RESEARCH & DEVELOPMENT

Stormwater Runoff Monitoring and Analysis for Aviation Mode Facilities

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NCDOT Project RP-2019-04

FHWA/NC/2019-04

September 2020

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Technical Report Documentation Page

1. Report No. FHWA/NC/2019-04	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Stormwater Runoff Monitoring and Analysis for Aviation Mode Facilities		5. Report Date October 1, 2020
		6. Performing Organization Code
7. Author(s) William F. Hunt; Daniel Line, Rebecca Rahn		8. Performing Organization Report No.
9. Performing Organization Name and Address North Carolina State University, Biological & Agricultural Engineering Dept.		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address North Carolina Department of Transportation Research and Development Unit 104 Fayetteville Street Raleigh, North Carolina 27601		13. Type of Report and Period Covered Final Report Final Report Contract Period: 8/1/18 to 9/30/20
Supplementary Notes:		

16. Abstract

Rainfall and runoff were monitored for about one year at five sites on two small airports located in the Piedmont region of NC. Land use in the drainage areas to the five sites were representative of the airside of small airports with three sites (INT-Run, INT-Taxi, and BUY-Taxi) on the runway/taxiway area and two sites (INT-Term and BUY-Apron) on the terminal apron area. Flow-proportional samples of runoff were collected during at least 20 storms and analyzed for total Kjeldahl nitrogen (TKN), nitrate+nitrite nitrogen (NOx-N), total phosphorus (TP) and total suspended solids (TSS). Rainfall-runoff relationships for three of the four sites were similar to those from conventional residential development while one taxiway site (BUY-Taxi) was similar to a residential low impact development (LID). Concentrations of TN, TP, and TSS in runoff from all five airport sites were less than those from urban runoff across the U.S. and less than those reported for several residential areas of NC, but they were greater than some of those reported for commercial areas. Mean concentrations of TP and TSS for all five sites and TN for 4 of the 5 sites were less than the corresponding concentrations at which stormwater control measures become less or not effective. Cumulative storm event load data documented that both terminal and one runway/taxiway sites had annual TN, TP, and TSS export was less than conventional residential sites of NC, but greater than two LID residential areas. One taxiway (BUY-Taxi) site had TN, TP, and TSS export less than or equal to that reported for a residential LID.

17. Key Words Runoff, airports, air side, water quality		18. Distribution Statement	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 55 Pages	22. Price

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

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ACKNOWLEDGEMENTS

The authors wish to thank the NC DOT steering committee for their direction and guidance, especially Rachel Bingham, John Kirby, and others at the NC DOT. We also very much appreciate the cooperation of the Burlington-Alamance and Smith-Reynolds airport personnel, especially Dan Danieley and Shoaib Quader, without whose help this project could not have been completed. We also thank Shawn Kennedy for his help in installing the monitoring stations.

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Executive Summary

Monitoring of runoff from one airport in Wilmington, NC and several in Florida have shown that, due to the configuration (downslope of impervious surfaces) and extent of grassed areas, runoff from airports located in coastal regions was similar to runoff from low impact development (LID) residential development. This project was conducted to determine if this was also the case for small airports located in the Piedmont region of NC. Rainfall and runoff were monitored for about one year at five sites on the Burlington-Alamance (BUY) and Smith-Reynolds (INT) airports located in the Piedmont region of NC. Land use in the drainage areas to the five sites were representative of the airside of airports with three sites (INT-Run, INT-Taxi, and BUY-Taxi) on the runway/taxiway area and two sites (INT-Term and BUY-Apron) on the terminal apron area.

Rainfall was monitored at each airport via a tipping bucket raingage and runoff from 4 of the 5 sites was monitored continuously via automated samplers. The fifth site was in the swale along a taxiway where above-ground objects were prohibited, so no runoff measurement was possible; hence, samples were collected based on rainfall. Flow-proportional samples were collected during storm event runoff from at least 20 storms throughout the year and analyzed for total Kjeldahl nitrogen (TKN), nitrate+nitrite nitrogen (NOx-N), total phosphorus (TP) and total suspended solids (TSS). In addition, the specific conductivity, turbidity, and temperature of runoff from a runway/taxiway site was monitored in-situ during 16 storm events. From the monitoring data the following conclusions were made:

- Rainfall-runoff relationships for three of the four sites were similar to those from conventional residential development while one taxiway site (BUY-Taxi) was similar to a residential LID development. Thus, runoff from some of the runway/taxiway areas of airports in the Piedmont is likely similar to LID while others likely are not.
- Levels of conductivity and turbidity in runoff from a runway/taxiway site were less than those considered to be a water quality concern.
- Concentrations of TN, TP, and TSS in runoff from all five airport sites were less than those from urban runoff across the U.S. and less than those reported for several residential areas of NC, but they were greater than some of those reported for commercial areas. Mean concentrations of TP and TSS for all five sites and TN for 4 of the 5 sites were less than the corresponding concentrations considered to be irreducible (concentrations at which stormwater BMPs become less or ineffective).
- Cumulative storm event load data documented that for three of the four airport sites TN, TP, and TSS export was less than conventional residential sites of NC, but greater than two LID residential areas. The fourth site had TN, TP, and TSS export less than or equal to that reported for a residential LID.
- Given that TN, TP, and TSS export from the runway/taxiway areas of both airports was less than those from monitored residential areas and one was similar to a residential LID and that runway/taxiways comprise >60% of the land area of small airports, it is reasonable to conclude that TN, TP, and TSS export from small rural airports is less of a water quality concern than that of residential developed areas.

1 Introduction

Small airports in North Carolina typically have relatively small runways, taxiways, and aprons surrounded by large grassed infield areas. Hence, it is reasonable to assume that the grassed areas effectively reduce pavement runoff and pollutant concentrations/loads from the paved area. Runoff monitoring conducted at the Wilmington International Airport (ILM) as part of a previous study (Goldstein et al., 2018) has indicated that runoff volume and pollutant concentrations and loads are at levels similar to those of residential Low Impact Development (LID). Another study of runoff from several airports in Florida yielded similar results (FDOT, 2008). These two studies were conducted for airports located on flat ground with highly permeable soils. While these studies provide data for airports located in the Coastal Plain physiographic region of NC, the degree to which runoff from airports in the Piedmont and Mountain regions of NC with their rolling topography and less permeable soils is similar to that from residential LID is unknown. Runoff data for airports located on soils and topography of the Piedmont and Mountain physiographic regions of NC is not available.

Thus, the objective of this project was to monitor runoff from two small NC airports located in the Piedmont region. The monitoring was designed to quantify runoff rate, volume, and quality from the three main components of the airside of the airport: the runway, the taxiway, and the apron in front of the terminal. The runoff volume and quality will then be compared to runoff from LID and conventional developments.

2 Literature Review

An airport landscape is comprised of 'airside' and 'landside' entities. The 'airside' includes areas designated for aircraft operation and servicing as well as areas for takeoff and landing of aircraft. This airside is physically separate from the areas accessible by the public, or the 'landside.' The airside is typically characterized by large expanses of open space separated by linearly expansive taxiways and runways. Width and length requirements for taxiways and runways vary based on the types and size of aircraft served (FAA, 2014). Other impervious structures on the airside include hangars and aprons for storing and servicing aircraft.

For safety and other reasons, stormwater management on the airside of airports has traditionally been focused on minimizing hydroplaning hazards of aircraft during takeoff and landing (FAA, 2013) and safely transporting runoff from maintenance, fueling, and loading areas off-site. The Federal Aviation Administration's (FAA) air safety regulations recommend a separation distance of 8 km to attractants that could cause hazardous wildlife movement into the approach or departure airspace (FAA, 2020), which limited the use of stormwater control measures (SCMs) such as detention and retention ponds as these attract waterfowl. In fact, in North Carolina, the Department of Environmental Quality (NCDEQ) is prohibited from requiring airports and developments within 8 km of an airport to use SCMs that support standing water [N.C.G.S. §143-214.7.(c3)].

Safe and efficient operation of aircraft requires elimination of visual and physical obstructions; thus, airside vegetation is limited to turf grass (FAA, 2014). In addition, grass varieties with a deep, matted root system that provide a dense, smooth surface cover with minimum top growth are recommended (FAA, 2014). Separation distance requirements of 45 to 150 m (depending on size of aircraft served) between runways and taxiways typically extend vegetated areas. In addition, slope and length requirements for swales and other grassed areas result in well-vegetated, relatively flat areas between runways and taxiways. In most cases the slope and length requirements for these areas satisfy the minimum requirements of infiltrative SCMs [e.g., grass swales and vegetative filter strips (VFS)] required by NCDEQ. Further, the drainage design recommendations per the FAA are comparable to design elements for LID, including (1) minimizing imperviousness, (2) disconnecting impervious surfaces, (3) increasing flow paths, and (4) integrating micro-scale stormwater control measures (EPA, 2000).

The uniform and relatively level impervious surfaces of the runways and taxiways at the upslope end of the vegetated areas are similar to a combination of a level-spreader and vegetated filter strip (LS-VFS). Line and Hunt (2009) found 49%, 62%, and 48% reductions in runoff volume, total nitrogen, and total phosphorus from a 17.1-m long LS-VFS receiving highway runoff during 13 storm events. In evaluations of LS-VFS systems receiving parking lot runoff, Winston et. al (2011) determined volume reductions between 40-50% and Knight et al. (2013) demonstrated volume reductions between 36-59%.

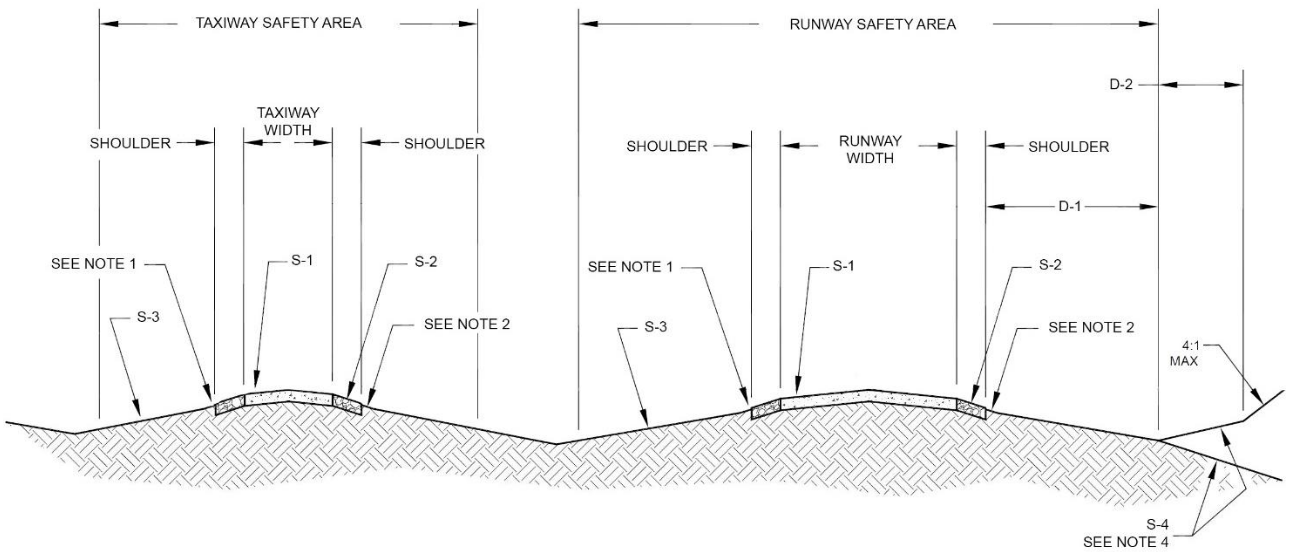
After flowing through the VFS runoff from runways and taxiways is often transported downslope by grassed swales. While the main function of the swales are to convey runoff, several studies have demonstrated their capacity for pollutant removal (Backstrom, 2002; Barrett et al., 1998; Deletic and Fletcher, 2006; Lucke et al., 2014; Knight et al., 2013; Winston et al., 2017; Yu et al., 2001) and runoff volume reduction (Kaighn & Yu, 1996; Knight et al., 2013; Lucke et al., 2014; Shafique et al., 2018). The runoff and pollutant load reduction effectiveness of swales is correlated with longitudinal length and slope, cross section shape (e.g., triangular or trapezoidal), vegetation density, and the hydraulic conductivity of the underlying soil (Backstrom, 2002; Barrett et al., 1998; Lucke et al., 2014; Winston et al., 2017; Yu et al., 2001).

The correlation between TSS removal and longitudinal length was demonstrated by four swales in Australia that reduced TSS concentrations 50% to 80% within the first 10 m and an additional 10% to 20% when length increased by 20 m (Lucke et al., 2014). But as shown in Table 1, there was considerable variability in the pollutant removal effectiveness of swales indicating that factors other than length and slope can also influence effectiveness. Even with the variability, the data show that grassed swales were effective at reducing TSS, TN and TP in almost all cases.

Table 1. Studies of the Pollutant Removal Effectiveness of Grass Swales.

Reference	Length	Longitudinal	Pollutant Removal Efficiencies		
		Slope	TSS	TN	TP
	m	%	%	%	%
Backstrom (2002)	5-10	0.5	79-98	-	-
Lucke et al. (2014)	10	1	50-80	-	-
Knight et al. (2013)	10	1	78	24	-21
Yu et al. (2001)	15	1	75	14-24	34-41
Kaighn & Yu (1996)	30	2.5	30	-	0
Kaighn & Yu (1996)	30	5	49	-	33
Lucke et al. (2014)	30	1	60-100	-	20-23
Yu et al. (2001)	30	1	50-86	14-23	29-77
Deletic & Fletcher (2006)	65	1.6	69	56	46
Yu et al. (2001)	275	3	94	-	99
Barrett et al. (1998)	356	0.7	87	-	44
Barrett et al. (1998)	1055	1.7	85	-	34

The FAA airport design standards (figure 1) results in most of the airside of airports being similar to LID, in that, nearly all runoff from impervious surfaces must pass through VFSs and swales prior to being transported off-site. Further, the relatively gentle slopes of the VFSs and swales provide enhanced opportunities for infiltration, as well as physical and biological pollutant removal mechanisms. The average overland flow distance before runway and taxiway runoffs are concentrated in a channel are generally in excess of 25 to 50 ft due to FAA grading and safety concerns. This distance meets the requirements for disconnected impervious surfaces (DIS) in North Carolina and the grassed receiving areas qualify as VFS per the minimum design criteria (MDC) detailed in the North Carolina *Stormwater Design Manual* (NCDEQ, 2018). The March 2017 airport addendum to the Manual included a component related to the disconnected impervious taxiway and runway areas stating that "To be deemed permitted, a maximum width of 100 feet of pavement shall drain to a minimum width of 10 feet of vegetated receiving area. The maximum slope of the pavement shall be eight percent for most soils and meet the other minimum design consideration for disconnection areas in the state stormwater manual" (NCDEQ 2017)." This acceptance by the state signals a shift to understand the role of airside design on stormwater management.



NOTES:

1. CONSTRUCT A 4CM DROP BETWEEN PAVED AND UNPAVED SURFACES
2. MAINTAIN A -5% GRADE FOR 3M OF UNPAVED SURFACE ADJACENT TO THE PAVED SURFACE
3. S-2 APPLIES WHEN SHOULDERS ARE PROVIDED.
4. S-4 SHOULD BE 0% OR NEGATIVE (UNLIMITED) TO THE EDGE OF THE RUNWAY OFA IF PRACTICABLE. ALLOWABLE POSITIVE SLOPE BASED ON AIRPLANE DESIGN GROUP.

APPROACH CATEGORY	A & B	C, D, AND E
S-1	1.0% TO 2.0%	1.0% TO 1.5%
S-2 (≥S-1)	1.5% TO 5.0%	1.5% TO 5.0%
S-3	1.5% TO 5.0%	1.5% TO 3.0%

ADG	I	II	III	IV	V	VI
D-1	VARIES BASED ON AAC & ADG SMALLEST MIN = 9 m | LARGEST MIN = 46 m					
D-2 (m)	7.5	12	18	26	32.5	40
S-4 (MAXIMUM)	8:1		10:1		16:1	

Figure 1. FAA requirements for runways and taxiways at airports.

The similarity between the airside of small airports and LID is supported by preliminary data from an airport runoff study in the coastal plain of North Carolina (Goldstein, et al., 2018). Runoff monitoring at the Wilmington International Airport (ILM) documented that for 62% of the 118 storm events (accumulation from 0.01 to 4.23 inches) occurring there was no outflow from the combination of vegetative filter strip and swale (Goldstein et al., 2018) downstream from an apron and taxiway. The vast majority (~90%) of storms that produced no runoff had a total accumulation of less than 0.32 inches. When there was outflow from the swale, it had mean nitrogen and phosphorus concentrations lower than runoff from monitored urban areas of the U.S., and even several monitoring studies of residential and commercial LID in North Carolina (Table 2). As shown in Table 2, there has been a relatively wide range of TN and TP concentrations reported for urban areas. The Nationwide Urban Runoff Program (NURP) study (U.S. EPA, 1983) of U.S. urban runoff included runoff from a broad range of land uses (i.e.

commercial, industrial, and residential) and thus representative of urban runoff in general. Maestro and Pitt (2005) gathered monitoring data from stormwater permits for cities across the southern U.S. and pacific northwest and reported mean concentrations in residential runoff. For North Carolina, concentrations of N, P, and TSS in runoff from conventional (curb and gutter; full width streets, sidewalks, and alleys; complete clearing and grading, roof runoff not conveyed to pervious areas, and regular-sized footprint homes) residential developments in the Piedmont region were reported by Line et al. (2002) and Line and White (2007). Both of these residential areas were in relatively high-end recently completed developments in which vegetation was being established and many had employed landscapers to plant and maintain the vegetation. Also in the Piedmont, concentrations of N, P, and TSS in runoff from a low impact development (LID) residential development (no curb and gutter; narrow streets, permeable sidewalks, and permeable parking spaces; minimized clearing and grading; roof and some surface runoff collection and reuse; minimized footprint homes; and bioretention areas) in the Piedmont region of the state were published by Line and White (2016). This study included two areas of the LID with a different finishing practice; one with runoff from the development spread evenly over an undisturbed wooded riparian buffer (LID1) and the other with the runoff conveyed to a detention/irrigation pond (LID2). Other studies listed in Table 2 report data for runoff from a single land use type within an urban area.

Besides comparing to runoff from LID, another way to assess the concentrations of pollutants in runoff is to compare them to the ‘irreduceable concentrations’ as reported by Schueler (2000) and shown in Table 2. These are the concentrations below which stormwater BMPs become relatively ineffective.

While concentration data provide some indication of a given land use/areas contribution to overall pollutant loading in a watershed, they are not the best measure, as a low pollutant concentration with high runoff can still contribute a high load. Therefore, pollutant load or export will also be computed in this project and compared to the export rates shown in the lower section of Table 2. Annual export rates for residential and commercial areas varied considerably also due to many factors including percent of imperviousness, soils, types and effectiveness of LID practices/measures, and climate. For example, the North Carolina (NC) residential LID site was built on clay soils with relatively low infiltration rates (Line and White, 2016). Further, LID sites with different imperviousness and practices can result in substantially varying export rates such as for the NC residential LID site (Line and White, 2016). The residential LID1 site had an undisturbed wooded riparian buffer downstream on which the runoff from the developed area was spread, whereas the LID2 site had a detention/irrigation pond at the downstream end of the site/drainage area. Export from other developments, including commercial LID, also vary considerably with imperviousness, location, soils, and other factors (Table 2).

Table 2. Concentrations and Annual Export of Nutrients in Runoff from Completed Studies.

Authors	Site Description	Imp. %	Runoff /Rain	Concentration (mg/L) TN	TP	TSS
U.S. EPA, 1983	U.S. Urban, NURP[1]	na	na	3.31	0.46	na
Maestro & Pitt, 2005	U.S. Residential[2]	na	na	2.65	0.41	92

Line & White, 2007	NC Residential	53	0.55	4.31	0.38	514
Line et al., 2002	NC Residential	na	0.57	6.71	0.59	73
Line & White, 2016	NC Residential LID1	12	0.24	1.85	0.17	61
Line & White, 2016	NC Residential LID2	24	0.56	2.16	0.12	18
Line at al., 2012	NC Commercial	90-97	0.44-0.89	0.96-1.0	0.06-0.09	31-34
Wilson et al., 2015	NC Commercial LID	84	na	0.87	0.05	10
Line et al., 2012	NC Commercial LID	76	0.58	1.25	0.06	18
Goldstein et al., 2018	ILM Airport-VFS	na	na	0.56	0.03	3
Goldstein et al., 2018	ILM Airport-Apron	na	na	0.35	0.01	3
Schueler & Holland, 2000	Irreducible conc.	na	na	1.90	0.15-0.2	20-40
		Imp	Run/rain	Annual Export (kg/ha-yr)		
Line et al., 2002	NC Residential	na	0.57	23.9	2.30	387
Line and White, 2007	NC Residential	53	0.55	18.0	1.70	1958
Line & White, 2016	NC Residential LID1	12	0.24	3.59	0.37	160
Line & White, 2016	NC Residential LID2	24	0.56	13.9	0.89	166
Line et al., 2012	NC Commercial	97	6.87	5.46	0.42	244
Line et al., 2012	NC Commercial LID	76	0.58	7.89	0.24	8

[1] Nationwide Urban Runoff Program (NURP) includes data from 28 urban areas in U.S.
[2] From National Stormwater Quality Database (NSQD) includes data from 65 U.S. urban areas.

A study by the Florida Department of Transportation (FDOT, 2008) characterized runoff from 41 different sites on the airside of 10 Florida airports. The event mean concentrations (EMCs) for TN, TP, and TSS (Table 3) were all lower than those reported for urban areas of the U.S. as well as residential areas of NC (Table 2).

Table 3. Airside Average EMCs from Impervious Surfaces at Florida Airports.

Airside Impervious Surface Type	Event Mean Concentration in Runoff (mg/L)				
(Main Use)	TSS	NOx	TKN	TN	TP
Apron (GA)[1]	7	0.14	0.20	0.34	0.05
Apron (Terminal)	5	0.18	0.21	0.39	0.06
Apron (Air Cargo)	4	0.15	0.12	0.27	0.05
Runway (GA)	7	0.12	0.23	0.35	0.08
Runway (Air Carrier)	10	0.17	0.19	0.36	0.05
Taxiway (Air Carrier)	24	0.12	0.39	0.51	0.12

[1] GA = General Aviation

Both the NC and FL studies of airport runoff were conducted on flat areas with mostly highly pervious (sandy) soils where conditions were optimum for facilitating the effectiveness of grass strips and swales. However, the effectiveness of grass strips and swales on airports located in areas where land slopes are greater and soils less pervious, such as the Piedmont physiographic region of NC is not known.

3 Methodology

Two small airports were selected for this study: (1) Smith Reynolds Airport (INT) in Winston-Salem, NC and (2) Burlington-Alamance Regional Airport (BUY) near Burlington, NC (figure 2). These airports were chosen because they were located in the Piedmont physiographic region of NC, they were representative of urban and rural airports, and the authorities were cooperative. Both airports receive a moderate amount of airport traffic annually and are classified as general aviation (GA) facilities per the FAA. The FAA airport classification is based on the number of annual passenger enplanements and identified as (1) commercial service airports, receiving 2,500 or more enplanements, (2) reliever airports, or (3) general aviation (GA) airports. Though GA airports are typically smaller than commercial airports they comprise approximately 90% of airports nationally and 75% of annual airport activity in the U.S. (FAA, 2012).

Several factors went into selecting specific monitoring locations/sites on the airside of the airports. These included (1) the drainage areas (DA) had to include portions of either the terminal area or taxiways/runways (2) the DAs needed to be representative of similar land use throughout the airside (3) the site had to be appropriate for monitoring runoff from the standpoint of allowing equipment to comply with airfield obstruction restrictions and having runoff concentrated to allow for sampling (4) the site had to be accessible and have physical characteristics that facilitated rainfall and runoff monitoring. Based on these requirements, five monitoring locations were selected at the two airports.

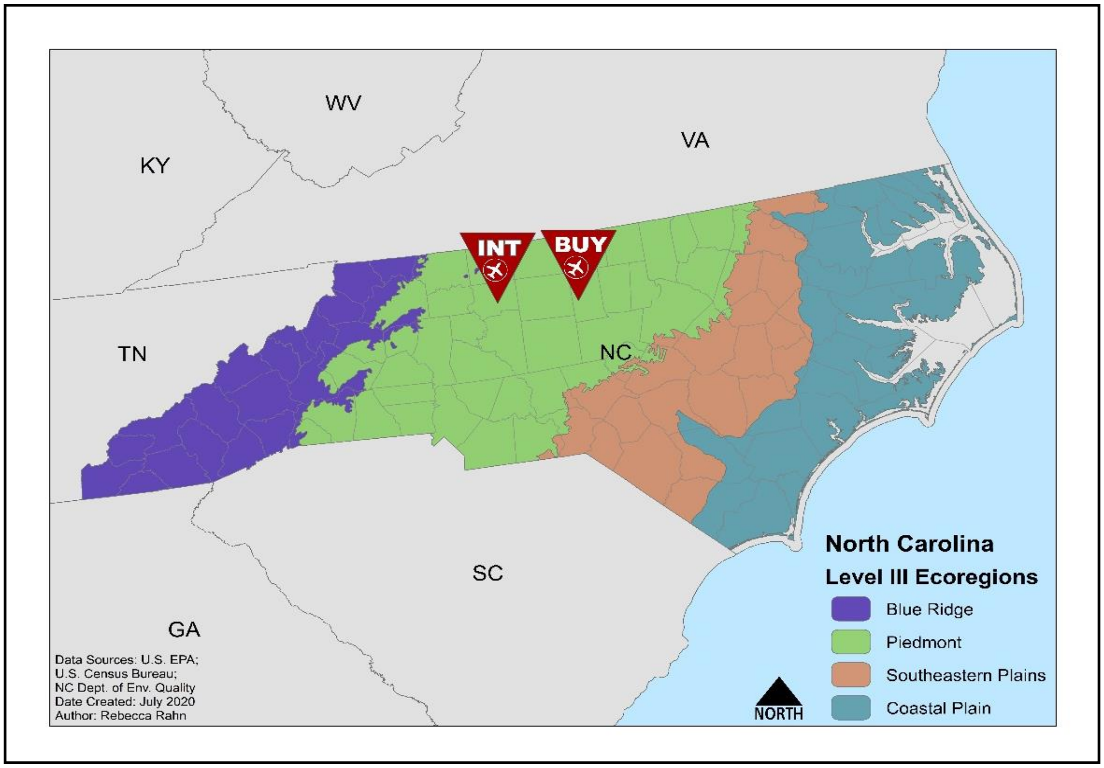


Figure 2. Locations of the Smith-Reynolds (INT) and Burlington-Alamance airports.

3.1 Airport and Monitoring Site Descriptions

Smith-Reynolds Airport (INT) is located approximately 3.1 miles northeast of the central business district of Winston-Salem, NC. It encompasses approximately 700 acres of land at an elevation of 968 ft above mean sea level. The airside operations area of the airport is about 350 acres with the other 350 acres being surrounding land, repair facilities, and other land. There were 45,427 arrivals and departures reported for a 12-month period ending May 23, 2019 (FAA, 2020). The airside of the airport includes two asphalt runways designated as 15/33 and 04/22. Runway 15/33 is the larger, more frequented runway measuring 2,217 yd in length and 49 yd wide. It has a parallel taxiway measuring 22 yd wide that is separated by a 55-yd wide grassed area containing yard inlets and culverts to carry stormwater off the runway/taxiway area. The size and strength of this runway accommodates aircraft with up to two dual wheels in tandem and weighing up to 358 MT. The smaller runway, 04/22 measures 1,312 yd in length and is 32 yd wide with an adjacent 16 yd wide taxiway. The runway and taxiway are separated by a grassed area tapering from 38 to 73 yd with yard inlets to carry runoff off the area. The size and strength of this runway accommodates aircraft weighing up to 11 MT (FAA, 2020).

Airport personnel stated that anti-icing material was applied to the main runway and taxiway just prior to the freezing precipitation event of 1/12/19; however, no de-icing of aircraft had occurred. Urea, which is 46% nitrogen by weight, was used as the anti-icing material on the runway and taxiway surfaces. Personnel also said that Urea is being phased out as an anti-icing material, because the U.S. Environmental Protection Agency has prohibited the use of urea-based anti-icing materials, which will occur once the airport exhausts its current supply.

Three monitoring stations were installed to monitor runoff from (1) terminal apron and adjacent areas, (2) the taxiway associated with the smaller runway (04/22), and (3) the runway and taxiway of the larger runway (15/33). Locations and characteristics of the monitored watersheds are summarized in Table 4.

Table 4. Locations and Characteristics of Monitoring Sites at the Smith-Reynolds Airport (INT).

Characteristic	Site Name		
	INT-Term	INT-Run	INT-Taxi
Land use	Terminal apron	Runway 15/33 + Taxiway 15/33	Taxiway 04/22
Coordinates	36°8'9"N, 80°13'43"W	36°7'54"N, 80°13'18"W	36°5'6"N, 80°13'45"W
Area (ac)	4.2	5.2	0.62
Imperviousness	90%	40%	64%

The terminal monitoring site (INT-Term) received runoff from a 4.2-ac area comprised of 90% impervious surfaces including most of the paved terminal pad on the airside of the terminal building and much of the building roof (figure 3**)**. The extent of the drainage area for this site was difficult to accurately determine as the asphalt pad is nearly flat. Stormwater from the terminal building and pad/apron was conveyed off-site via a curb and gutter and storm drain system (figure 4a); thus, nearly all of the impervious surfaces were directly connected to the stormdrain system. The monitoring site was near the outlet of the system, which was the end of a 46-cm diameter concrete culvert (figure 4b). An area-velocity probe and a sampler intake were fastened to the bottom of the culvert about 6 ft and 3 ft, respectively upslope from the end. Runoff water flowed unobstructed downslope (away) from the pipe thereby providing consistent hydraulics for measuring discharge.

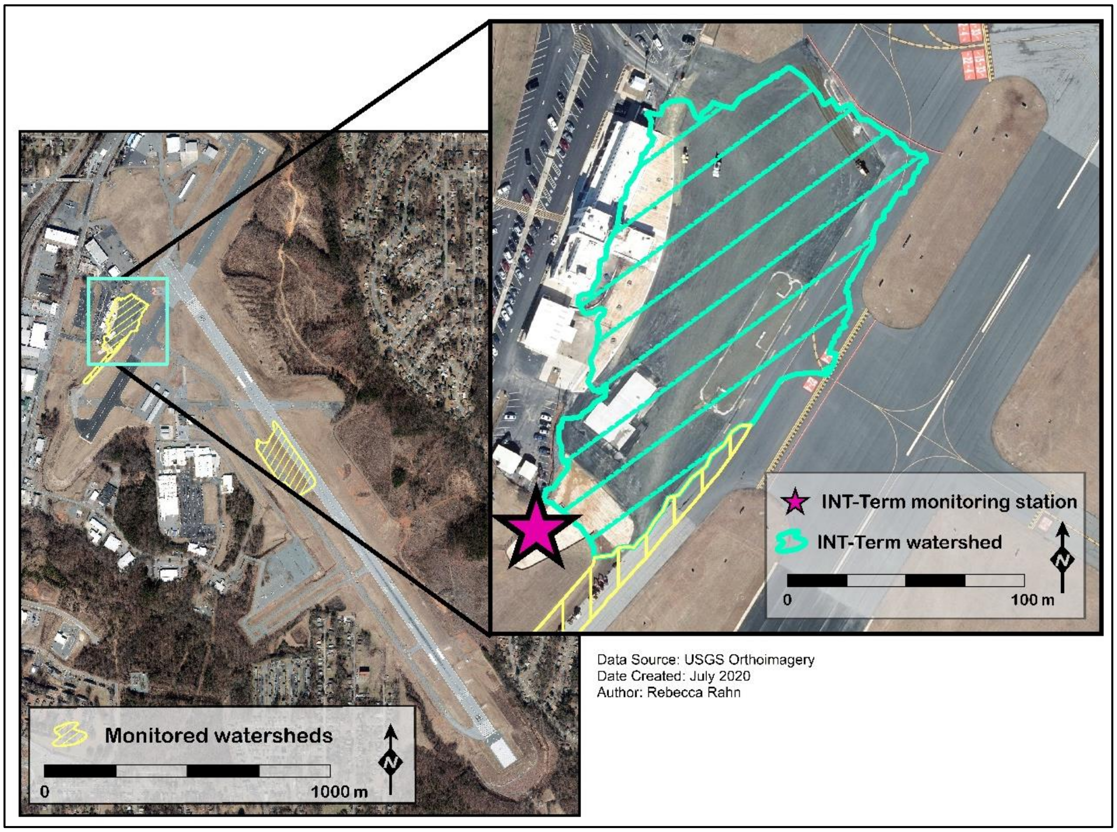


Figure 3. Aerial view of INT-Term drainage area and location of the monitoring site.

(a) (b)

Figure 4. Curb and gutter (a) and storm drain outlet (b) for INT-Term drainage area.

The runway site at INT (INT-Run) received runoff from a portion of Runway 15/33 and the parallel taxiway (fig. 5). The area (5.2-ac) was characterized by 40% impervious surfaces surrounded by grassed strips and swales. Approximately half of the width and 66 ft of the length of the runway plus the entire width and the same length of taxiway were included in the drainage area. The rest of the area included the 164 ft wide grassed strip and swale separating the runway and taxiway. Another grass strip and swale were on the other side of the taxiway (fig. 6). Two yard inlets in the swales directed runoff underground to a 12-in. diameter concrete culvert, which carried water off the taxiway/runway area to a channel where the monitoring station was installed. A 90-degree v-notch weir was installed across the channel to facilitate the continuous measurement of discharge (fig. 7a). The notch of the weir was about 5 inches above the channel bottom to create a stilling area upstream of the weir, which is necessary for use of the standard weir equation. In addition, a piece of plywood was hung over the end of the culvert to ensure that the water leaving the pipe had low energy so that a stilling area upstream of the weir would be maintained even during periods of high discharges (fig. 7b).

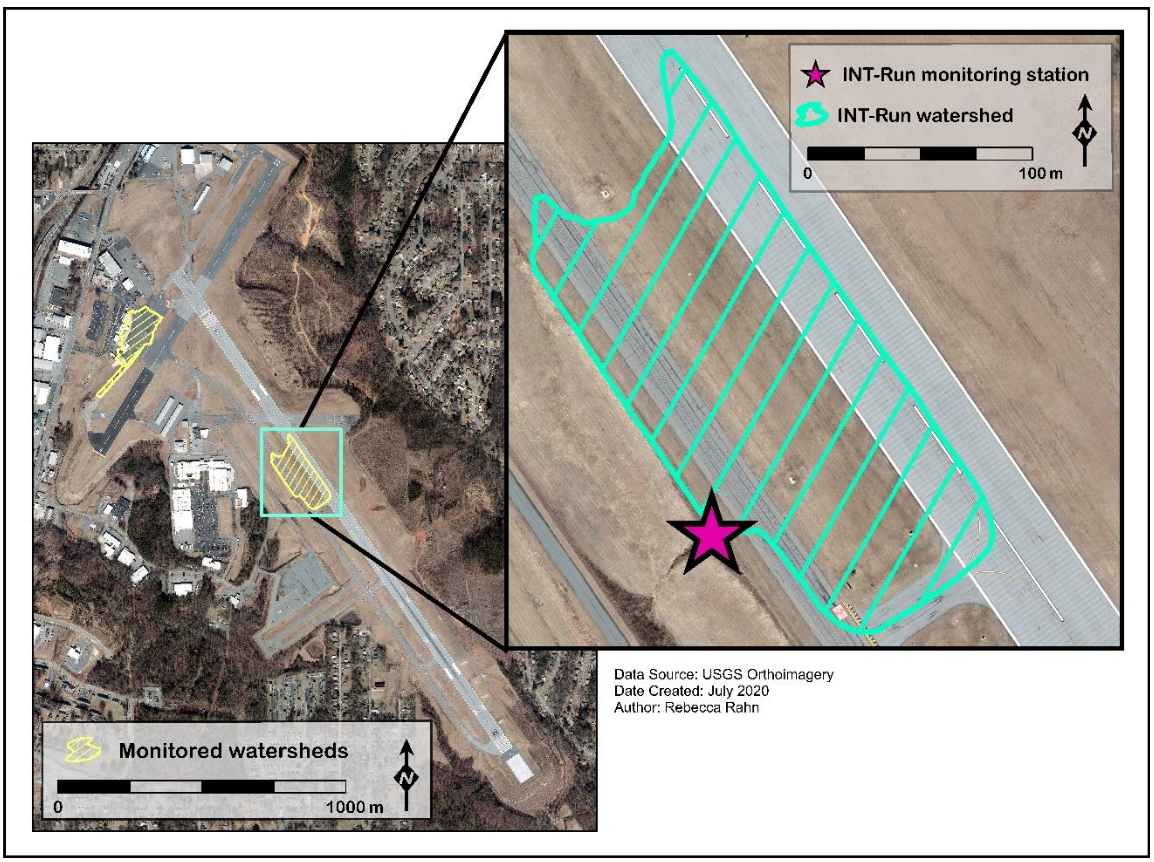


Figure 5. Aerial map of INT-RUN site and drainage area.

Figure 6. Grass strip and swale along taxiway at INT-RUN.

Figure 7. V-notch weir at outlet of INT-RUN site storm drain (a) and during runoff (b).

(a)

(b)

The taxiway site at INT (INT-Taxi) received runoff from 0.62 acres comprised of a portion of the taxiway adjacent to Runway 04/22 and the corresponding grassed swale. Runoff from half the width of the taxiway flows toward the swale where is it conveyed to a yard inlet. Approximately 64% of the 0.62 acres is covered by impervious surfaces. A slot drain (fig. 8) was installed at a low point in the swale approximately 98 ft before runoff would reach the yard inlet. The slot drain was installed with its lip at ground level so that it collected runoff as it flowed over the opening in the swale (fig. 9). A metal grate was fastened across the opening per FAA airfield safety regulations. Discharge was not monitored at this site due to the prohibition against any above ground object in this area.

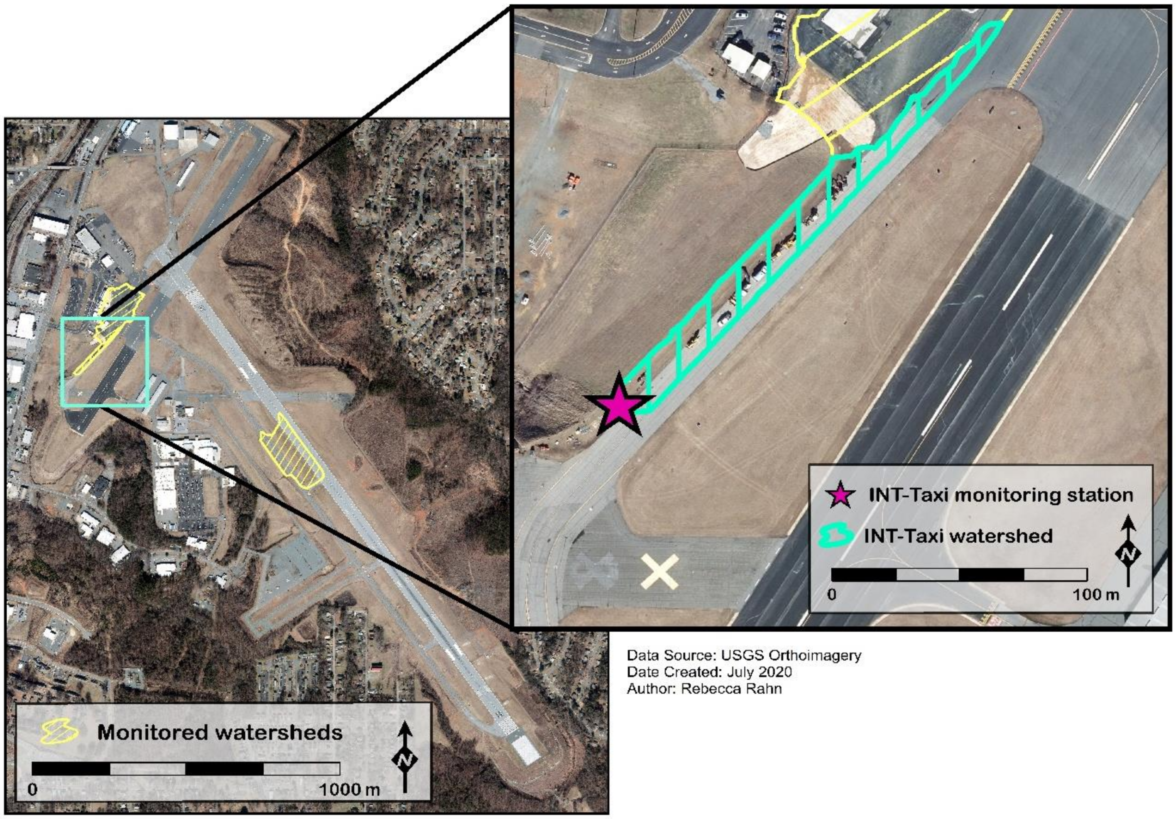


Figure 8. Aerial map of INT-Taxi site

(a) (b)

Figure 9. Slot drain collector for the INT-Taxi site.

Burlington-Alamance Regional Airport (BUY) encompasses about 350 acres of land near the central business district of Burlington, NC. The terminal and apron made up about 4 acres, the runway/taxiways 215 acres, and the other areas, such as hangars and aircraft parking lots, 131 acres. The property sits at an elevation of 616 ft above mean sea level. The airport has one asphalt runway designated as 06/24, measuring 6406 ft long by 98 ft wide. The BUY serves at a regional scale with the latest data reporting 74,450 arrivals and departures during a 12-month period ending August 7, 2017 (FAA, 2020).

Two monitoring stations were installed on the airside of the BUY. Their drainage areas included impervious surfaces associated with either (1) terminal operations or (2) the taxiway. Locations and characteristics of the monitoring sites are outlined in Table 5.

Table 5. Location and characteristics of the BUY Airport Monitoring Sites.

Characteristic	Site Name	
	BUY-Apron	BUY-Taxi
Impervious surface contributions in watershed	Terminal apron	Taxiway 06/24
Coordinates (degrees minutes seconds)	36°3'1"N, 79°28'37"W	36°3'2"N, 79°28'26"W
Area (ac)	2.70	0.89
Imperviousness	95%	34%

The terminal site at BUY (BUY-Apron) received runoff from the terminal area, which was comprised of 95% impervious surfaces including most of the paved apron on the airside of the terminal building (fig. 10). Observed activity on the apron consisted of passenger loading/unloading, refueling, and temporary storage of airplanes. There was construction observed off of the southwest corner of the apron; however, it was likely the actual area of construction did not drain to the pad, but dust and possibly stray soil from the construction area did reach the apron.

Airport authority personnel stated that deicing/anti-icing material(s) were not applied to runways, taxiways, aprons, or aircraft during freezing temperatures. Rather, plowing of travel surfaces was conducted as needed and air traffic was delayed until sufficient melting had occurred.

Runoff from the apron was conveyed underground via several yard inlets to a storm drain system. The storm drains carried water to a catchbasin at the northeast corner of the apron where the flow monitoring and sample collection site was installed (fig. 11a). An area-velocity probe and sampler intake were fastened to the bottom of an 18-inch diameter concrete pipe just upstream of the catchbasin. An automated sampler and raingage were installed above ground next to the catchbasin (fig. 11b).

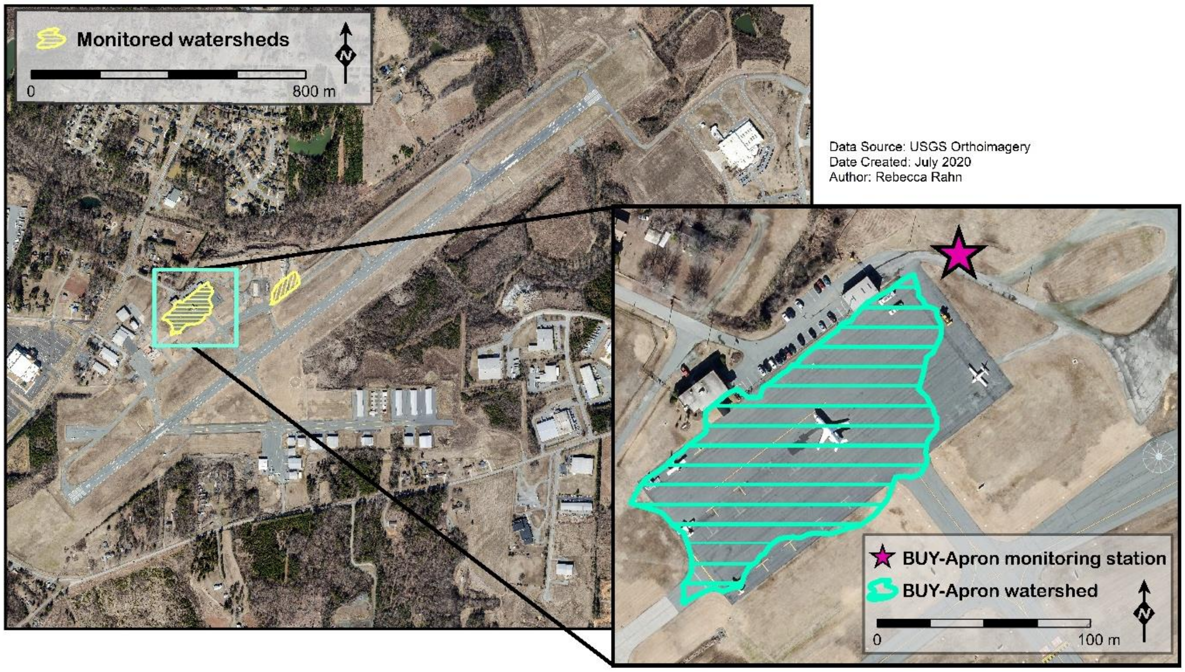


Figure 10. Aerial view of BUY-Apron site.

(a) (b)

Figure 11. Airplane at BUY-Apron site (a) and monitoring set-up (b).

The taxiway site at BUY (BUY-Taxi) received runoff from a 0.89-ac area comprised of 34% impervious surfaces including approximately half of the width of the taxiway parallel to Runway 06/24 (fig. 12). Observation documented airplanes slowly travelling down the taxiway on several visits. Several abandoned planes were stored on the grassed area adjacent to the taxiway, but only one was possibly in the drainage area. Runoff from the area collected in two yard inlets which directed it into a 12-in diameter concrete pipe that carried the water off the site (fig. 13a). The monitoring station was installed at the outlet of the pipe. A 90-degree v-notch weir was installed about 3 ft downslope from the outlet of the pipe with the notch being about 6 inches higher than the invert of the pipe to create a stilling area for the flow (fig. 13b). The weir was also offset from the culvert to prevent high velocity water from flowing directly through.

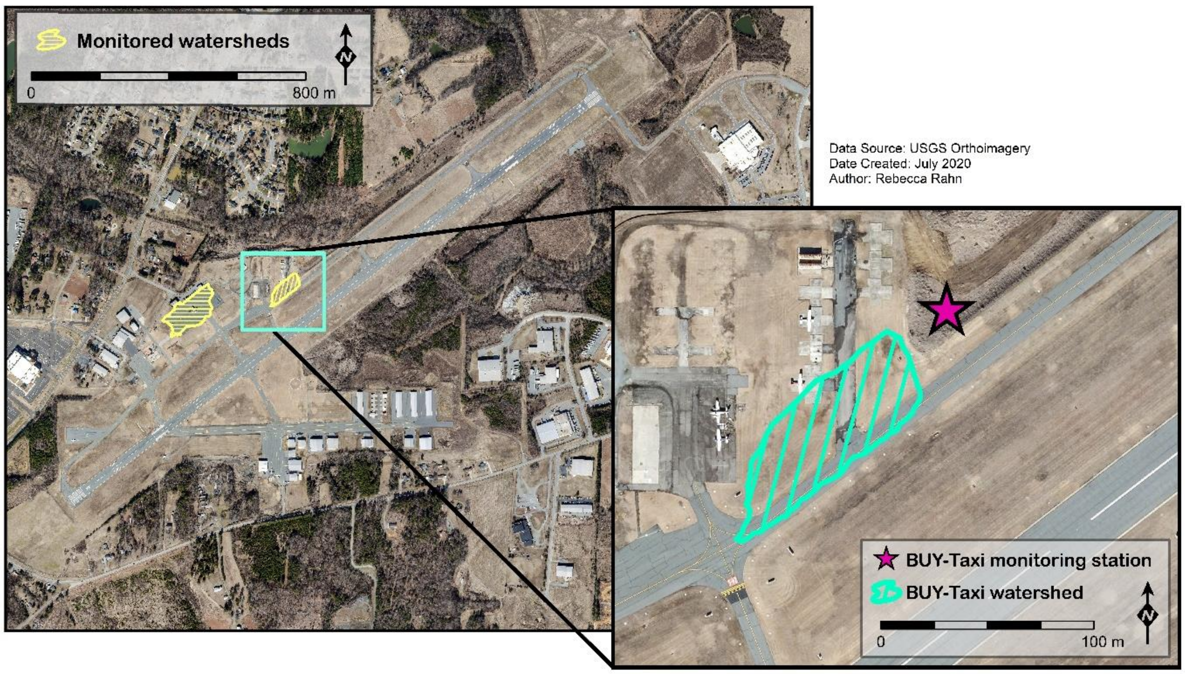


Figure 12. Aerial view of BUY-Taxi site.

(a) (b)

Figure 13. Yard inlet (a) and outlet of drain pipe (b) for BUY-Taxi site.

3.2 Stormwater Monitoring Design/protocol

Hydrologic and water quality monitoring took place during a 13-month period between October 2018 and November 2019. Water quality samples were collected from all sites and runoff/discharge was monitored at all sites, except the INT-taxi site for which airfield obstruction restrictions prevented the installation of above ground flow measuring devices. A standard 8 in tipping bucket rain gauge was installed at each airport, one at BUY-Pad in October, 2018 and one at INT-Taxi in January, 2019. The tipping bucket gauges recorded precipitation at a 0.01-inch resolution. A manual rain gauge was installed at INT to account for underestimation during high intensity events. At INT, estimates of precipitation for events occurring prior to the installation of the gauge was obtained from the Automated Surface Observing System (ASOS) hourly precipitation data provided by North Carolina State Climate Office. This data source was also utilized during periods of instrument failure at respective airports and as a check of rainfall data that appeared inconsistent with observation or other data. Only storm events with at least 0.08 in. precipitation depth following a 6-hour inter-event dry time were included in the analysis. Both raingages were located more than 100 ft away from any trees or other tall structures that might interfere with rainfall measurements.

Each monitoring site was outfitted with a small shelter that housed an automated sampler. For INT-Run and BUY-Taxi, an integrated flow module was added to the sampler to measure the stage/level of water above the v-notch in the weir. The level measurement was made in still water outside of the drawdown area of the weir. The stage measurements were converted to discharge by the sampler controller via the standard stage-discharge rating table for the weir. At INT-Term and BUY-Apron an area-velocity (AV) module attached to the sampler measured water velocity via the Doppler method and the water depth/stage. The two synchronous measurements along with the geometry of the round pipe were then used to compute discharge continuously. Stage-discharge relationships were plotted and regression equations developed for both sites. The AV module and sensor at BUY-Apron was replaced with a bubbler (level/stage only) flowmeter after five storm events. The stage-discharge relationship developed with the AV flowmeter was then used to compute discharge from continuous stage/level measurements made by the bubbler flow meter.

At INT-Term, INT-Run, BUY-Apron, and BUY-Taxi the automated samplers were programmed to collect samples for a given volume of discharge (flow-proportional sampling) over the duration of runoff from a storm event. At INT-Taxi, because discharge could not be measured, samples were collected for a given accumulation/depth of rainfall measured on-site. Stormwater quality at a given location varies greatly both between storms and during a single storm event, and thus a small number of samples are not likely to provide a reliable indication of stormwater quality at a given site. Therefore, collection of numerous samples is generally needed in order to accurately characterize stormwater quality at a site. For this project a minimum of 20 storm event composite samples from at least 20 storms were collected at each site (See Quality Assurance Project Plan (QAPP) in appendix for further discussion).

At INT-Run a Sonde was installed in the runoff channel just upstream of the v-notch weir to measure specific conductance at 25 ºC (conductivity), turbidity, and temperature of the runoff from 12/15/18 to 3/15/15. This period was chosen to measure the effects of possible nongrowing season application of anti-icing materials to the runway. The Sonde was programmed to conduct an in-situ measurement every 5 minutes; however, only measurements made during runoff were used.

All of the automated samplers were programmed to collect duplicate samples in adjacent 1000 mL bottles: the odd-numbered bottles were spiked with sulfuric acid (H_2SO_4) to maintain a pH of <2 from the time of collection to analysis, while even-numbered bottles were unpreserved (EPA, 1982). The sites were visited by North Carolina State University (NCSU) personnel within 5 days (access to INT sites was by appointment only) of each monitored storm event. During the visit, a composite sample was made from the odd-numbered bottles to be analyzed for total Kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_3-N), nitrate+nitrite or inorganic nitrogen (NOx-N), and total phosphorus (TP). A second composite sample was made from the even-numbered bottles to be analyzed for total suspended solids (TSS). Samples were transported to the NCSU BAE Environmental Analysis Lab (EAL) and placed in a refrigerator until analysis. The BAE EAL followed Standard Methods (Eaton et al., 1995) for lab analysis. Additional details about sample collection and handling procedures are contained in the QAPP in the Appendix.

3.3 Quality Assurance

Quality assurance is an important, yet often overlooked, part of monitoring projects. It addresses not only sample collection, handling and analyses, but also data acquisition, management, and analyses. While the QAPP, included in the Appendix, outlines procedures and checks followed during this project for both sample and data acquisition and handling, the focus of this section is on sample handling and analysis. In accordance with the QAPP, sample duplicates, field blanks, and blind standards were prepared and submitted for analyses. For the duplicates, differences in concentrations were 0.7 to 8.7% for the nitrogen (N) and phosphorus (P) concentrations which indicated good/acceptable repeatability of the sampling and laboratory analysis procedures (Table 6). Three field blanks were prepared; however, due to a miscommunication two were deemed uncertain; thus, only one result was reported as shown in Table 6 (row labelled BAE EAL). The concentrations of TKN, NOx-N, TP and TSS in the field blank were each less than the corresponding practical quantitative limit (PQL); however, NH_3-N was greater than its PQL. As a check another blank was prepared and submitted to a state certified lab (labeled CAAE). The results from the CAAE for TKN, NOx-N, TP were less than the corresponding PQL for the BAE EAL, whereas the concentration for NH_3-N (0.025 mg/L) was still slightly greater than the BAE EAL PQL of 0.02 mg/L. The CAAE concentration of NH_3-N highlights the difficulty of obtaining blanks for NH_3-N given the presence of NH_3-N in the air and the uncertainty involved in analyzing samples at low concentrations. However, since the concentration of NH_3-N in the field blank analyzed by the BAE EAL was more than twice the PQL, greater then acceptable uncertainty in NH_3-N data is indicated; therefore, these data were not reported with the results of this project.

Also as part of the QAPP, a spot check of the maximum holding time (MHT) for 5 samples (5% of total number of project samples) was conducted, which revealed MHTs from 26 to 32 days. At least two of the MHTs were greater than the 28-day MHT recommended in Standard Methods (Eaton, et al., 1995) and U.S. EPA's 'Methods for Chemical Analysis of Water and Wastes' (EPA-600/4-79-020). In considering the implications of these MHTs, it is important to note that the recommended 28-day MHT is a regulatory requirement (not a true, experimental MHT) designed to account for the most severe biological conditions and is thus conservative, especially for relatively stable surface runoff samples like the ones collected for this project. In fact, a U.S. EPA study of wastewater and drinking water samples (Prentice and Bender, 1987), found that experimentally determined MHTs were longer than 28 days (MHTs evaluated were up to 32 days) for TKN, NH_3-N, NOx-N, and TP when cooled to <4º C and spiked with H_2SO_4 to pH<2. This agreed with a study by USGS (Patton and Gilroy, 1998) which documented no statistically significant effect on TKN, NH_3-N, NOx-N, and TP concentrations in thousands of surface and groundwater samples (collected from across the U.S.) stored (<4º C and H_2SO_4 to pH<2) for up to 35 days (35 days was the longest MHT tested). Thus, these studies document that the extended MHTs found in the spot check of MHTs for this project would not compromise TKN, NOx-N, and TP concentration data quality.

Table 6. Field and Laboratory Quality Assurance Data.

	TKN mg/L	**NH_3N** mg/L	**NOxN** mg/L	**TP** mg/L	**TSS** mg/L
BAE EAL PQL	0.20	0.020	0.011	0.03	2.5
Field Duplicate	1.21	0.30	0.15	0.22	-
Field Duplicate	1.20	0.27	0.13	0.22	-
Field Blank (BAE EAL)	0.170	0.050	0.009	0.01	0.00
Field Blank (CAAE)	0.073	0.025	0.004	0.00	-
Blind Standard 0.1 mg/L (BAE EAL)	-	-	0.091	0.100	-
Blind Standard 0.1 mg/L (CAAE)	-	-	0.111	0.105	-

Laboratory Quality Control (QC) results are shown in Table 7. Lab blanks were less or equal to the PQL, duplicates were within 15% difference, and recoveries were within the acceptable range (88-115%); thus, these results indicate acceptable QC, although the spike recover for TKN is at the upper limit of the acceptable range. To assess the lab analysis results near the midpoint of the range of sample concentrations expected from this project, certified NOx-N and TP standards were purchased and diluted with distilled water from the BAE EAL to 0.1 mg NOx-N/L and 0.1 mg TP/L. The standards were submitted to the lab like normal runoff samples with a split sample also submitted to the CAAE lab. Results are shown in Table 6 for row labeled "Blind Standard …". As shown lab results are within 10% of the standard concentration indicating acceptable agreement.

Table 7. Laboratory Quality Control Data.

	TKN	NH_3-N	NOx-N	TP	TSS
Blank, mg/L	-0.01 to 0.01	-0.01 to 0.01	-0.02 to 0.01	-0.01 to 0.01	0.06~0.06
Lab Duplicate, Diff%	0-13	0-6	0~5	0-14	0-15
QC Sample, Recovery%	90-110	89-96	88-102	90 -110	NA
Spike Sample, Recovery%	95-115	95-108	100-110	98-107	NA
Samples, number	10	10	10	10	10

Overall, the quality assurance tests for the laboratory yielded acceptable results; however, for TKN, several of the test results (e.g. field blank and spike sample recovery) were at the high end of acceptability, thereby indicating a possible slight upward bias in low sample TKN concentrations (near the PQL). Results for NOx-N, TP, and TSS were well within acceptable ranges. Finally, unconventional laboratory procedures such as not documenting the chain-of-custody through lab analysis and extended holding times (more than 28 days) potentially add uncertainty to the nitrogen and phosphorus concentration data.

3.4 Data and Statistical Analysis

Runoff/discharge and concentration data were combined to compute loads for monitored storms. For storms in which runoff was not monitored, it was estimated via a rainfall-runoff relationship developed from data for storms that were successfully monitored. This occurred for less than 10% of the runoff from BUY-Apron and INT-Run and 0% for BUY-Taxi and INT-Term. For storms in which the runoff was not sampled due to equipment failure or other reasons, the average concentration of all samples collected for the site was used to compute the load for that storm. The exception to this was for large storms (>2.0 inches) where the concentration from a large storm occurring during the same season (nongrowing versus growing) was used to compute the storm load.

Statistical analyses were conducted to compare runoff quantity and quality data to those from conventional and LID residential and commercial areas to determine if indeed runoff from small airports is similar to runoff from LID. Because these comparisons involve comparisons of the relationship between independent and dependent variables (rainfall and hydrologic response), analysis of covariance (ANCOVA) was used for the statistical analyses. This analysis compares two linear relationships between independent and dependent variables (the dependent variable is the same for both relationships) to determine if they are significantly different.

4 Results and Discussion

Conductivity, turbidity, and temperature varied considerably for each storm event monitored. Generally the conductivity and turbidity for the first flush of runoff was greater than for the rest as illustrated in the figure 14. As shown, the conductivity (purple line) and turbidity (red) were about 2 times greater for the first 20-30 minutes of runoff (blue circles) as compared to the rest of the storm runoff. Runoff temperatures varied during storms such during cold days temperatures decreased as runoff/discharge rate increased, while during warm days (not shown), temperatures increased with increasing runoff rate. Figure 14 also illustrates the limits of valid measurements, in that only measurements made during appreciable runoff (to within 15 minutes) were considered valid.

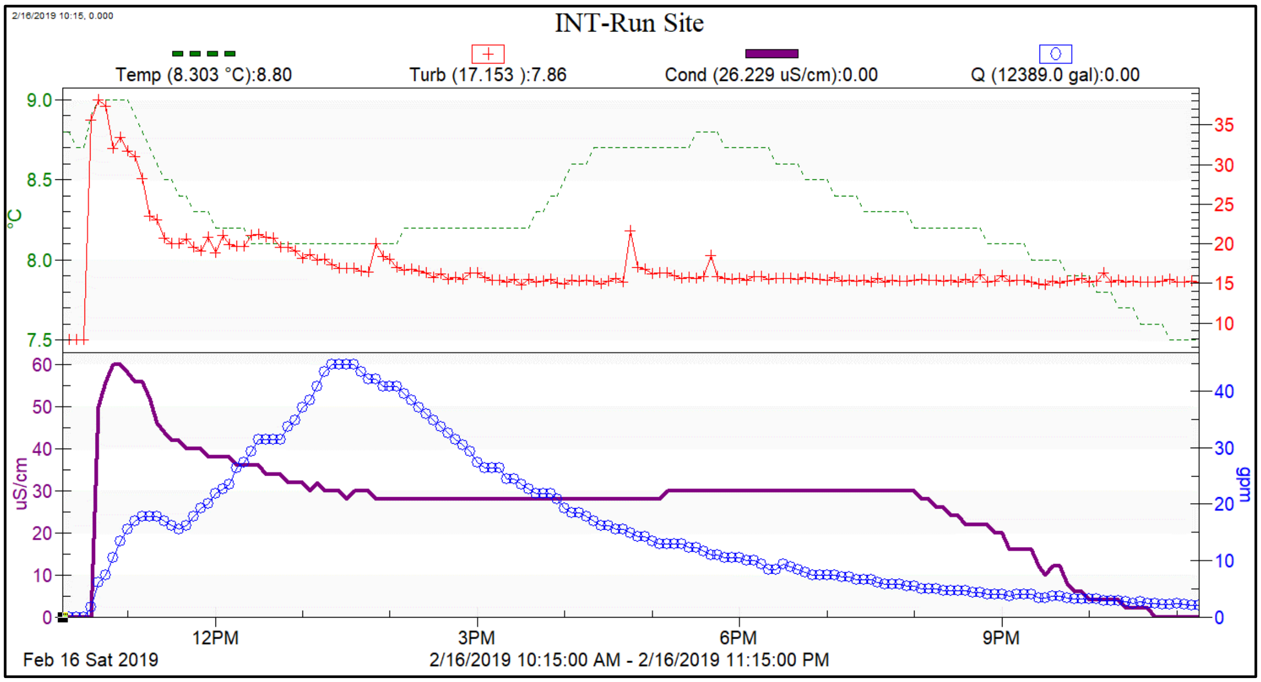


Figure 14. Temperature, conductivity, and turbidity of runoff from INT-Run.

The average of the valid conductivity and turbidity measurements for each storm are shown in figure 15. Means of the conductivity for the 16 storms monitored ranged from 18.1 to 38.5 with the highest being for the 1/13/19 storm. This storm produced freezing precipitation which required the application of de-icing material to the runway and taxiway thereby resulting in the elevated conductivity. The peak conductivity for this event was 100 µS/cm and the peak for all of the events was 120 µS/cm (Table B6 in appendix). Considering that inland streams supporting good mixed fisheries have conductivities ranging from 150-500 µS/cm, even the peak conductivities measured would not pose a significant water quality concern.

Mean turbidities ranged from 10.3 to 19.7 ntu with the highest being for the 3/15/19 storm. The definitive reason for the high turbidity for this storm is unknown, but could be related to the fact that this storm had the 2nd highest 1-hr rainfall intensity and a relatively low total runoff volume (Table B2 in appendix). This storm also had the highest peak turbidity (170 ntu), which was more than 3 times the peak for any other storm (Table B6 in appendix). The high measurements for this storm (only 5 over 50 ntu) could have been caused by debris or other anomolies with the in-situ equipment. There was no storm event sample analyzed for this storm so it cannot be compared to TSS concentrations in runoff to help confirm the turbidity measurement. In any case >95% of the measurements were less than 50 ntu, which is the standard for NC class C receiving waters, so theses data show that turbidity in runoff is not a significant water quality concern.

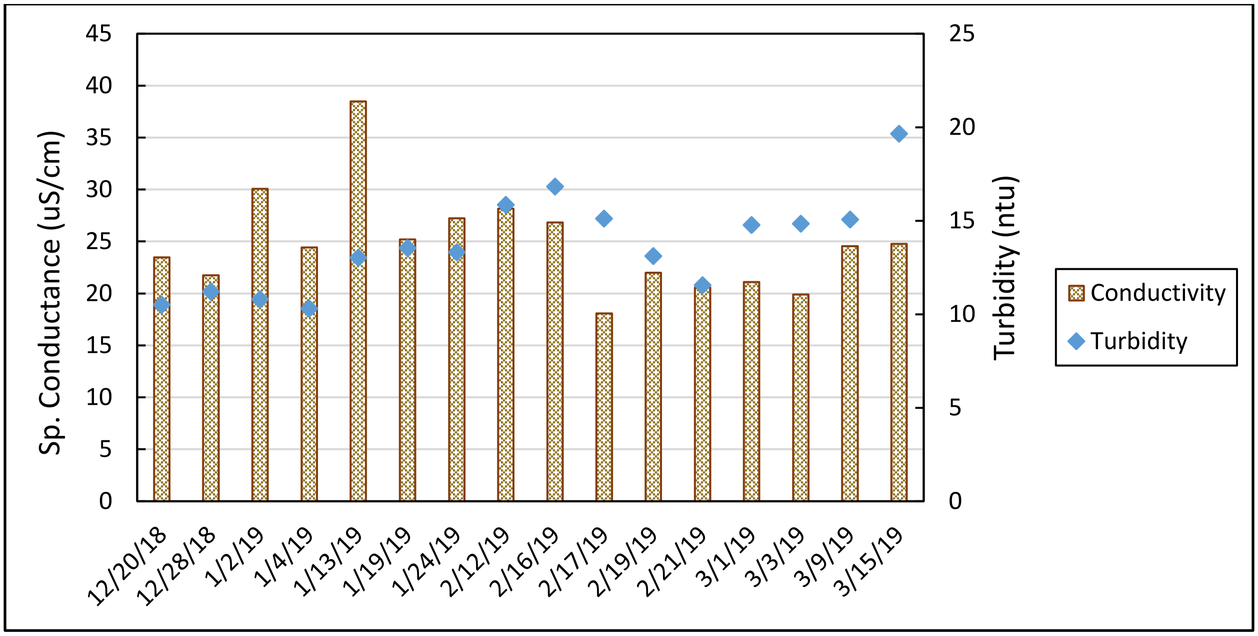


Figure 15. Mean conductivity and turbidity of storm event runoff from the INT-Run site.

To assess the representativeness of the other storm event monitoring data it is important to know the duration of monitoring, how many storms occurred, and how many were successfully monitored and sampled. As shown in Table 8, the monitoring duration for each site was about a year, except for INT-Taxi which did not have runoff monitoring. Each site had at least 19 storms monitored during the nongrowing (Nov.-March) and growing (Apr.-Oct.) seasons. These numbers included only storms of greater than 0.1-inch accumulation, all but 5 (3 at INT-Run and 2 BUY-Apron) of which had successful runoff monitoring. The monitored storms had a wide range of rainfall accumulations and intensities. The number of samples analyzed (≥20 from each site) was less than the number of storms sampled, because on several occasions, 2 or at most 3, storms occurred between visits to retrieve the samples; therefore, the composite sample retrieved was collected during more than one storm. In these cases, the same sample concentration was used to compute loads for more than one storm, but only 1 concentration was used to compute summary statistics for concentration data. Relatively few storms were sampled at BUY-Taxi during the nongrowing season, because 16 of the 25 storms occurring during this season did not produced enough runoff (>400 gal.) to sample (see Appendix B for individual storm data). Storms with minimal runoff occurred at other sites also, especially those with considerable grassed areas such as INT-Run. Thus, this project sampled at least 23 storms from each site with the storms distributed over both the nongrowing and growing season such that annual climate, soil, and vegetation variability should be adequately represented in the runoff data collected. In comparison, a study of airport runoff in Florida concluded that sampling 10 storms per site was sufficient for valid inferences from statistical analyses (FDOT, 2008).

Table 8. Monitoring Duration and Storm Data.

	Dur.	Storms Monitored		Storms Sampled[1]		Samples Analyzed[1]	
		Nov-March	Apr-Oct	Nov-March	Apr-Oct	Nov-March	Apr-Oct
	yr	no.	no.	no.	no.	no.	no.
Smith-Reynolds							
INT-Term	1.0	26	38	14	15	11	13
INT-Run	1.0	25	34	16	10	12	9
INT-Taxi	0.8	19	39	8	15	7	13
Burlington-Alamance							
BUY-Apron	1.0	25	27	14	10	13	8
BUY-Taxi	1.0	27	26	22	4	16	4

[1] Number of storms that samples were collected and analyzed. Some samples were collected from 2 or more storms occurring in close proximity to each other.

Summaries of rainfall, runoff, and sample analysis data are shown in Table 9. The cumulative rainfall for the airport sites varied somewhat due to the different starting and ending dates (BUY= 10/12/19 and INT=11/26/19) for monitoring at each site. The rainfall totals were greater than the long-term average annual precipitation for both airports of 45 inches. The runoff to rainfall ratio ranged from 24% to 62% with the lowest occurring for BUY-Taxi and the highest for INT-Term. The high ratio at INT-Term and low at BUY-Taxi was expected given the high percent of impervious surface for INT-Term (90%) and low (34%) for BUY-Taxi. The relatively low runoff to rainfall ratio for BUY-Apron was unexpected given that it was 95% impervious, but it could be the result of a leaky stormdrain system. After several storm events low flow (<10 gpm) was observed for several days in the stormdrain where the monitoring station was located. This indicated that water was leaking into the drains as the apron was dry, which also indicated that water could leak out. On top of this, the monitoring station was not equipped to measure low flow as highly impervious sites typically do not have extended periods of low flow, so this low flow was not included in the monitored runoff/discharge. The runoff to rainfall ratio for INT-Run (0.34) was higher than expected given that none of the impervious surfaces were directly connected to storm drains; however, 40% of the drainage area to INT-Run was impervious, which would provide a considerable volume of runoff to infiltrate.

The considerable differences in runoff depth compared to rainfall between airport sites indicated significant differences in the rainfall-runoff relationships between sites; therefore, an ANCOVA was conducted to evaluate the statistical significance of the relationships. Prior to conducting the ANCOVA, the assumption of normality was visually evaluated via a Q-Q scatterplot and proved satisfactory. Also, homoscedasticity of the data were confirmed based on the Brown-Forsythe F test ($F_{3,265} = 1.14$, $p = 0.335$).

The full ANCOVA model (all 4 sites with runoff monitoring) indicated that rainfall depth was significantly predictive of runoff depth ($F_{1,261} = 1877.86$, $p < .001$), there was also strong evidence of differences in runoff depths among sites after adjusting for the effect of rainfall on runoff ($F_{3,261} = 3.34$, $p = .020$). Further, the model indicated a statistically significant difference between slopes ($F_{3,261} = 22.02$, $p < .001$) providing substantive evidence that the impact of rainfall on runoff depth differs among sites. Though this result provides statistical evidence of violation to the ANCOVA assumption of independence between the covariate (i.e., rainfall depth) and categorical predictor variable (i.e., site), the observational design of this study affords assurance that these variables are independent. Further, the statistically significant interaction constrains the comparison of runoff depths between sites to specific values of rainfall depth.

To assess how runoff from the airport sites compare to conventional and LID residential sites, an ANCOVA was conducted on the rainfall-runoff relationship for each site. Rainfall and runoff data from the Line and White (2007) study was used for conventional development while data from the Line and White (2016) study was used for the LID. For BUY, the rainfall-runoff relationships for BUY-Apron and the conventional development of Line and White (2007) were not significantly different (fig. 14), whereas the relationships for BUY-Taxi was significantly different from the conventional (Line and White 2007), but was not significantly different from the LID1 of Line and White (2016). Hence, runoff from BUY-Apron was like conventional development and runoff from BUY-Taxi site was similar to LID.

The same analysis was performed for INT-Term and INT-Run. Results showed that the slope of the rainfall-runoff relationship for INT-Term was significantly greater than the conventional development of Line and White (2007) and the slope for INT-Run was not significantly different (figure 15). The high runoff for INT-Term was expected given that the site was covered with a higher percentage of impervious surface (90%) than the conventional development site (53%) and both had impervious surfaces directly connected to storm drains. The similarity between rainfall-runoff relationships for conventional development and INT-Run was not expected given that all of its impervious surfaces drained to pervious grassed areas. However, runoff from the impervious surfaces (40%) likely exceeded the infiltration capacity of the permeable areas, especially during larger storms and possibly for storms occurring during the nongrowing season. In fact, the runoff to rainfall ratio for monitored storms of greater than 1 inch was 0.56 and the ratio for the nongrowing season was nearly twice that for the growing season. In addition, soils on the site appeared to have a relatively high clay content and were likely packed in order to support larger aircraft. These factors combined to lower soil infiltration rates in the permeable, grassed areas. Overall the data for the INT sites show that neither INT-Term nor INT-Run were similar to LID sites from a runoff perspective.

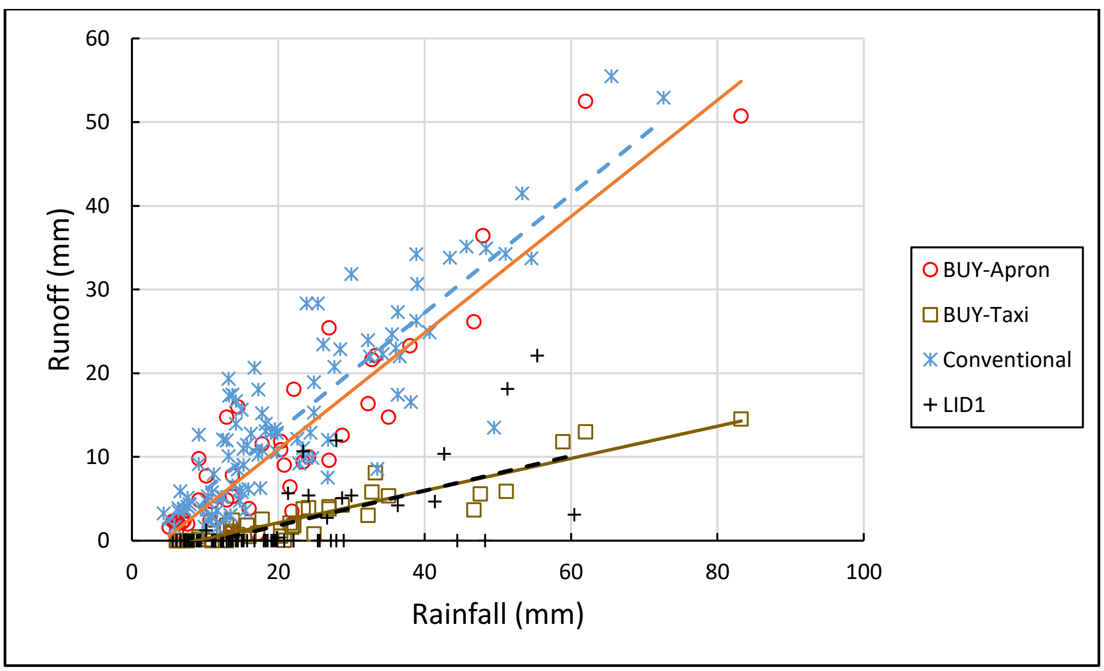


Figure 14. Rainfall-runoff relationships for BUY sites and conventional development.

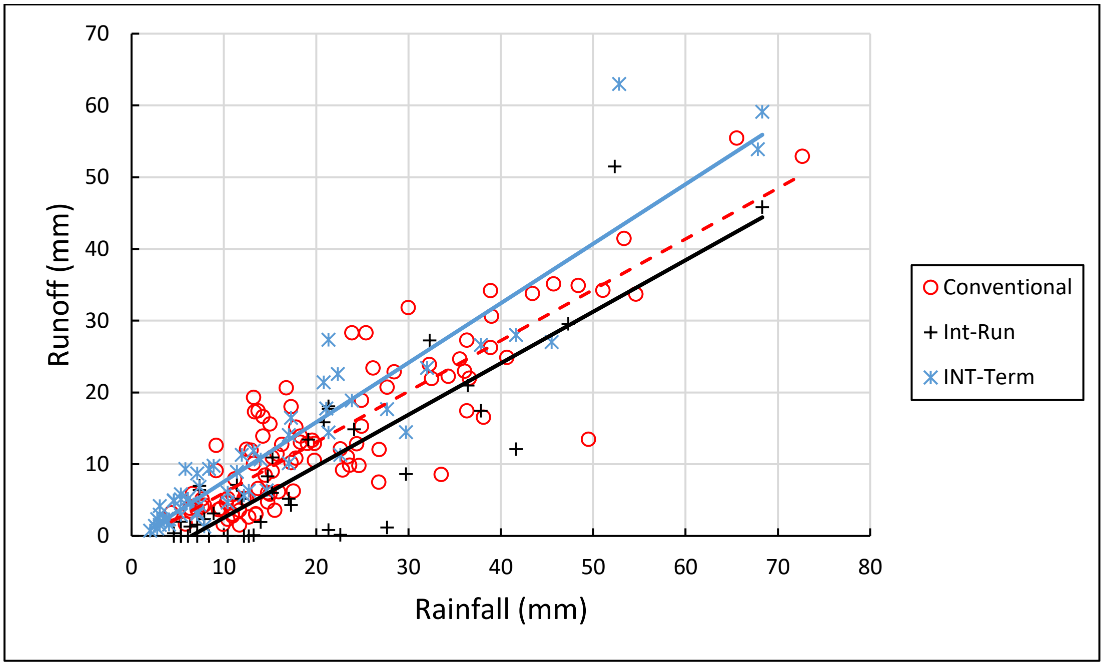


Figure 15. Rainfall-runoff relationships for INT-Term and INT-Run sites.

While runoff quantity provides one metric of comparison with urban land uses, from a water resource perspective more valuable/important comparisons involve pollutant concentrations and loads. The average of the concentrations of TKN, NOx-N, TP, and TSS in runoff samples for each site are shown in Table 9. Because they were flow-proportional samples, the values for INT-Term, INT-Run, BUY-Apron, and BUY-Taxi are equivalent to event mean concentrations (EMCs), while the values for INT-Taxi are simply a general mean concentration. The EMC for TN was highest for the INT-Run site and lowest for the BUY-Apron site. The elevated EMC for INT-Run was expected given that anti-icing material (urea) containing nitrogen was applied to the runway and taxiway in the monitoring station's drainage area, while for BUY-Apron the low TN EMC was expected given that no de-icing/anti-icing materials were applied and runoff was relatively high. The lower TN for INT-Term can be attributed to increased runoff diluting the effect of the anti-icing material. The EMCs for TP were similar among sites, except for the low EMC for BUY-Apron. Given that there was no known addition of phosphorus to any of the sites, the reason for the low TP EMC for BUY-Apron was unknown.

Because there are no standards for N, P, and TSS concentrations in runoff, concentration in runoff will be compared to similar data from other studies for context. Comparing TN and TP concentrations to those from urban runoff in general (Table 2) monitored during the NURP (EPA, 1983), the EMCs from the airport sites were much less. Similarly, mean concentrations of TN, TP, and TSS in runoff from residential areas across the south and northwest U.S. (Table 2) as reported by Maestre and Pitt (2005) were also greater than those from the airport sites. Compared to two commercial sites in NC with no stormwater controls (Table 2) monitored by Line et al. (2012) and Wilson et al. (2015), concentrations of TN and TP in runoff from INT-Run, INT-Taxi, and BUY-Taxi were greater; however, they were much less than TN (4.3 mg/L) and TP (0.38 mg/L) concentrations in runoff from a conventional residential site in the NC

Piedmont region (Line and White, 2007). Concentrations of TSS in runoff from all of the airport sites were less than those from the NC commercial and residential sites.

Table 9. Rainfall, Runoff, and Mean Sample Concentration Data for Airport Sites.

	Start Date	Rain in/yr	Runoff in/yr	Run/ Rain	TN mg/L	TKN mg/L	NOxN mg/L	TP mg/L	TSS mg/L
Smith-Reynolds									
INT-Term	12/13/18	54.19	33.5	0.62	0.98	0.82	0.16	0.13	28.5
INT-Run	12/19/18	54.92	18.8	0.34	2.56	2.46	0.11	0.15	12.9
INT-Taxi	2/10/19	54.17	na	na	1.65	1.33	0.13	0.12	5.9
Burlington-Alamance									
BUY-Apron	10/10/18	52.30	25.2	0.48	0.65	0.50	0.15	0.05	6.6
BUY-Taxi	10/12/18	49.86	11.7	0.24	1.47	1.28	0.20	0.18	4.9

[1] U.S. EPA (1983).

Finally, Schueler and Holland (2000) presented concentrations of N, P, and TSS below which stormwater BMPs become less or even not effective and referred to these as ‘irreducible’ concentrations (Table 2). For TN, the only site with a mean concentration greater was INT-Run and for TP and TSS no site was greater than the irreducible concentration. This indicates that even if stormwater BMPs were required at these sites, significant reductions in concentrations would likely be difficult to obtain.

Annual pollutant export from the four airport sites with runoff monitoring is shown in Table 10. The BUY airport sites had much lower TN, TP, and TSS export rates than the two sites at INT. The reason for the greater TN export at INT was likely the application of an N-based anti-icing material (urea) at INT during winter (nongrowing period) precipitation event(s). This resulted in nongrowing period TN export being more than 1.6 times greater than growing season export for both sites, while the TP export was relatively equal for both periods.

Table 10. Annual Pollutant Export for Airport Sites.

	Start Date	Duration yr	TN	TKN	NOxN	TP	TSS
			----------------------		kg/ha-yr		----------------------
Smith-Reynolds							
INT-Term	12/13/18	0.97	8.48	7.28	1.19	0.92	156
INT-Run	12/19/18	0.95	9.58	9.15	0.43	0.54	43
Burlington-Alamance							
BUY-Apron	10/10/18	1.01	3.63	2.80	0.83	0.31	32
BUY-Taxi	10/12/18	1.00	1.69	1.47	0.22	0.20	6
Other studies							
NC Residential[1]			18-24	16-21	1.8-3.2	1.7-2.3	387-1958
NC Residential LID[2]			3.6-13.9	2.8-10.5	0.8-3.4	0.4-0.9	160-166
NC Commercial[3]			4.5-6.9	3.4-5.5	0.1-1.4	0.4-0.5	97-244
NC Commercial LID[3]			0.1-4.3	0.1-1.5	0.1-2.7	0.01-0.2	2-8

[1] Line et al. (2002) and Line and White (2007).
[2] Line and White (2007).

[3] Line et al. (2012) and Wilson et al. (2015).

The TN, TP, and TSS annual load/export (Table 10) from all 4 airport sites were less than those reported for two newly-developed residential sites in Piedmont NC (Line et al., 2002 and Line and White, 2007). Compared to residential LID, TN export from the INT sites was near the middle of the range, while TP export was similar to the range for LID with the export for INT-Run being near the bottom of the range and that for INT-Term near the top. Export of TSS from INT-Term was similar to that from residential LID, while export from INT-Run was much less. For the BUY sites, export of TN, TP, and TSS was near or less than the bottom of the range for the residential LID sites. Thus, these data indicate that overall, TN, TP, and TSS export from airports is less than conventional residential areas, but greater than LID residential areas.

The TN export from the INT sites was greater than that for the commercial sites, mostly because the TKN export was much greater. This can be attributed to the urea application for airfield anti-icing as urea is nearly all ammonia, which is a part of TKN, but not NOx-N. The TP export from INT-Term was greater than that for the commercial sites, while export from INT-Run was similar. Export of TSS was within the range or less than that from the commercial sites, likely because the INT sites were either covered with nonerodible surfaces or stable vegetation. Export of TN, TP, and TSS was much greater than that for the commercial LID sites. For the BUY sites, TN, TP, and TSS export was less than those for the commercial sites; however, export of TP and TSS from BUY-Term was greater than those from the commercial LID sites, while TN was within the range of export from the commercial LID sites. For the BUY-Taxi site, export of TN, TP, and TSS was within the ranges of exports from the commercial LID sites. Hence, while pollutant export from the two BUY sites could be considered similar to that from commercial LID sites, export from the two INT sites were more like conventional commercial sites.

When considering TN, TP, and TSS export from the BUY airport overall, the relative extent of the areas must be considered. At BUY the taxiway/runway comprised about 61% of the airport land area with another 38% being areas with permeable grassed areas between impermeable surfaces and concentrated flow conveyances; therefore, TN, TP, and TSS export from the airport should be similar to that from BUY-Taxi, which was similar to a residential LID. For INT, the runway/taxiways comprised about 57% of the airside of the airport, while the rest of the area was repair facilities; miscellaneous buildings, paved, and unpaved areas; thus, TN, TP, and TSS export from the airport overall is uncertain.

5 Summary and Conclusions

Monitoring of runoff from one airport in Wilmington, NC and several in Florida have shown that, due to the configuration (downslope of impervious surfaces) and extent of grassed areas, runoff from airports located in coastal regions was similar to runoff from LID residential development. This project was conducted to determine if this was also the case for small airports located in the Piedmont region of NC. Rainfall and runoff were monitored for about one year at five sites on the Burlington-Alamance (BUY) and Smith-Reynolds (INT) airports located in the Piedmont region of NC. Land use in the drainage areas to the five sites were representative of the airside of airports with three sites (INT-Run, INT-Taxi, and BUY-Taxi) on the runway/taxiway area and two sites (INT-Term and BUY-Apron) on the terminal apron area.

- Rainfall-runoff relationships for three of the four sites were similar to those from conventional residential development while one taxiway site (BUY-Taxi) was similar to a residential LID development. Thus, runoff from some of the runway/taxiway areas of airports in the Piedmont is likely similar to LID while others likely are not.
- Levels of conductivity and turbidity in runoff at INT-Run measured during 16 storm events were less than those considered to be a water quality concern.
- Concentrations of TN, TP, and TSS in runoff from all five airport sites were less than those from urban runoff across the U.S. and less than those reported for several residential areas of NC, but they were greater than some of those reported for commercial areas. Mean concentrations of TP and TSS for all five sites and TN for 4 of the 5 sites (the site with the elevated TN had urea applied as an airfield anti-icing agent) were less than the corresponding concentrations considered to be irreducible (concentrations at which stormwater BMPs become less or ineffective).
- Cumulative storm event load data documented that for three of the four airport sites TN, TP, and TSS export was less than conventional residential sites of NC, but greater than two LID residential areas. The fourth site had TN, TP, and TSS export less than or equal to that reported for a residential LID.
- While TN, TP, and TSS export from the two BUY sites could be considered similar to that from commercial LID sites, export from the two INT sites were more similar to conventional commercial sites.
- Given that TN, TP, and TSS export from the runway/taxiway areas of both airports was less than those from monitored residential areas and one was similar to a residential LID and that runway/taxiways comprise >60% of the land area of small airports, it is reasonable to conclude that TN, TP, and TSS export from small rural airports is less of a water quality concern than that of residential developed areas. However, additional monitoring data is needed to substantiate this.

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Appendix A: QAPP

A. Quality Assurance Project Plan

This Quality Assurance Project Plan (QAPP) is similar (with some specific information for this project added) to the one that NCSU-BAE personnel have used for several water quality monitoring projects conducted for NC DOT, NCDEQ, NC DMS, and U.S. EPA. The sample collection, handling, and data management procedures are generally ones that have been accepted by these state and federal agencies as well as the research community.

A1. Problem Definition/Background

Problem Statement

Few data exist to characterize the quantity and quality of runoff on the airside of small airports, especially those in the Piedmont region of NC. Thus, the purpose of this project was characterize concentration and runoff of airside usage areas within small airports in the Piedmont area of NC.

Intended Usage of Data

It has been suggested that overland flow over grassed areas on the airside of small airports effectively reduces pollutant concentrations and loads to levels similar to LID developments. Thus, presumptive pollution control requirements (BMPs) that have been required to treat and control runoff from the airside of large commercial airports, highways, parking lots, and commercial development may not be needed for small airports. The monitoring data from this project will be combined with data from an airport in the Coastal Plain and compared to data from conventional and LID residential and commercial areas to guide future policy/decisions regarding runoff from small airports.

A2. Project/Task Description

General Overview of Project

The objective of this project was to monitor runoff from the two major land use areas of the airside of two relatively small airports located in the Piedmont region of NC. The areas include the runway/taxiway and terminal areas of each airport. Monitoring will be conducted for about one year to collect runoff data for both the growing and nongrowing seasons. Monitoring will require the use of tipping bucket raingages, automated samplers, and flowmeters. Most of this equipment is currently available in the NCSU BAE Dept., but some will need to be repaired/reconditioned prior to use. Cooperation from two airports (already obtained) will be critical to the success of this project. The relatively short timeframe will require that there is enough equipment and personnel to operate all 5 monitoring stations simultaneously, that the stations be installed quickly, and that most of the storms that occur will be successfully monitored.

Project Timetable

Activity	Start Date	Known or Anticipated Date of Completion
Install monitoring stations	10/5/18	2/1/19
Monitor storms/runoff	10/6/18	11/25/19
Analyze data	2/1/19	6/15/20
Write reports	12/31/19	8/30/20

B. Quality Objectives and Criteria

B1. Data Representativeness.

There are at least two aspects to data representativeness: 1. Does the proposed monitoring design/configuration including location represent runoff from small airports and 2. Does the monitoring scheme adequately represent the quantity and quality of the runoff at each monitoring station on the airports. The Burlington airport is a small more rural airport, while the Smith-Reynolds airport is a small to medium-sized more urban airport in the Piedmont region of NC. Together they should adequately represent the range of conditions at small airports in the Piedmont. Nevertheless all airports are unique; thus, the degree to which these airport represent the actual range of small airports in the Piedmont is unknown. Airports have basically two main land uses on the airside: a terminal area and runways/taxiways. This project was designed to monitor runoff from the majority of the two terminal areas and parts of 3 taxiway/runway areas. Runoff from the terminal areas should be adequately characterized because the monitoring included most of the area at each airport. Because runoff from the runway/taxiway areas was widespread only runoff from part of the area could be monitored; however, since all of the taxiway/runways are basically built to the same specifications, any part should be representative of the whole as long as it wasn't either end. None of the three monitoring sites will be at the end of the taxiway/runway.

The monitoring scheme included continuous measurement of rainfall and runoff in addition to flow proportional sampling of runoff for at least 20 storms during a year with some occurring during both the growing and nongrowing seasons. The drainage area to the monitoring stations should encompass at least an acre from each desired land use. A range of storm sizes and types and antecedent conditions is expected to occur during the 20 storms in one-year period so that variations in both storm characteristics and land use activities will be encountered. In general, a minimum of 15-20 storms events has been shown to be adequate to characterize runoff from nonpoint source areas such as those from the airports. A study of airport runoff in Florida concluded that 10 storms sampled per site were sufficient for valid inferences from statistical analyses (FDOT, 2008). Hence, this scheme should be adequate to characterize the quantity and quality of runoff from the airport land use areas.

FDOT. (2008). Technical report for the Florida statewide airport stormwater study. Florida Department of Transportation (FDOT).

B2. Data Comparability

Monitoring data from the sites with discharge measurement and flow-proportional sampling will be collected in the same manner, so it is comparable within and outside the project. Flow proportional samples will be collected which is considered the most representative of runoff sampling methods. Standard methods of analysis will be used to provide analyses data that is comparable to other studies. Loads will be computed using discharge and sample concentration data. A sufficient number of storms will be monitored during the project to provide and accurate measure of annual load/export. Given the standard monitoring techniques and analysis methods, these data will be comparable to any runoff data collected similarly.

B3. Data Completeness

Parameter	Valid Samples Anticipated (no.)	Valid Samples needed (no.)	Percent Needed
EMC for N, P, TSS[1]	**20**	**20**	**100**
Export/load for N, P, TSS	**20**	**20**	**100**
Rainfall	**20**	**varies**	**na**
Discharge	**20**	**20**	**100**
Conductivity	**Varies**	**10 storms**	**na**

[1] Event mean concentration for nitrogen (N), phosphorus (P), and TSS.

C. Documents and Records

Recording Medium	Purpose	Responsible Party
Computer Spreadsheet	NCSU Lab data	D. Line/R. Rahn

Computer spreadsheet	In situ and sample analysis data	D. Line/R. Rahn
Field Book	Observations in the field	R. Rahn

D. Sampling Process Design

Rationale for Selection of Sampling Sites

Monitor runoff from land uses representative of taxiways, runways, and terminal areas of airports. At least one area from each airport to provide a measure of variability in airports. In addition, Burlington is a more rural small airport whereas Smith-Reynolds in Winston-Salem is more urban. Actual site selections will be based on finding a stormwater outfall/drainage feature that is suitable for monitoring which also represents the land use and one that the airport will facilitate/allow access to. Airports cannot allow people on or near the runways/taxiways or in some other areas so choice of sites will be limited.

Sample Design Logistics - Sample numbers and frequency

Type of Sample/ Parameter	Number of Samples	Sampling Frequency and Period
Storm sample	1/storm; 20 per/site	Storm events for growing and nongrowing season of one year
Rainfall	varies during 20+ storms	Continuous every 5-10 minutes for the project period
Discharge	varies during 20+storms	Continuous but varies for sites; whole project
Conductivity	Varies depending on storms; 5+ storms	Continuous every 15 minutes for 5+ storms during nongrowing season

D1. Sampling Methods - Identify sampling equipment, collection methods and SOPs

Parameter	Sampling Equipment	Sampling Method
N, P, and TSS	auto sampler	Flow proportional
Discharge	sampler flowmeter	In-situ continuous

Rainfall	Tipping bucket	On-site & continuous
Conductivity	Sonde	In-situ continuous for 5+ storms

Sample**s** will be collected by an automated sampler during runoff events. Sampler intake will be mounted in a stormwater conveyance channel such that during most rainfall events the intake will be submerged. Runoff from low accumulation (<0.1 inch) and/or low intensity rainfall (<0.02 in/hr) may not be sampled due to the sampler intake not being submerged sufficiently. A computer-controlled peristaltic pump will draw sub-samples/aliquots from the runoff in the channel in proportion to the runoff/discharge measured at the site. Where discharge measurement is not possible, either rainfall or time-paced sampling will be conducted. Flow-proportional sampling requires that discharge be measured continuously. This will be accomplished via an integrated flowmeter connected to the sampler which will continuously measure water level and convert these measurements to discharge via a stage-discharge relationship. The stage-discharge relationship will be programmed into the automated sampler according to the type of flow measuring device (i.e. v-notch weir, area-velocity (AV) meter installed in round pipe) being employed. Duplicate flow-proportional sub-samples will be collected during each event with one placed in odd-numbered bottles (H_2SO_4 added to bring pH to <2 immediately) and the other in even-numbered bottles (no preservation).

For rainfall, a tipping bucket raingage will be installed at each airport and connected to one of the automated samplers. The raingage will be installed level and will be located at least 100ft from trees or other tall objects to prevent interference from the objects. A manual raingage will also be installed at the airport for comparison to the tipping bucket gage or in case of a malfunction.

Conductivity measurements will be made during 5+ winter storms via a Sonde with a specific conductance probe installed in the runoff conveyance channel such that during a storm event the probe will be submerged. Water level will be measured simultaneously so that only measurements made when the probe is submerged will be used.

D2. Sample Handling and Custody

Standard Methods for Water and Wastewater recommends that water samples be maintained at less than 4º C from the time of sample collection until being processed by the laboratory (Eaton et al., 1995). This is primarily a regulatory requirement that was established assuming a high level of biological activity as is often the case for wastewater, but is rarely the case for stormwater. Airport security, site-access constraints, the unpredictability of storm events, and high temperatures made it impossible to continuously store samples, collected by automated samplers, at <4º C using ice from the time of collection until delivery to the lab. Use of refrigeration equipment was also impractical if not impossible, particularly at runway sites due to height restrictions and lack of power supply. This is the case for many if not most stormwater monitoring research projects. In fact, many NC DOT research studies of stormwater runoff from highways and other facilities (e.g. Wu and Allan, 2009) and many other monitoring studies of runoff have left samples unpreserved at ambient conditions in automated samplers for up to 48 hours prior to retrieving the samples and cooling them.

At both airports in this project, samples to be analyzed for N and P will be preserved at ambient temperatures by adding appropriate amounts of H_2SO_4 to the sampler bottles (odd numbered bottles from which the N and P analysis was conducted) to reduce the pH<2 immediately upon collection. This has been shown to be an adequate method of preservation of surface water samples for up to 7 days (Line, 2015; Kotlash and Chessman, 1998; Burke et al., 2002 see references below). Most samples will be retrieved and delivered to the laboratory refrigerator within 48 hours of collection; however, samples will still be considered acceptable if retrieved and delivered to the lab refrigerator (cooled to <4º C) within 7 days of sample collection. Sample in bottles (even numbered) used for TSS analysis will be unpreserved until delivered to the laboratory refrigerator. Because nearly all of the mass of solids in the sample will be soil particles, which are very stable over time, the sample TSS concentration should be stable over at least 7 days at ambient conditions. This was confirmed by Line (2015) for surface water samples held in an automated sampler. The H_2SO_4 in bottles prior to sample retrieval and delivery to a lab refrigerator and no preservative for TSS samples is the same method of preservation used in a Florida study of stormwater runoff from airports (Florida Dept. of Transportation, 2008 see reference below) as well as Line (2015) and Burke et al. (2002).

When retrieved by NCSU personnel, sampler bottles will be capped prior to handling to eliminate the possibility of touching the inside or rim of the bottles. Bottles will then be removed and vigorously shaken while being inverted. Then an appropriate volume of sub-sample (based on the volume of sample in each bottle) will be poured (odd numbers for N and P and even for TSS) into a graduated compositing bottle. When the appropriate amount of sub-sample from each sampler bottle has been added to the composite sample, it will be capped, shaken, and then poured into the appropriate laboratory bottle. Composite samples will be submitted to the BAE Environmental Analysis Lab (BAE) where they will be held at <4ºC until analysis. A chain-of-custody form (see example in Appendix) will accompany the sample from retrieval through lab analysis. Analysis will be conducted using standard/approved methods as outline in the Table D3 below.

Conductivity analysis of samples was conducted in-situ via a Eureka Sonde that was calibrated prior to installation. Data from the Sonde will be transmitted to and stored in the automated sampler on-site.

Field personnel (graduate student) responsible for sample and data collection will be provided with in-house training on sample prior to their involvement with sampling and data collection.

Burke, P.M., S. Hill, N. Iricanin, C. Douglas, P. Essex, D. Tharin. 2002. Evaluation of Preservation Methods for Nutrient Species Collected by Automatic Samples. Environmental Monitoring and Assessment 80:149-173.

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Wu, J. and C. Allan. 2008. Evaluation of Nutrient Loading Rates and Effectiveness of Roadside Vegetative Connectivity for Managing Runoff from Secondary Roadways. RP2007-04. North Carolina Department of Transportation, Center for Transportation and the Environment, Raleigh, North Carolina.

Parameter	Preservation	
TKN, NH3, NOx, TP	H_2SO_4 to pH<2 in field and cool <4º C in lab	
TSS	None in field and cool<4º C in lab	
Conductivity	None, analysis in-situ	

D3. Analytical Methods

Parameter	Method	Source	PQL or RL
			mg/L
TKN	4500N orgB	Standard Methods	0.20
NH3-N	4500-NH3 G	Standard Methods	0.02
NOx-N	4500-NO3-E	Standard Methods	0.01
TP	4500-P F	Standard Methods	0.03
TSS	2540D	Standard Methods	3.0

D4. Quality Assurance/Quality Control

Field QC Checks

Activity	QC Procedure	Purpose
Field blank	Fill lab bottle with distilled water cap submit to lab	Test field and lab procedures for contamination. Test lab for uncertainty near low end of measurement range.
Blind standard	Purchase certified standard and dilute with lab DI water to median/average concentration of runoff samples	Test accuracy of lab analysis near middle of measurement range
Duplicate	Make two composite samples from sampler bottles submit	Test repeatability/technique of composite sample

Laboratory QC Checks - Describe Laboratory QC procedures

Laboratory QC checks will be made during the project. Analyses of matrix spike and matrix spike duplicate samples are required to demonstrate method accuracy and precision, and to monitor interferences caused by the sample matrix. A series of 10 recoveries, blanks, and spikes will be run for about every 100 samples analyzed. In addition, a spot check of maximum holding times (MHTs) for 5% of samples will be conducted.

Data Analysis QC Checks- Describe data analysis QC procedures

Data are checked by both lab manager and project manager for consistency. Samples are saved for 30 days. If sample concentration is >2x mean then data analysis is checked and if requested sample is reanalyzed. Discharge and rainfall data are also checked for consistency. Water level measurements are checked during each site visit. Unusual and/or missing rainfall measurements are compared to nearby NC Climate Office gages and adjustments made, if necessary.

D5. Instrument/Equipment Testing, Inspection, and Maintenance -

Equipment Type	Inspection Frequency	Type of Inspection
Laboratory equipment		Follows manufacturers approved procedures

Field equipment are thoroughly checked and cleaned prior to installation and routinely checked during each visit. Maintenance is conducted as needed to ensure proper operation during monitoring. Deviations from the normal such as unexpected sample volume, no sample collected, and improper level measurement are investigated and corrected, if needed, as soon as possible. Level measurements by automated sampler flow module are compared to actual water depths during visits and adjustments made as need.

D6. Inspection/Acceptance of Supplies and Consumables

Equipment/Supply	Inspection/Maintenance Activity	Acceptance Criteria
ISCO 6712 Sampler	Record screen data	Level and bottle fill record consistent with storm data
Lab bottles	Look for cracks and cleanliness	no cracks or dirt, etc.
Sampler tubing	Observe every site visit	No cracks, holes, or kinks

D7. Non-Direct and Direct Measurements -

Data Element/Measurement	Minimum Data Recording Method
NA	

D8. Data Management

• Rainfall and runoff/discharge data will be downloaded directly from the automated samplers onsite. Readings of key variables such as sampler status, water level, bottles filled, and flow volume will be recorded on field forms. The downloaded data and field forms will be forwarded to a central data-management location.
• Field and downloaded sampler data will be combined into one master file for each event.
• Lead engineer and/or student will reduce the data using graphical procedures for each event.
Graphs of stage-discharge, rainfall-runoff and hydrograph-hyetograph overlays will be prepared and individually evaluated.
• Reduced and interpreted data will be used for the volume portion of the load calculation.
• The project laboratory will provide results in electronic format to lead engineer/student who will enter into master file.
• Extreme or unexpected values will be examined and evaluated as to cause.
• Data from field blanks, blind standards, laboratory QC analysis, and "Split" or duplicate samples will be reviewed by the lead engineer and the laboratory manager to assess validity of the data.

Data Type	Management and Storage
Sample analysis data	Spreadsheet with data emailed from lab to desktop PC in office, data entered into master spreadsheet file
Observation data	Observations entered into field book by technician and brought to office, data then entered into spreadsheet file

Photos	Digital photos of site entered into project directory

D9 Data Review, Verification and Validation

Field blanks will be acceptable if the measured parameters are less than the Practical Quantification Limit (PQL) or reportable limit (RL) set by the lab. If greater than the PQL, lab and field techniques and supplies will be reviewed for the source of the uncertainty and/or contamination. Corrections in technique or changes in supplies such as bottles will be made. Field duplicates will be acceptable if measured parameters are within 15% of each other for samples with concentrations within the interquartile range (1^{st} to 3^{rd} quartile). If outside 15% techniques will be evaluated and retesting will occur.

D10. Verification and Validation Methods

Data Element	Typical Validation and Verification Methods
Data chain-of-custody	data will be managed by project QA officer
Data presentations/reports	raw data will be held by project QA officer and released on a limited basis, data in reports will be preliminary until adequately checked and confirmed by the project manager

Biological and Agricultural Engineering, NCSU
Environmental Analysis Lab (BAE EAL)

Chain of Custody Sheet

Date sampled: ____________ Date Submitted ____________

Number of Samples ____________

Delivered by: ____________ PA Number: ____________

Site: ____________

Type: ________ Source: ____________ Nature: ____________

Liquids (mg/L) Solids (ug/g wet weight unless noted)

CODE	TKN	NH3N	NO3N	TP	O-PO4-P	CL	COD	PH	%TS/MC	%VS	TSS	VSS	COND	ALKAL	TOC
Burl-padN&P	X	X	X	X											
Burl-padTSS											X				
Burl-taxiN&P	X	X	X	X											
Burl-taxiTSS											X				

WS-runN&P	X	X	X	X											
WS-runTSS											X				
WS-termN&P	X	X	X	X											
WS-termTSS											X				
WS-taxiN&P	X	X	X	X											
WS-taxiTSS											X				

Appendix B: Monitoring Data

Table B1. Monitoring Data for INT-Term.

Date	****** Precipitation ******				****** Runoff ******			**** Sample Analysis ****			
	Total in	Peak in/hr	Ave in/hr	Dur. hr	Total gal	Peak gpm		TKN mg/l	NOx mg/l	TP mg/l	TSS mg/l
12/13/18	1.10[1]	na	na	28	71672	621	30	0.57	0.12	0.05	11.2
12/20/18	1.86[1]	na	na	24	82606	265	34	3.12	0.10	0.10	9.9
12/28/18	1.27[1]	na	na	16	88548	848	17				
12/31/18	0.18[1]	na	na	7	14498	55	15				
1/2/19	0.60[1]	na	na	16	19233	60	15				
1/4/19	0.60[1]	na	na	13	29658	120	24	0.75	0.08	0.12	36.1
1/13/19	0.95[1]	na	na	30	42786	175	24	0.24	0.10	0.09	11.3
1/19/19	0.75[1]	na	na	15	47835	340	21	0.45	0.14	0.04	30.1
1/24/19	1.43[1]	na	na	24	118016	600	27	0.31	0.10	0.09	12.0
2/10/19	0.18	0.05	0.02	11	14102	62	12				
2/11/19	0.23	0.05	0.01	17	26933	108	11				
2/12/19	0.12	0.09	0.04	3	12060	299	4	0.41	0.22	0.02	1.8
2/16/19	0.21	0.06	0.04	6	14709	190	10				
2/17/19	0.83	0.19	0.09	9	51287	400	10	0.28	0.05	0.03	25.8
2/19/19	0.84	0.08	0.02	38	78873	370	48				
2/21/19	2.08	0.15	0.04	48	181848	470	72				
3/1/19	0.82	0.24	0.12	7	61792	643	8	0.94	0.25	0.02	43.2
3/3/19	0.29	0.10	0.07	4	19819	230	12	0.78	0.13	0.04	16.7
3/9/19	0.28	0.03	0.00	60	25179	105	60	1.31	0.72	0.17	30.5
3/15/19	0.47	0.22	0.06	8	32672	750	22				
3/21/19	0.21	0.05	0.02	9	16750	80	12				
3/25/19	0.18	0.04	0.03	6	14336	105	11				
4/5/19	0.68	0.12	0.10	7	47578	270	21	1.79	0.17	0.17	5.9
4/8/19	0.35	0.13	0.03	14	28241	470	20				
4/12/19	0.45	0.34	0.45	1	25834	805	3	1.40	0.10	0.12	158.8
4/13/19	0.29	0.1	0.05	5.4	12534	172	7	1.51	0.10	0.13	144.7
4/15/19	0.08	0.07	0.04	1.9	2113	115	2				
4/19/19	0.11	0.05	0.02	6.8	3079	79	8				
4/26/19	0.15	0.1	0.06	2.4	6843	307	8				
5/4/19	0.16	0.03	0.01	19	4557	60	21				
5/7/19	0.10	0.07	0.03	3	4100	223	11				
5/11/19	0.33	0.18	0.07	4.4	26934	576	11	0.63	0.11	0.36	4.0
5/12/19	0.41	0.24	0.26	1.6	17393	426	6	0.61	0.10	0.44	15.8
5/23/19	0.48	0.34	0.14	3.3	16288	522	6				
5/31/19	0.50	0.41	0.25	2	18267	1043	4				
6/2/19	0.28	0.21	0.37	0.8	9590	628	4				
6/5/19	0.12	0.1	0.13	0.9	5726	311	4				

6/6/19	0.28	0.25	0.26	1.1	8804	844	6				
6/7/19	2.67	0.38	0.06	41	155586	1473	46				
6/10/19	0.12	0.11	0.21	0.6	4388	209	3	0.67	0.11	0.06	33.9
6/12/19	0.67	0.03	0.11	6	40605	270	18	0.43	0.04	0.32	4.8
6/17/19	1.26	0.13	0.16	8	67663	1420	14	0.54	0.25	0.06	31.40
6/18/19	0.94	0.18	0.13	7	54461	1400	12	0.65	0.18	0.06	33.3
6/20/19	0.58[1]	0	0.00	0	18375	1600	5				
6/22/19	1.79[1]	0	0.00	0	77996	2200	24				
7/7/19	0.25	0.07	0.25	1	13082	600	7				
7/9/19	0.16	0.14	0.06	3	3859	85	4				
7/22/19	1.64	0.27	0.05	30	80896	600	33	0.53	0.24	0.14	9.52
8/1/19	0.41	0.27	0.09	5	13503	240	12	0.92	0.36	0.12	8.21
8/13/19	0.15	0.15	0.45	0	6505	400	3				
8/19/19	1.09	0.66	0.55	2	51067	2100	3				
8/22/19	1.17	1.10	2.34	1	41724	2100	3				
8/24/19	0.55	0.22	0.14	4	30759	360	6				
9/28/19	0.89	0.50	0.89	1	32634	1800	2				
10/13/19	0.21	0.11	0.05	4	8473	170	6				
10/16/19	0.84	0.18	0.11	8	41647	320	14	0.36	0.07	0.23	2.38
10/19/19	1.49	0.41	0.17	9	76816	800	9	0.49	0.04	0.04	2.26
10/22/19	0.67	0.53	0.17	4	29246	1200	9				
10/27/19	0.52	0.19	0.09	6	34240	440	14				
10/30/19	2.69	0.41	0.07	36	170589	1050	40				
11/7/19	0.11	0.03	0.05	5	6819	40	5				
11/12/19	0.24	0.10	0.05	5	14938	90	7				
11/18/19	0.12	0.05	0.04	3	8566	60	6				
11/23/19	0.88	0.19	0.11	8	65212	275	21				

[1] Rainfall from NC State Climate Office.

Table B2. Monitoring Data for INT-Run.

Date	****** Precipitation ******				****** Runoff ******			**** Sample Analysis ****			
	Total in	Peak in/hr	Ave in/hr	Dur. hr	Total gal	Peak gpm	Dur. hr	TKN mg/L	NOx mg/L	TP mg/L	TSS mg/L
12/20/18	1.86[1]	na	na	24	187,354	344	56	1.59	0.09	0.07	16.3
12/28/18	1.27[1]	na	na	16	172,698	991	29				
12/31/18	0.18[1]	na	na	7	2,451	4	16				
1/2/19	0.60[1]	na	na	16	37,962	105	27				
1/4/19	0.60[1]	na	na	13	69,246	152	17	3.06	0.05	0.39	6.6
1/13/19	0.95[1]	na	na	30	94,280	276	28	4.71	0.08	0.08	3.3
1/19/19	0.75[1]	na	na	15	85,219	416	18	1.46	0.12	0.05	5.4
1/24/19	1.43[1]	na	na	24	132,818	567	24	0.91	0.08	0.10	5.4
2/10/19	0.18	0.05	0.02	11	0	0	0				
2/11/19	0.23	0.05	0.00	17	0	0	0				
2/12/19	0.34	0.09	0.19	3	52,790	123	19	2.93	0.12	0.22	10.8
2/16/19	0.21	0.06	0.04	6	12,613	45	17				
2/17/19	0.84	0.19	0.09	9	112,211	852	24	1.37	0.06	0.08	13.5
2/19/19	0.84	0.08	0.02	38	134,720	297	44				
2/21/19	2.06	0.15	0.04	48	341,924	711	50	1.34	0.06	0.03	3.36
3/1/19	0.82	0.24	0.12	7	100,577	617	16	1.69	0.05	0.06	7.2
3/3/19	0.29	0.10	0.07	4	44,207	228	15	4.41	0.09	0.21	9.9
3/9/19	0.28	0.03	0.00	60	9,918	32	12	1.85	0.15	0.11	7.8
3/15/19	0.47	0.22	0.06	8	32,979	220	12				
3/21/19	0.21	0.05	0.02	9	0	0	0				
3/25/19	0.18	0.04	0.03	6	0	0	0				
4/5/19	0.68	0.12	0.10	7	27,199	130	18	3.69	0.14	0.22	57.1
4/8/19	0.35	0.13	0.03	14	19,862	61	22				
4/12/19	0.45	0.34	0.45	1	45,042	650	8	4.02	0.05	0.16	17.4
4/13/19	0.29	0.10	0.05	5	40,689	102	19	3.03	0.04	0.04	12.3
4/15/19	0.08	0.07	0.04	2	0	0	0				
4/19/19	0.11	0.05	0.02	7	0	0	0				
4/26/19	0.15	0.10	0.06	2	0	0	0				
5/4/19	0.16	0.03	0.01	19	0	0	0				
5/7/19	0.10	0.07	0.03	3	0	0	0				
5/11/19	0.33	0.18	0.07	4	0	0	0				
5/12/19	0.41	0.24	0.26	2	0	0	0				
5/23/19	0.48	0.34	0.14	3	4,055	na	na				
5/31/19	0.50	0.41	0.25	2	5,612	na	na				
6/2/19	0.28	0.21	0.37	1	0	0	0				
6/5/19	0.12	0.10	0.13	1	0	0	0				
6/6/19	0.28	0.25	0.26	1	0	0	0				
6/7/19	2.67	0.38	0.67	4	174,448	na	na				
6/10/19	0.12	0.11	0.21	1	0						

6/12/19	0.67	0.03	0.11	6	18,838	na	na				
6/17/19	1.26	0.13	0.16	8	107,890	1100	9				
6/18/19	0.94	0.18	0.13	7	126,968	1250	11	2.38	0.00	0.05	5.1
6/20/19	0.58[1]	na	na	na	47,870	620	11	2.93	0.19	0.21	5.9
6/22/19	1.79[1]	na	na	na	106,136	na	na				
7/7/19	0.25	0.07	0.25	1	8,307	150	3				
7/9/19	0.16	0.14	0.06	3	24,922	200	6				
7/22/19	1.64	0.27	0.05	30	76,662	300	22	2.12	0.19	0.12	13.5
8/1/19	0.41	0.21	0.10	4	0	0	0				
8/19/19	1.09	0.66	0.55	2	7,521	145	5				
8/22/19	1.17	1.10	2.34	1	54,754	1050	4				
8/24/19	0.55	0.22	0.14	4	12,322	145	7				
9/28/19	0.89	0.50	0.89	1	1,122	32	3				
10/13/19	0.21	0.11	0.05	4	0	0	0				
10/16/19	0.84	0.18	0.11	8	5,144	48	12	3.42	0.53	0.33	58.1
10/19/19	1.49	0.41	0.17	9	110,518	470	13	0.86	0.06	0.21	3.33
10/22/19	0.67	0.53	0.17	4	33,043	370	9	1.87	0.05	0.13	4.00
10/27/19	0.52	0.19	0.09	6	839	5	11				
10/30/19	2.69	0.41	0.07	36	290,672	910	44				
11/12/19	0.24	0.1	0.05	5	0	0	0				
11/18/19	0.12	0.05	0.04	3	0	0	0				
11/23/19	0.88	0.19	0.10	9	65,642	400	24	1.94	0.07	0.23	4.90

[1] Rainfall from NC State Climate Office.

Table B3. Monitoring Data for INT-Taxi.

Date	****** Precipitation ******				**** Sample Analysis ****			
	Total in	Peak in/hr	Ave in/hr	Dur. hr	TKN mg/L	NOx mg/L	TP mg/L	TSS mg/L
2/10/19	0.18	0.05	0.02	11.3	0.98	0.12	0.07	5.88
2/11/19	0.23	0.05	0.01	16.8	0.98	0.12	0.07	5.88
2/12/19	0.12	0.09	0.04	3.1				
2/16/19	0.21	0.06	0.04	5.8				
2/17/19	0.75	0.19	0.08	9.2	0.59	0.06	0.06	4.55
2/19/19	0.84	0.08	0.02	38.0				
2/21/19	1.94	0.15	0.05	42.0	0.56	0.08	0.02	0.74
2/24/19	0.14	0.03	0.02	5.8				
3/1/19	0.89	0.24	0.05	19.1	0.64	0.18	0.01	2.22
3/3/19	0.29	0.10	0.07	4.0	0.59	0.15	0.04	4.32
3/8/19	0.14	0.05	0.01	11.3				
3/9/19	0.14	0.03	0.01	12.5				
3/15/19	0.09	0.07	0.11	0.8				
3/15/19	0.38	0.22	0.09	4.3				
3/20/19	0.21	0.05	0.02	8.9				
3/25/19	0.17	0.04	0.03	5.7				

4/5/19	0.68	0.12	0.05	12.7	1.37	0.25	0.13	2.56
4/8/19	0.35	0.13	0.02	14.4				
4/12/19	0.45	0.34	0.45	1.0	1.31	0.13	0.08	4.24
4/13/19	0.29	0.10	0.05	5.4	1.50	0.05	0.07	11.76
4/15/19	0.08	0.07	0.04	1.9				
4/19/19	0.11	0.05	0.02	6.8				
4/19/19	0.05	0.05	0.60	0.1				
4/26/19	0.15	0.10	0.06	2.4				
5/4/19	0.16	0.03	0.01	19.1				
5/7/19	0.10	0.07	0.03	3.0				
5/11/19	0.33	0.18	0.07	4.4	2.61	0.13	0.45	5.38
5/12/19	0.41	0.24	0.26	1.6				
5/23/19	0.48	0.34	0.14	3.3				
5/31/19	0.50	0.41	0.25	2.0				
6/2/19	0.28	0.21	0.37	0.8				
6/5/19	0.12	0.10	0.13	0.9				
6/6/19	0.28	0.25	0.26	1.1				
6/7/19	2.67	0.38	0.06	41.3	0.98	0.06	0.03	2.73
6/10/19	0.12	0.11	0.21	0.6				
6/12/19	0.67	0.03	0.11	6.0	0.86	0.04	0.06	1.61
6/17/19	1.26	0.13	0.16	8.0	1.13	0.04	0.05	1.72
6/18/19	0.94	0.18	0.13	7.0	1.68	0.16	0.21	8.93
6/20/19	0.58[1]	na	na	na				
6/22/19	1.79[1]	na	na	na				
7/7/19	0.25	0.07	0.25	1.0				
7/9/19	0.16	0.14	0.06	2.5				
7/22/19	1.64	0.27	0.05	30.0	1.95	0.03	0.08	16.52
8/1/19	0.41	0.27	0.09	4.5	3.75	0.32	0.38	18.87
8/13/19	0.15	0.15	0.45	0.3				
8/19/19	1.09	0.66	0.55	2.0				
8/22/19	1.17	1.1	2.34	0.5				
8/24/19	0.55	0.22	0.14	4.0				
9/28/19	0.89	0.5	0.89	1.0				
10/13/19	0.21	0.11	0.05	4.0				
10/16/19	0.84	0.18	0.11	8.0	1.56	0.41	0.25	17.07
10/19/19	1.49	0.41	0.17	9.0	0.68	0.12	0.05	0.72
10/22/19	0.67	0.53	0.17	4.0	1.60	0.07	0.11	2.48
10/27/19	0.52	0.19	0.09	6.0				
10/30/19	2.69	0.41	0.07	36.0				
11/12/19	0.24	0.1	0.05	5.0				
11/18/19	0.12	0.05	0.04	3.0				
11/23/19	0.88	0.19	0.11	8.0	1.20	0.13	0.22	0.00

[1] Rainfall from NC State Climate Office.

Table B4. Monitoring Data for BUY-Apron.

Date	****** Precipitation ******				****** Runoff ******			**** Sample Analysis ****			
	Total	Peak	Ave	Dur.	Total	Peak	Dur.	TKN	NOx	TP	TSS
	in	in/hr	in/hr	hr	gal	gpm	hr	mg/L	mg/L	mg/L	mg/L
10/11/18	2.44	0.67	0.27	9.0	138686	2100	11	0.56	0.06	0.03	0.9
10/26/18	1.87[1]	na	na	na	150901	460	18	0.18	0.07	0.07	1.1
11/2/18	0.57[1]	na	na	na	42,205	1250	12	0.18	0.09	0.03	5.0
11/4/18	1.89[1]	0.41	0.24	7.8	96207	1093	18	0.08	0.03	0.03	3.4
11/9/18	0.68[1]	0.2	0.11	6.0	2359	46	4				
11/12/18	3.28[1]	0.5	0.18	18.0	140029	500	18	0.22	0.03	0.03	2.1
11/15/18	1.13	0.11	0.08	15.0	34481	50	12				
11/24/18	1.06	0.22	0.06	18.3	25366	167	38	0.35	0.05	0.01	4.2
12/1/18	0.36	0.08	0.02	17.3	25898	42	34				
12/10/18	2.02	0.14	0.06	36.0	123586	na	na	0.50	0.18	0.06	4.2
12/14/19	0.87	0.05	0.03	31.5	47825	281	50	0.31	0.16	0.03	3.9
12/20/18	1.84	0.16	0.13	14.1	71913	250	25				
1/2/19	0.40	0.08	0.03	15.3	20422	100	13				
1/4/19	0.51	0.09	0.03	16.1	38948	166	45	0.44	0.14	0.03	5.5
1/13/19	1.06	0.17	0.08	13.4	67127	365	62	0.15	0.13	0.09	3.9
1/19/19	0.70	0.12	0.07	10.0	8689	26	48	1.04	0.25	0.24	14.5
1/24/19	0.92	0.24	0.09	9.9	24873	1151	64	0.29	0.06	0.09	17.7
2/12/19	0.54	0.28	0.04	12.3	20572	775	24	0.71	0.16	0.05	11.4
2/16/19	0.36	0.08	0.04	8.3	12870	31	30				
2/17/19	0.95	0.2	0.07	13.0	26440	143	33	0.41	0.11	0.05	6.7
2/21/19	0.42	0.09	0.05	8.7	6488	12	11				
2/22/19	0.86	0.09	0.04	24.1	9306	20	27				
2/23/19	1.38	0.14	0.11	12.6	38992	196	13	0.26	0.09	0.02	2.9
3/1/19	0.53	0.15	0.11	5.0	5138	23	18				
3/3/19	0.62	0.28	0.17	3.8	28347	na	na				
3/15/19	0.23	0.1	0.03	8.0	6432	31	18				
3/21/19	1.27	0.19	0.13	10	44772	160	17				
4/5/19	0.80	0.15	0.07	12	29167	120	24				
4/9/19	0.80	0.16	0.08	9.8	31846	241	31				
4/12/19	1.31	1.18	1.19	1.1	60003	2496	86				
4/13/19	1.29	0.47	0.26	5.0	58788	730	12				
4/19/19	0.85	0.5	0.09	9.9	16927	1173	18				
4/26/19	0.30	0.16	0.11	2.7	5284	282	12				
5/4/19	0.28	0.06	0.01	19.3	6350	20	24				
6/7/19	1.50	0.14	0.05	28.9	63597	994	25	0.44	0.16	0.04	10.7
6/20/19	0.63	0.37	0.13	4.8	10056	698	6	0.64	0.23	0.04	4.7
7/7/19	0.27	0.12	0.08	3.5	5730	64	8				
7/12/19	0.24	0.24	0.96	0.3	2792	558	0				
7/18/19	0.05[1]	na	na	na	5287	432	5				

7/23/19	1.91[1]	na	na	na	76161	612	23	0.71	0.21	0.02	5.6
7/31/19	0.43	0.33	0.11	3.9	11954	489	7				
8/1/19	0.25	0.09	0.07	3.6	5463	34	4	1.16	0.37	0.10	17.1
8/6/19	0.20	0.18	0.18	1.1	4270	361	2				
8/7/19	0.22	0.22	0.88	0.3	6196	500	5				
8/8/19	0.54	0.51	0.81	0.7	13817	191	13	1.32	0.43	0.02	6.3
8/13/19	0.51	0.51	0.76	0.7	12720	820	1				
8/19/19	0.09	0.09	0.11	0.8	1126	40	2				
8/21/19	0.24	0.16	0.02	12	5683	95	9				
8/24/19	0.82	0.5	0.16	5	24360	17	18				
9/27/19	0.13	0.11	0.07	2	3808	110	6				
10/12/19	0.30	0.09	0.03	10	88	107	6				

[1] Rainfall from NC State Climate Office.

Table B5. Monitoring Data for BUY-Taxi.

Date	****** Precipitation ******				****** Runoff ******			**** Sample Analysis ****			
	Total	Peak	Ave	Dur.	Total	Peak	Dur.	TKN	NOx	TP	TSS
	in	in/hr	in/hr	hr	gal	gpm	hr	mg/L	mg/L	mg/L	mg/L
10/26/18	1.87[1]	na	na	na	14740	73	11.0	0.50	0.10	0.08	3.33
11/2/18	0.57[1]	na	na	na	1965	34	4.0	1.75	0.11	0.17	6.84
11/4/18	1.89[1]	0.41	0.24	7.8	31241	319	6.0	0.56	0.08	0.04	2.44
11/9/18	0.68[1]	0.2	0.11	6.0	2359	48	4.0	1.55	0.08	0.15	1.27
11/12/18	3.28[1]	0.5	0.18	18.0	38412	140	16.0	0.38	0.10	0.14	0.25
11/15/18	1.13	0.11	0.08	15.0	11254	47	4.0	0.40	0.08	0.00	2.08
11/24/18	1.06	0.22	0.06	18.3	9975	82	13.0	0.84	0.08	0.33	1.30
12/1/18	0.36	0.08	0.02	17.3	1234	4	14.0				
12/10/18	2.02	0.14	0.06	36.0	15579	34	24.0				
12/14/19	0.87	0.05	0.03	31.5	4724	14	37.5	0.69	0.08	0.09	1.03
12/20/18	1.84	0.16	0.13	14.1	9694	38	13.8				
1/2/19	0.40	0.08	0.03	15.3	252	2	4.1				
1/4/19	0.51	0.09	0.03	16.1	4891	19	21.6	0.70	0.08	0.05	2.33
1/13/19	1.06	0.17	0.08	13.4	10665	79	16.0	0.53	0.11	0.08	3.70
1/19/19	0.70	0.12	0.07	10.0	6781	54	9.6	0.55	0.09	0.04	1.15
1/24/19	0.92	0.24	0.09	9.9	10031	126	9.5	0.78	0.08	0.05	4.82
2/12/19	0.54	0.28	0.04	12.3	2804	51	8.0	1.04	0.14	0.08	4.35
2/16/19	0.36	0.08	0.04	8.3	438	4	3.0				
2/17/19	0.95	0.2	0.07	13.0	10441	89	8.9	0.57	0.11	0.01	4.35
2/21/19	0.42	0.09	0.05	8.7	2417	15	12.0				
2/22/19	0.86	0.09	0.04	24.1	4289	14	22.0				
2/23/19	1.38	0.14	0.11	12.6	14155	49	13.3	0.47	0.10	0.02	1.55
3/1/19	0.53	0.15	0.11	5.0	2972	17	6.5	1.22	0.08	0.02	7.81
3/3/19	0.62	0.28	0.17	3.8	4876	42	5.0	0.66	0.11	0.04	5.30

3/15/19	0.23	0.1	0.03	8.0	0	0	0				
3/21/19	1.27	0.19	0.13	10	7968	63	8.0				
4/5/19	0.80	0.15	0.07	12	1394	15	4.0				
4/9/19	0.80	0.16	0.08	9.8	3118	25	6.0				
4/12/19	1.31	1.18	1.19	1.1	21425	630	2.5				
4/13/19	1.29	0.47	0.26	5.0	15370	270	6.0				
4/19/19	0.85	0.5	0.09	9.9	5569	210	2.8				
4/26/19	0.30	0.16	0.11	2.7	0	0	0				
5/4/19	0.28	0.06	0.01	19.3	0	0	0				
6/7/19	1.50	0.14	0.05	28.9	2146	64	1.3	2.02	0.13	0.15	9.01
6/20/19	0.63	0.37	0.13	4.8	1317	47	1.3	1.47	0.11	0.20	7.14
7/7/19	0.27	0.12	0.08	3.5	0	0	0.0				
7/12/19	0.24	0.24	0.96	0.3	0	0	0.0				
7/18/19	0.05[1]	na	na	na	0	0	0.0				
7/23/19	1.91[1]	na	na	na	0	0	0.0				
7/31/19	0.43	0.33	0.11	3.9	0	0	0.0				
8/1/19	0.25	0.09	0.07	3.6	0	0	0.0				
8/6/19	0.20	0.18	0.18	1.1	0	0	0.0				
8/7/19	0.22	0.22	0.88	0.3	6436	237	1.9	1.73	0.12	0.56	10.00
8/8/19	0.54	0.51	0.81	0.7	4.7	4	1				
8/13/19	0.51	0.51	0.76	0.7	0	0	0				
8/19/19	0.09	0.09	0.11	0.8	0	0	0				
8/21/19	0.24	0.16	0.02	12	128	4	1.0				
8/24/19	0.82	0.5	0.16	5	0	0	0				
9/27/19	0.13	0.11	0.07	2	0	0	0				
10/12/19	0.30	0.09	0.03	10	14740	73	11.0	0.50	0.10	0.08	3.33

[1] Rainfall from NC State Climate Office.

Table B6. In-situ Runoff Monitoring Data from INT-Run.

Storm Date	Mean[1] Temp ºC	mean[1] Cond uS/cm	Peak cond uS/cm	mean[1] Turb ntu	Peak Turb ntu
12/20/18	0.26	23.47	120	10.5	38
12/28/18	0.31	21.74	90	11.2	26
1/2/19	0.21	30.07	58	10.8	18
1/4/19	0.23	24.43	48	10.3	24
1/13/19	0.29	38.47	100	13.0	40
1/19/19	0.28	25.21	85	13.5	30
1/24/19	0.39	27.22	78	13.3	40
2/11-12/19	6.38	28.15	70	15.8	35
2/16/19	8.28	26.84	58	16.8	9
2/17/19	6.50	18.09	42	15.1	12
2/19/19	5.67	21.98	50	13.1	30
2/21/19	7.42	20.58	34	11.6	12

3/1/19	7.10	21.09	58	14.8	55
3/3/19	7.20	19.91	50	14.8	54
3/9/19	6.90	24.55	60	15.1	25
3/15/19	14.2	24.78	55	19.7	170

[1] Average for all measurements during the storm event.