| Mar-16 | 0.040 | 0.020 | 0.030 | 0.100 | 0.060 | 0.050 | 0.020 | 0.020 |
| May-16 | 0.031 | 0.037 | 0.035 | 0.046 | 0.021 | 0.011 | 0.009 | 0.029 |
| Nov-16 | 0.38 | 0.38 | 0.67 | 0.17 | 0.15 | 0.12 | 0.12 | 0.09 |
| Mar-17 | 0.15 | 0.16 | 0.27 | 0.48 | 0.86 | 0.26 | 0.30 | 0.82 |

### Stormflow

| **$NH_4$ (mg/L)** | WO-1S | WO-2S | WO-3S | WO-4S | WO-5S | WO-6S | WO-7S | WO-8S | WO-RG | WO-CD | WO-DD | WO-CS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dec-15 | 0.003 | 0.003 | 0.003 | 0.030 | 0.003 | 0.040 | 0.040 | 0.040 |  |  |  |  |
| Sep-16 | 0.18 | 0.17 | 0.17 | 0.15 | 0.18 | 0.11 | 0.23 | 0.52 | 0.43 |  |  |  |
| Dec-16 | 0.23 | 0.17 | 0.23 | 0.42 | 0.60 | 1.05 | 0.65 | 0.52 |  | 0.22 | 0.22 |  |
| Jan-17 | 0.97 | 0.44 | 0.23 | 0.11 | 0.11 | 0.13 | 0.20 | 0.77 |  | 0.17 |  |  |
| Feb-17 | 0.33 | 0.21 | 0.17 | 0.15 | 0.14 | 0.19 | 0.20 | 0.60 | 0.65 | 1.02 |  |  |
| Apr-17 | 0.14 | 0.11 | 0.16 | 0.64 | 1.36 | 0.65 | 0.52 | 0.41 | 0.22 | 0.19 |  | 0.05 |

### Baseflow

| $NO_3$+$NO_2$ (mg/L) | WO-1 | WO-2 | WO-3 | WO-4 | WO-5 | WO-6 | WO-7 | WO-8 |
|---|---|---|---|---|---|---|---|---|
| Jul-15 | 0.020 | 0.033 | 0.043 | 0.046 | 0.251 | 0.080 | 0.020 | 0.020 |
| Sep-15 | 0.009 | 0.007 | 0.012 | 0.043 | 0.282 | 0.006 | 0.009 | 0.009 |
| Oct-15 | 0.020 | 0.040 | 0.040 | 0.100 | 0.220 | 0.070 | 0.030 | 0.050 |
| Dec-15 | 0.010 | 0.020 | 0.030 | 0.160 | 0.190 | 0.020 | 0.050 | 0.030 |
| Mar-16 | 0.040 | 0.000 | 0.050 | 0.150 | 0.190 | 0.140 | 0.010 | 0.030 |
| May-16 | 0.001 | 0.019 | 0.009 | 0.151 | 0.269 | 0.001 | 0.001 | 0.001 |
| Nov-16 | 0.001 | 0.001 | 0.04 | 0.04 | 0.18 | 0.05 | 0.001 | 0.001 |
| Mar-17 | 0.006 | 0.012 | 0.074 | 0.182 | 0.161 | 0.208 | 0.132 | 0.119 |

### Stormflow

| $NO_3$+$NO_2$ (mg/L) | WO-1S | WO-2S | WO-3S | WO-4S | WO-5S | WO-6S | WO-7S | WO-8S | WO-RG | WO-CD | WO-DD | WO-CS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dec-15 | 0.010 | 0.010 | 0.030 | 0.190 | 0.160 | 0.150 | 0.070 | 0.070 | | | | |
| Sep-16 | 0.001 | 0.01 | 0.01 | 0.06 | 0.21 | 0.07 | 0.02 | 0.01 | 0.001 | | | |
| Dec-16 | 0.014 | 0.027 | <MDL | 0.058 | 0.185 | 0.280 | 0.017 | 0.042 | | <MDL | 0.03 | |
| Jan-17 | 0.02 | 0.04 | 0.10 | 0.10 | 0.38 | 0.27 | 0.12 | 0.03 | | 0.32 | | |
| Feb-17 | 0.041 | 0.054 | 0.096 | 0.228 | 0.281 | 0.148 | 0.028 | 0.020 | 0.033 | 0.016 | | |
| Apr-17 | 0.006 | 0.009 | 0.062 | 0.112 | 0.131 | 0.039 | 0.018 | 0.122 | 0.113 | 0.038 | | 0.086 |

## Baseflow

| **$PO_4$ (mg/L)** | WO-1 | WO-2 | WO-3 | WO-4 | WO-5 | WO-6 | WO-7 | WO-8 |
|---|---|---|---|---|---|---|---|---|
| Jul-15 | 0.029 | 0.035 | 0.037 | 0.028 | 0.029 | <0.001 | 0.046 | 0.037 |
| Sep-15 | 0.003 | 0.004 | 0.010 | 0.003 | <0.001 | 0.017 | <0.001 | 0.015 |
| Oct-15 | 0.016 | <0.004 | 0.021 | 0.014 | <0.004 | 0.023 | <0.004 | 0.044 |
| Dec-15 | 0.011 | 0.016 | 0.021 | <0.004 | 0.022 | 0.049 | 0.026 | 0.025 |
| Mar-16 | 0.017 | 0.009 | 0.026 | 0.007 | 0.019 | 0.034 | 0.028 | 0.011 |
| May-16 | 0.004 | 0.009 | 0.004 | 0.001 | 0.004 | 0.008 | 0.013 | 0.018 |
| Nov-16 | 0.001 | 0.002 | 0.014 | 0.001 | 0.004 | 0.001 | 0.001 | 0.001 |
| Mar-17 | <MDL | <MDL | <MDL | <MDL | 0.012 | 0.005 | 0.004 | 0.030 |

## Stormflow

| **$PO_4$ (mg/L)** | WO-1S | WO-2S | WO-3S | WO-4S | WO-5S | WO-6S | WO-7S | WO-8S | WO-RG | WO-CD | WO-DD | WO-CS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dec-15 | <0.004 | <0.004 | 0.021 | 0.014 | 0.016 | 0.026 | 0.032 | 0.025 |  |  |  |  |
| Sep-16 | 0.001 | 0.001 | 0.001 | 0.001 | 0.003 | 0.019 | 0.023 | 0.023 | 0.092 |  |  |  |
| Dec-16 | <MDL | 0.009 | 0.034 | 0.011 | <MDL | 0.017 | 0.020 | 0.039 |  | 0.008 | 0.007 |  |
| Jan-17 | 0.079 | 0.006 | 0.006 | <MDL | <MDL | 0.017 | 0.022 | 0.005 |  | <MDL |  |  |
| Feb-17 | <MDL | 0.007 | 0.008 | <MDL | 0.021 | <MDL | <MDL | <MDL | <MDL | <MDL |  |  |
| Apr-17 | <MDL | <MDL | <MDL | <MDL | <MDL | 0.036 | <MDL | 0.006 | <MDL | <MDL |  | 0.064 |

## Baseflow

| **Cl (mg/L)** | WO-1 | WO-2 | WO-3 | WO-4 | WO-5 | WO-6 | WO-7 | WO-8 |
|---|---|---|---|---|---|---|---|---|
| Jul-15 | 28 | 26 | 34 | 16 | 20 | 1944 | 5985 | 12810 |
| Sep-15 | 67 | 26 | 47 | 17 | 18 | 8728 | 8690 | 7465 |
| Oct-15 | 129 | 21 | 29 | 13 | 16 | 15 | out of range | out of range |
| Dec-15 | 24 | 21 | 28 | 19 | 25 | out of range | out of range | out of range |
| Mar-16 | 18 | 22 | 17 | 26 | 17 | 310 | 1144 | 5670 |
| May-16 | 24 | 28 | 53 | 32 | 22 | 744 | >744.234 | >744.234 |
| Nov-16 | 38 | 47 | 45 | 27 | 26 | 3826 | 5777 | 5622 |
| Mar-17 | 25 | 28 | 38 | 29 | 18 | 8323 | 1731 | 8398 |

## Stormflow

| **Cl (mg/L)** | WO-1S | WO-2S | WO-3S | WO-4S | WO-5S | WO-6S | WO-7S | WO-8S | WO-RG | WO-CD | WO-DD | WO-CS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dec-15 | 23 | 19 | 24 | 16 | 17 | 862 | 1878 | out of range | | | | |
| Sep-16 | 58 | 85 | 28 | 29 | 77 | 1882 | 3241 | 1958 | 22 | | | |
| Dec-16 | 38 | 69 | 37 | 29 | 19 | 365 | 3659 | 526 | | 233 | 9 | |
| Jan-17 | 29 | 30 | 36 | 35 | 20 | 395 | 2292 | 365 | | 52 | | |
| Feb-17 | 27 | 38 | 23 | 24 | 16 | 9286 | 4755 | 4462 | 39 | 132 | | |
| Apr-17 | 18 | 13 | 17 | 18 | 9 | 18990 | 9257 | 4417 | 36 | 10 | | 201 |

### Baseflow

| DOC (mg/L) | WO-1 | WO-2 | WO-3 | WO-4 | WO-5 | WO-6 | WO-7 | WO-8 |
|---|---|---|---|---|---|---|---|---|
| Jul-15 | 15.5 | 7.2 | 6.2 | 7.3 | 3.4 | 8.5 | 9.2 | 5.4 |
| Sep-15 | 13.3 | 5.8 | 7.4 | 8.0 | 3.5 | 6.0 | 5.5 | 5.1 |
| Oct-15 | 8.3 | 6.3 | 5.9 | 4.5 | 3.1 | 4.5 | 4.7 | 5.2 |
| Dec-15 | 14.6 | 15.3 | 9.1 | 10.0 | 6.5 | 4.6 | 7.4 | 8.5 |
| Mar-16 | 15.0 | 17.5 | 12.8 | 21.1 | 14.2 | 21.4 | 27.8 | 30.6 |
| May-16 | 21.9 | 24.6 | 24.0 | 27.1 | 21.9 | 31.2 | 37.6 | 32.3 |
| Nov-16 | 23.4 | 28.6 | 23.9 | 27.8 | 20.7 | 27.5 | 28.4 | 23.4 |
| Mar-17 | 23.4 | 25.4 | 23.1 | 29.3 | 21.1 | 33.6 | 31.3 | 30.5 |

### Stormflow

| DOC (mg/L) | WO-1S | WO-2S | WO-3S | WO-4S | WO-5S | WO-6S | WO-7S | WO-8S | WO-RG | WO-CD | WO-DD | WO-CS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dec-15 | 7.4 | 9.6 | 11.1 | 7.3 | 5.6 | 8.5 | 10.2 | 10.1 |  |  |  |  |
| Sep-16 | 32.6 | 24.7 | 26.7 | 26.3 | 28.2 | 37.2 | 37.8 | 29.1 | 48.3 |  |  |  |
| Dec-16 | 24.7 | 27.5 | 25.1 | 22.3 | 20.2 | 27.3 | 26.8 | 28.0 |  | 20.9 | 8.9 |  |
| Jan-17 | 22.4 | 22.8 | 23.2 | 30.7 | 19.9 | 24.5 | 28.9 | 24.4 |  | 26.3 |  |  |
| Feb-17 | 23.1 | 19.7 | 23.7 | 27.8 | 21.0 | 28.3 | 23.7 | 26.3 | 10.3 | 18.8 |  |  |
| Apr-17 | 24.5 | 21.1 | 24.2 | 44.0 | 18.0 | 29.3 | 26.8 | 11.4 | 7.1 | 13.7 |  | 12.8 |

## Baseflow

| **TDN (mg/L)** | WO-1 | WO-2 | WO-3 | WO-4 | WO-5 | WO-6 | WO-7 | WO-8 |
|---|---|---|---|---|---|---|---|---|
| Jul-15 | 0.56 | 0.50 | 0.46 | 0.52 | 0.53 | 0.55 | 0.53 | 0.51 |
| Sep-15 | 0.81 | 0.72 | 0.74 | 0.77 | 0.82 | 0.78 | 0.77 | 0.76 |
| Oct-15 | 1.15 | 1.14 | 1.05 | 1.13 | 1.11 | 1.12 | 1.11 | 1.14 |
| Dec-15 | 0.83 | 0.82 | 0.77 | 0.79 | 0.86 | 0.79 | 0.74 | 0.79 |
| Mar-16 | 0.95 | 0.85 | 0.85 | 0.96 | 0.99 | 1.01 | 0.99 | 0.96 |
| May-16 | 0.96 | 0.91 | 0.85 | 0.95 | 0.95 | 0.93 | 0.98 | 1.01 |
| Nov-16 | 1.10 | 1.04 | 1.04 | 1.04 | 1.21 | 1.11 | 1.10 | 1.11 |
| Mar-17 | 1.51 | 1.42 | 1.42 | 1.50 | 1.42 | 1.56 | 1.54 | 1.53 |

## Stormflow

| **TDN (mg/L)** | WO-1S | WO-2S | WO-3S | WO-4S | WO-5S | WO-6S | WO-7S | WO-8S | WO-RG | WO-CD | WO-DD | WO-CS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dec-15 | 0.75 | 0.76 | 0.80 | 0.83 | 0.78 | 0.87 | 0.86 | 0.84 |  |  |  |  |
| Sep-16 | 1.21 | 1.14 | 1.18 | 1.12 | 1.28 | 1.20 | 1.22 | 1.19 | 1.72 |  |  |  |
| Dec-16 | 1.51 | 1.42 | 1.50 | 1.49 | 1.42 | 1.42 | 1.49 | 1.49 |  | 1.42 | 1.42 |  |
| Jan-17 | 1.51 | 1.42 | 1.50 | 1.42 | 1.42 | 1.48 | 1.50 | 1.42 |  | 1.51 |  |  |
| Feb-17 | 1.53 | 1.42 | 1.53 | 1.56 | 1.54 | 1.54 | 1.49 | 1.42 | 1.51 | 1.49 |  |  |
| Apr-17 | 1.61 | 1.53 | 1.55 | 1.53 | 1.53 | 1.52 | 1.42 | 1.50 | 1.42 | 1.42 |  | 1.6 |

### Baseflow

| **DON (mg/L)** | WO-1 | WO-2 | WO-3 | WO-4 | WO-5 | WO-6 | WO-7 | WO-8 |
|---|---|---|---|---|---|---|---|---|
| Jul-15 | 0.51 | 0.43 | 0.37 | 0.42 | 0.25 | 0.46 | 0.49 | 0.34 |
| Sep-15 | 0.75 | 0.68 | 0.69 | 0.68 | 0.51 | 0.63 | 0.41 | 0.44 |
| Oct-15 | 1.12 | 1.08 | 1.00 | 0.93 | 0.88 | 1.03 | 1.06 | 0.98 |
| Dec-15 | 0.82 | 0.80 | 0.70 | 0.57 | 0.67 | 0.77 | 0.68 | 0.73 |
| Mar-16 | 0.87 | 0.83 | 0.77 | 0.71 | 0.74 | 0.82 | 0.96 | 0.91 |
| May-16 | 0.93 | 0.85 | 0.81 | 0.75 | 0.66 | 0.92 | 0.97 | 0.98 |
| Nov-16 | 0.72 | 0.66 | 0.33 | 0.83 | 0.89 | 0.93 | 0.98 | 1.02 |
| Mar-17 | 1.36 | 1.25 | 1.07 | 0.84 | 0.39 | 1.09 | 1.11 | 0.59 |

### Stormflow

| **DON (mg/L)** | WO-1S | WO-2S | WO-3S | WO-4S | WO-5S | WO-6S | WO-7S | WO-8S | WO-RG | WO-CD | WO-DD | WO-CS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dec-15 | 0.74 | 0.75 | 0.77 | 0.61 | 0.62 | 0.68 | 0.75 | 0.73 | | | | |
| Sep-16 | 1.03 | 0.96 | 1.00 | 0.91 | 0.89 | 1.02 | 0.98 | 0.66 | 1.29 | | | |
| Dec-16 | 1.27 | 1.22 | 1.27 | 1.01 | 0.63 | 0.09 | 0.82 | 0.93 | | 1.20 | 1.2 | |
| Jan-17 | 0.52 | 0.94 | 1.17 | 1.21 | 0.93 | 1.08 | 1.17 | 0.61 | | 1.02 | | |
| Feb-17 | 1.15 | 1.15 | 1.26 | 1.19 | 1.11 | 1.20 | 1.26 | 0.80 | 0.83 | 0.46 | | |
| Apr-17 | 1.46 | 1.41 | 1.33 | 0.78 | 0.03 | 0.83 | 0.88 | 0.97 | 1.09 | 1.19 | | 1.5 |

### Baseflow

| **DIN (mg/L)** | WO-1 | WO-2 | WO-3 | WO-4 | WO-5 | WO-6 | WO-7 | WO-8 |
|---|---|---|---|---|---|---|---|---|
| Jul-15 | 0.05 | 0.07 | 0.09 | 0.10 | 0.28 | 0.10 | 0.03 | 0.17 |
| Sep-15 | 0.05 | 0.05 | 0.05 | 0.09 | 0.31 | 0.15 | 0.35 | 0.32 |
| Oct-15 | 0.03 | 0.06 | 0.05 | 0.20 | 0.23 | 0.09 | 0.05 | 0.16 |
| Dec-15 | 0.01 | 0.02 | 0.07 | 0.22 | 0.19 | 0.02 | 0.06 | 0.06 |
| Mar-16 | 0.08 | 0.02 | 0.08 | 0.25 | 0.25 | 0.19 | 0.03 | 0.05 |
| May-16 | 0.03 | 0.06 | 0.04 | 0.20 | 0.29 | 0.01 | 0.01 | 0.03 |
| Nov-16 | 0.38 | 0.39 | 0.72 | 0.21 | 0.32 | 0.17 | 0.12 | 0.09 |
| Mar-17 | 0.15 | 0.17 | 0.35 | 0.66 | 1.02 | 0.47 | 0.43 | 0.94 |

### Stormflow

| **DIN (mg/L)** | WO-1S | WO-2S | WO-3S | WO-4S | WO-5S | WO-6S | WO-7S | WO-8S | WO-RG | WO-CD | WO-DD | WO-CS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dec-15 | 0.01 | 0.01 | 0.03 | 0.22 | 0.16 | 0.19 | 0.11 | 0.11 | | | | |
| Sep-16 | 0.18 | 0.18 | 0.18 | 0.21 | 0.40 | 0.18 | 0.25 | 0.53 | 0.43 | | | |
| Dec-16 | 0.24 | 0.20 | 0.23 | 0.48 | 0.79 | 1.33 | 0.67 | 0.56 | | 0.22 | 0.25 | |
| Jan-17 | 1.00 | 0.48 | 0.33 | 0.21 | 0.49 | 0.40 | 0.32 | 0.80 | | 0.49 | | |
| Feb-17 | 0.37 | 0.27 | 0.26 | 0.37 | 0.42 | 0.34 | 0.23 | 0.62 | 0.68 | 1.03 | | |
| Apr-17 | 0.15 | 0.12 | 0.22 | 0.75 | 1.49 | 0.69 | 0.54 | 0.53 | 0.33 | 0.23 | | 0.13 |

# APPENDIX D: NITRATE ISOTOPIC DATA

| Site-Date | δ $^{15}$N vs. Air | δ $^{18}$O vs. SMOW |
|---|---:|---:|
| WO-1 Jul-15 | 5.91 | 15.78 |
| WO-2 Jul-15 | 3.77 | 2.72 |
| WO-3 Jul-15 | 7.74 | 2.29 |
| WO-4 Jul-15 | 6.85 | 3.26 |
| WO-5 Jul-15 | 14.84 | 8.34 |
| WO-6 Jul-15 | 13.16 | 8.38 |
| WO-7 Jul-15 | 11.58 | 22.97 |
| WO-8 Jul-15 | 2.2 | 39.54 |
| WO-4 Oct-15 | 8.35 | 14.7 |
| WO-5 Oct-15 | 15.47 | 10.84 |
| WO-6 Oct-15 | 6.42 | 7.5 |
| WO-4 Sep-16 | 4.74 | 12.26 |
| WO-5 Sep-16 | 14.29 | 9.7 |
| WO-6 Sep-16 | 10.21 | 4.59 |
| WO-4 Nov-16 | 5.42 | 13.34 |
| WO-5 Nov-16 | 17.25 | 10.46 |
| WO-6 Nov-16 | 11.09 | 18.69 |

# APPENDIX E: STORMWATER RUNOFF AND NUTRIENT LOAD CALCULATIONS

## Water Control Structures

### CS-1

$R_V = 0.05 + (0.9 * 0.27) = 0.293$

$V = 3630 * 3.66\ in * 0.293 * 2.91\ ac = 11{,}328\ ft^3$

$R_A = 3630 * 60\ in * 0.9 * 0.293 * 2.91\ ac = 167{,}133\ ft^3$

$L_{TDN} = (2.83 * 10^{-5}) * 167{,}133\ ft^3 * 1.60\ mg/L = 7.57\ kg\text{-}N/yr$

$L_{PO4\text{-}P} = (2.83 * 10^{-5}) * 167{,}133\ ft^3 * 0.064\ mg/L = 0.30\ kg\text{-}PO_4\text{-}P/yr$

### CS-2

$R_V = 0.05 + (0.9 * 0.23) = 0.257$

$V = 3630 * 3.66\ in * 0.257 * 1.46\ ac = 4{,}985\ ft^3$

$R_A = 3630 * 60\ in * 0.9 * 0.257 * 1.46\ ac = 73{,}551\ ft^3$

$L_{TDN} = (2.83 * 10^{-5}) * 73{,}551\ ft^3 * 1.60\ mg/L = 3.33\ kg\text{-}N/yr$

$L_{PO4\text{-}P} = (2.83 * 10^{-5}) * 73{,}551\ ft^3 * 0.064\ mg/L = 0.13\ kg\text{-}PO_4\text{-}P/yr$

**CS-3**

$R_V = 0.05 + (0.9 * 0.27) = 0.293$

$V = 3630 * 3.66\ in * 0.293 * 0.45\ ac = 1{,}752\ ft^3$

$R_A = 3630 * 60\ in * 0.9 * 0.293 * 0.45\ ac = 25{,}845\ ft^3$

$L_{TDN} = (2.83 * 10^{-5}) * 25{,}845\ ft^3 * 1.60\ mg/L = 1.17\ kg\text{-}N/yr$

$L_{PO4\text{-}P} = (2.83 * 10^{-5}) * 25{,}845\ ft^3 * 0.064\ mg/L = 0.05\ kg\text{-}PO_4\text{-}P/yr$

**CS-4**

$R_V = 0.05 + (0.9 * 0.19) = 0.221$

$V = 3630 * 3.66\ in * 0.221 * 0.30\ ac = 880\ ft^3$

$R_A = 3630 * 60\ in * 0.9 * 0.221 * 0.30\ ac = 12{,}996\ ft^3$

$L_{TDN} = (2.83 * 10^{-5}) * 12{,}996\ ft^3 * 1.60\ mg/L = 0.59\ kg\text{-}N/yr$

$L_{PO4\text{-}P} = (2.83 * 10^{-5}) * 12{,}996\ ft^3 * 0.064\ mg/L = 0.02\ kg\text{-}PO_4\text{-}P/yr$

## CS-5

$R_V = 0.05 + (0.9 * 0.37) = 0.383$

$V = 3630 * 3.66\ in * 0.383 * 0.31\ ac = 1{,}577\ ft^3$

$R_A = 3630 * 60\ in * 0.9 * 0.383 * 0.31\ ac = 23{,}273\ ft^3$

$L_{TDN} = (2.83 * 10^{-5}) * 23{,}273\ ft^3 * 1.60\ mg/L = 1.05\ kg\text{-}N/yr$

$L_{PO4\text{-}P} = (2.83 * 10^{-5}) * 23{,}273\ ft^3 * 0.064\ mg/L = 0.04\ kg\text{-}PO_4\text{-}P/yr$

## Enhanced and Stabilized Swales

$R_V = 0.05 + (0.9 * 1.0) = 0.95$

$V = 3630 * 3.66\ in * 0.95 * 0.13\ ac = 1{,}641\ ft^3$

$R_A = 3630 * 60\ in * 0.9 * 0.95 * 0.13\ ac = 24{,}208\ ft^3$

$L_{TDN} = (2.83 * 10^{-5}) * 24{,}208\ ft^3 * 1.50\ mg/L = 1.03\ kg\text{-}N/yr$

$L_{PO4\text{-}P} = (2.83 * 10^{-5}) * 24{,}208\ ft^3 * 0.036\ mg/L = 0.02\ kg\text{-}PO_4\text{-}P/yr$

**Rock Check Dams**

$R_V = 0.05 + (0.9 * 1.0) = 0.95$

$V = 3630 * 3.66 \text{ in} * 0.95 * 0.10 \text{ ac} = 1{,}262 \text{ ft}^3$

$R_A = 3630 * 60 \text{ in} * 0.9 * 0.95 * 0.10 \text{ ac} = 18{,}621 \text{ ft}^3$

$L_{TDN} = (2.83 * 10^{-5}) * 18{,}621 \text{ ft}^3 * 1.46 \text{ mg/L} = 0.77 \text{ kg-N/yr}$

$L_{PO4\text{-}P} = (2.83 * 10^{-5}) * 18{,}621 \text{ ft}^3 * 0.007 \text{ mg/L} * = 0.004 \text{ kg-}PO_4\text{-P/yr}$

**Walkway**

$R_V = 0.05 + (0.9 * 1.0) = 0.95$

$V = 3630 * 3.66 \text{ in} * 0.95 * 0.08 \text{ ac} = 1{,}010 \text{ ft}^3$

$R_A = 3630 * 60 \text{ in} * 0.9 * 0.95 * 0.08 \text{ ac} = 14{,}897 \text{ ft}^3$

$L_{TDN} = (2.83 * 10^{-5}) * 14{,}897 \text{ ft}^3 * 1.55 \text{ mg/L} = 0.65 \text{ kg-N/yr}$

$L_{PO4\text{-}P} = 0.103 * 51.3 \text{ in/yr} * 0.092 \text{ mg/L} * 0.08 \text{ ac} = 0.04 \text{ kg-}PO_4\text{-P/yr}$

**Rain Garden**

$R_V = 0.05 + (0.9 * 1.0) = 0.95$

$V = 3630 * 3.66 \text{ in} * 0.95 * 0.08 \text{ ac} = 1{,}010 \text{ ft}^3$

$R_A = 3630 * 60 \text{ in} * 0.9 * 0.95 * 0.08 \text{ ac} = 14{,}897 \text{ ft}^3$

$L_{TDN} = (2.83 * 10^{-5}) * 14{,}897 \text{ ft}^3 * 1.55 \text{ mg/L} = 0.65 \text{ kg-N/yr}$

$L_{PO4\text{-}P} = 0.103 * 51.3 \text{ in/yr} * 0.092 \text{ mg/L} * 0.08 \text{ ac} = 0.04 \text{ kg-}PO_4\text{-P/yr}$