Ethan Berkowitz, Mayor

2019 Stormwater Outfall Monitoring Report

APDES Permit No. AKS-052558

MUNICIPALITY OF ANCHORAGE
WATERSHED MANAGEMENT PROGRAM

December 2019

WATERSHED MANAGEMENT

HDR

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WATERSHED MANAGEMENT PROGRAM

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WATERSHED
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List of Acronyms

°C	Degrees Celsius
%	Percent
µg/L	Micrograms/Liter
ADEC	Alaska Department of Environmental Conservation
APDES	Alaska Pollutant Discharge and Elimination System
AWC	Anchorage Waterways Council
AWQS	Alaska Water Quality Standard
AIA	Anchorage International Airport
BTEX	Benzene, Ethylebenzene, Toluene, and Xylenes
BMPs	Best Management Practices
BOD_5	Biochemical Oxygen Demand (5 Day)
COC	Chain of Custody
CI	Commercial Industrial
Cu	Copper
CWA	Clean Water Act
DO	Dissolved Oxygen
DOT&PF	Alaska Department of Transportation and Public Facilities
DOY	Day of Year
EPA	U.S. Environmental Protection Agency
FC/100 mL	Fecal Coliform units per 100 Milliliters
gpm	Gallons per Minute
Hr or Hrs	Hour or Hours
HGDB	Hydro-Geographic Database
L	Liter
LCS/LCSD	Laboratory Control Samples and Duplicates
mL	Milliliter
mg/L	Milligrams/Liter
MOA	Municipality of Anchorage
MS/MSD	Matrix Spike/Matrix Spike Duplicate
MS4	Municipal Separate Storm Sewer System
NADP	National Atmospheric Deposition Program
ND	Not Detected
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System

NTU	Nephelometric Turbidity Units
Nunaka	Rain Gauge off Boniface Parkway between Debar and East Northern Lights Boulevard
OGS	Oil/Grit Separator
PAHs	Polycyclic Aromatic Hydrocarbons
PANC	NOAA National Weather Service Station at AIA
QA/QC	Quality Assurance/Quality Control
QAP	Monitoring, Evaluation, and Quality Assurance Plan
QC	Quality Control
SMRC	Stormwater Managers Resource Center.
Spencer	Rain Gauge at Elmore and Huffman Roads
SRMs	Standard Reference Material
TAqH	Total Aqueous Hydrocarbons
TAH	Total Aromatic Hydrocarbons
TDS	Total Dissolved Solids
Thomas	Rain Gauge at Lake Otis Parkway and Tudor Road
TMDL	Total Maximum Daily Load
TNTC	Too Numerous to Count
TPAH	Total Polycyclic Aromatic Hydrocarbons
TSAIA	Ted Stevens Anchorage International Airport
TSS	Total Suspended Solids
USGS	United States Geological Survey

1.0 Introduction

This report details the findings of the 2019 Municipality of Anchorage (MOA) stormwater monitoring program. This program satisfies the stormwater outfall monitoring requirements of the current Municipal Separate Storm Sewer System (MS4) permit (Permit No. AKS-052558) in compliance with the National Pollutant Discharge Elimination System (NPDES) established under the Clean Water Act (CWA).

1.1 Background

The U.S Environmental Protection Agency (EPA) first issued a MS4 permit to the MOA and the Alaska Department of Transportation and Public Facilities (DOT&PF) in 1999. EPA reissued the permit in 2009 with the additional requirement to conduct stormwater outfall monitoring throughout the Anchorage Bowl. After reissuance of the permit, EPA delegated the NPDES stormwater program to the Alaska Department of Environmental Conservation (ADEC), which now oversees its implementation and administration within the state as part of the Alaska Pollutant Discharge Elimination System (APDES). ADEC reissued the MS4 permit in 2015, maintaining the requirement for stormwater outfall monitoring.

The Anchorage MS4 permit establishes control measures requiring the co-permittees to develop programs designed to prevent contaminants from entering the storm sewer system. The permit also identifies monitoring objectives, including stormwater outfall monitoring (Section 4.1.7 of the MS4 permit). The MOA has taken the lead role in administering the stormwater outfall monitoring program (SWM Program). The MS4 permit requires the selection of 10 priority outfall locations for stormwater monitoring that represent a variety of major land use areas within the Anchorage Bowl. The SWM Program requires selected outfall locations to be sampled four times each year during storm events that meet specific criteria for a designated set of physical and chemical parameters. Stormwater sampling conducted during 2019 represents the fourth year of monitoring under the 2015 MS4 permit and the ninth year of monitoring selected outfalls during storm events.

This report and the data collected under the SWM Program fulfill the annual outfall monitoring objectives of the MS4 permit. The current permit will expire on July 31, 2020 and will require reapplication on or before February 2, 2020.

1.2 Stormwater Definition

Urban stormwater is a major contributor of pollution to the nation’s waterways (EPA 1983). Precipitation and snowmelt events cause runoff that can transport urban contaminants into streams, rivers, and lakes. The runoff from impermeable surfaces such as roads, driveways, and sidewalks, as well as from semi-permeable surfaces such as golf courses, lawns, and gardens can carry a variety of pollutants through the storm sewer, generally discharging directly into local waterways without treatment. The EPA and delegated states use the MS4 permit to control these pollutants and limit contamination of local waterbodies.

Section 303(d) of the CWA requires that States submit to EPA a list of impaired waterbodies and develop water quality management plans, in the form of Total Maximum Daily Loads (TMDLs) for those waters. The current MS4 permit cites the 2010 EPA-approved list of impaired waters, which includes 13 waterbodies in the greater Anchorage area, as impaired for three pollutants of concern: fecal coliform bacteria, dissolved oxygen, and petroleum products. The 2016 EPA-approved list of impaired waters identifies 12 Anchorage-area waterbodies as impaired for fecal coliform (ADEC 2018). ADEC has developed, and EPA has approved, TMDLs for fecal coliform for all 12 listed waterbodies. The TMDL implementation plans identify urban runoff as the major contributor of fecal coliform pollution and establish specific reduction goals to improve stormwater quality and reduce the impact of fecal coliform on receiving waters.

Since 2010, ADEC has updated the listings for Ship Creek and Hood/Spenard Lake. The petroleum products impairment was removed from Ship Creek in 2012, following monitoring that demonstrated that the analytical indicators for petroleum hydrocarbons were not present in sufficient concentrations to exceed the water quality criteria. Ship Creek remains impaired for fecal coliform. Hood/Spenard Lake is no longer included on the Section 303(d) list of impaired waters. Following implementation of improved stormwater management practices and a waterfowl hazing program at the Ted Stevens Anchorage International Airport (TSAIA), water quality data has shown that Hood/Spenard Lake meets the water quality criteria for fecal coliform and dissolved oxygen. The fecal coliform bacteria impairment was removed in 2010 and the dissolved oxygen impairment was removed in 2016.

1.3 Monitoring Program Objectives

The overarching objectives of the monitoring program established in the Anchorage MS4 permit are to characterize the quality of stormwater discharges from the MS4 and track the effectiveness of best management practices (BMPs) implemented as part of the TMDL implementation plans. The SWM Program component of the overall monitoring program aims to meet these objectives through continued monitoring of 10 outfalls through the permit term. The SWM Program meets the following objectives specified in the MS4 permit:

- Broadly estimate the annual stormwater loading of fecal coliform and petroleum products discharged into specific watersheds from the MS4
- Assess the effectiveness of existing stormwater controls in reducing fecal coliform bacteria and petroleum product contamination
- Identify and prioritize portions of the MS4 that need additional controls

As of 2018, no waterbody in the Anchorage MS4 permit area is included on the Section 303(d) list of impaired waters for petroleum product contamination (ADEC 2018). However, because petroleum products were identified as a contaminant of concern in the current MS4 permit, and because stormwater runoff has the potential to transport petroleum products from a variety of sources, the stormwater outfall monitoring program continues to measure petroleum product contamination.

1.4 Report Organization

Section 2.0 of this report includes an overview of the SWM Program and provides background information regarding the outfall site selection process, the water quality parameters tested, and procedures followed as required by the MS4 permit. Section 2.0 details 2019 fieldwork conducted under the Program, including a discussion of the 2019 sampling events and the associated weather and precipitation data. Discussion of field-sampling procedures, sample handling and chain of custody, laboratory analyses, quality control, and data validation procedures is included.

Section 3.0 presents the results of the 2019 SWM Program, including tabular and graphical summaries of field measurements and lab data, as well as a discussion of results, site trends, yearly and seasonal trends, and annual loading from MS4 discharge.

Section 4.0 of the report presents a summary of findings as well as preliminary conclusions. References are included in Section 5.0. The body of the report is followed by appendices, which include site maps, field photographs, laboratory data reports, data validation summaries, and completed field log forms.

2.0 Program Description and Methodology

The SWM Program was developed to meet the MS4 permit requirements and is defined in the *Monitoring, Evaluation, and Quality Assurance Plan* (QAP) for the MS4 permit (MOA 2016). Appendix B of the QAP, *Stormwater Outfall Monitoring Plan* specifically details the SWM Program, including the program design rationale, sampling methodology and protocols, field crew training requirements, and results to be presented in the annual report.

2.1 Monitoring Sites

Per the requirements of the MS4 permit, the *Stormwater Outfall Monitoring Plan* includes a list of 30 outfalls prioritized as high and medium priority monitoring locations. The MOA developed the list to meet the requirements of the 2009 MS4 permit.

The methodology used to define the analysis corridor and identify and prioritize the outfalls is described in the QAP (MOA 2016). Under the 2009 MS4 permit, the MOA selected and ranked 30 subbasins within a targeted area of the Anchorage Bowl for inclusion in the SWM Program (MOA 2011). Selected subbasins include those zoned for a single predominant land use, subbasins zoned for mixed land uses, and subbasins with and without oil and grit separator (OGS) devices. These subbasins were then ranked based on the area of impervious surface directly connected to the storm drain system leading to the outfall, safe access to the outfall, and accessibility of the outfall from legal parking.

The SWM Program began in 2011 with ten priority outfalls selected for sampling. To facilitate sample labeling and simplify outfall identification in the field, the outfalls were sequentially numbered from south to north along the analysis corridor (SWM01 through SWM10).

Two outfalls, SWM01 and SWM02, were sampled from 2011 through 2016. However, these outfalls were replaced in 2017. SWM01 was discontinued due to inconsistent flow and the small size of the drainage area. The replacement outfall, SWM11, also drains a residential land use subbasin and has a larger drainage area than SWM01. SWM02 was discontinued when it was determined that the outfall is not truly representative of the contributing land use area as a result of influence of streamflow from Little Campbell Creek. SWM02 was replaced with SWM12, which also drains a commercial and industrial land use subbasin. SWM11 and SWM12 were not included on the original list of 30 prioritized subbasins but were selected because their location in the analysis corridor and the characteristics of their subbasins are most similar to those of SWM01 and SWM02.

SWM03 and SWM04 are located near Sylvan Drive and drain a residential area east of Campbell Creek. Though these outfalls are close together, their drainage areas are vastly different. SWM05 is located at the end of East 56th Avenue and drains a commercial and industrial area south of International Airport Road and east of C Street. SWM06 is located at the end of Maplewood Street and drains a residential area north of Northern Lights Boulevard. SWM07 and SWM08 are located at the Seward Highway where Chester Creek passes beneath the highway. They drain a commercial and industrial area north of the creek and a mixed land use area south of the creek, respectively. SWM09 is located near the Anchorage Football Stadium and drains the area around Ben Boeke and Sullivan Arenas. SWM10 is located at the end of Eagle Street and drains a mixed commercial and residential area south of Chester Creek. SWM11 is located at Johns Road and Botanical Circle and drains a large residential area north of Furrow Creek. SWM12 drains a commercial and industrial area near the Old Seward Highway and represents the inflow to the Lynwood retention basin.

Table 1 presents the characteristics of the outfalls sampled under the SWM Program, including physical location, geographic location, outfall dimensions, acreage of subbasin, and percent impervious surface of the subbasin. Figure 1 shows the locations of the 10 currently monitored outfalls and subbasins within the analysis corridor. Figure 1 also shows the locations of four tipping bucket rain gauges installed along the analysis corridor in 2019. Detailed site maps showing the outfalls and the land use types of the contributing subbasins are included as Appendix A.

Table 1. Outfalls Sampled under the Stormwater Outfall Monitoring Program, 2011 - 2019

Station ID	Subbasin ID	Outfall Node ID	Watershed	Contributing Land Use	OGS Present	Priority Rank[a]	Latitude	Longitude	Outfall Diameter (inches)	Subbasin Area (acres)	Subbasin Percent Impervious
SWM01	1040b	1040-3	Little Campbell	Residential	No	10	61° 07.526'	-149° 50.196'	18	91.38	36
SWM02	1210	847-1	Little Campbell	Commercial and Industrial	No	17	61° 08.665'	-149° 50.797'	18	37.17	82
SWM03	1224a	1224-1	Campbell	Residential	Yes	3	61° 09.548'	-149° 52.443'	36	92.78	70
SWM04	1224b	1224-2	Campbell	Residential	Yes	6	61° 09.545'	-149° 52.451'	18	20.10	32
SWM05	805	207-1	Campbell	Commercial and Industrial	Yes	1	61° 10.202'	-149° 52.326'	24	58.34	75
SWM06	219	314-22	Chester	Residential	Yes	2	61° 11.996	-149° 50.750'	24	33.81	37
SWM07	507	484-1	Chester	Commercial and Industrial	No	8	61° 12.100'	-149° 52.114'	24	50.17	83
SWM08	549	86-1	Chester	Mixed	No	6	61° 12.095'	-149° 52.114'	42	354.62	69
SWM09	132	499-1	Chester	Commercial and Industrial	Yes	4	61° 12.176'	-149° 52.554'	24	40.04	54
SWM10	554	525-2	Chester	Mixed	No	5	61° 12.161'	-149° 52.486'	24	47.51	75
SWM11	1103	348-3	Furrow	Residential	No	-	61° 06.448'	-149° 52.734'	36	86.32	39
SWM12	1449	1454-1	Campbell	Commercial and Industrial	No	-	61° 09.758'	-149° 52.525'	24	111.68	60

Note: Stations highlighted in red were sampled from 2011 through 2016. Stations highlighted in yellow were added to the SWM Program in 2017 to replace SWM01 and SWM02.
[a] MOA 2011

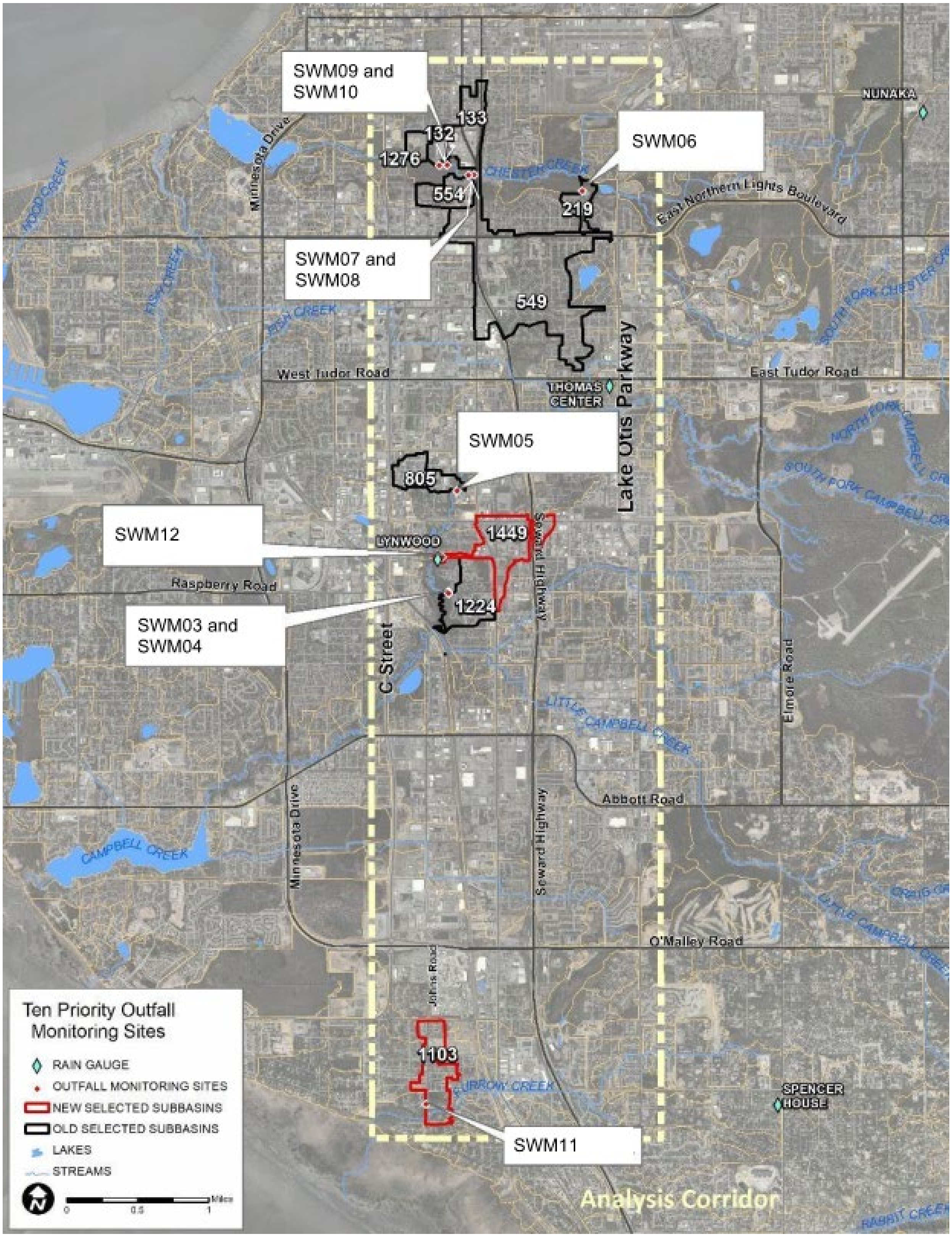


Figure 1. Overview Map of the Outfall Monitoring Sites and Subbasins.
Detailed maps of each subbasin are provided in Appendix A.

2.2 Measured Parameters

Monitoring of the selected outfalls includes both *insitu* measurements and discrete grab samples submitted for laboratory analyses. Table 2 lists all the parameters measured under the MS4 program, including sample type, measurement type, analysis method, and purpose of monitoring. Measurement quality objectives for each parameter including precision, accuracy, sensitivity, and measurement range are included in the QAP. In addition to the parameters listed in Table 2, field observations are recorded at each outfall including any evidence of oily sheen, scum, odor, detritus, floating material, water color and clarity, deposits or stains, vegetation, and any other pertinent observations.

Table 2. Sample Type, Measurement Type, and Method of Analysis for Measured Parameters

Parameter	Sample Type [a]	Measurement Type	Analysis Method	Purpose
Flow	IR	Field	Flow meter, or bucket	Characterize flow & loading
Specific Conductivity	IR	Field	EPA 120.1/ YSI 556	Stormwater quality
Dissolved Oxygen (DO)	IR	Field	EPA 360.1/ YSI 556	Stormwater quality
pH	IR	Field	EPA 150.2/ YSI 556	Stormwater quality
Temperature	IR	Field	SM2550B/ YSI 556	Stormwater quality
Turbidity	IR/G	Field	EPA 180.1/ Hach 2100	Stormwater quality
5-Day Biochemical Oxygen Demand (BOD_5)	G	Laboratory	SM 5210 B	Stormwater quality
Fecal Coliform	G	Laboratory	SM 9222D	Stormwater quality & loading
Total Suspended Solids (TSS)	G	Laboratory	SM 2540D	Stormwater quality
Total Aromatic Hydrocarbons (TAH)	G	Laboratory	EPA 624	Stormwater quality & loading
Total Aqueous Hydrocarbons (TAqH)	G	Laboratory	EPA 625 + EPA 624	Stormwater quality & loading
Dissolved Copper [b]	G	Laboratory	EPA 200.8	Stormwater quality
Total Hardness [b]	G	Laboratory	EPA 200.8	Stormwater quality

[a] IR = instantaneous recording of field analysis; G = grab sample for analysis
[b] Dissolved copper and total hardness were added to the SWM Program in 2016.

Table 3 details which parameters are monitored at each selected outfall. Only samples from outfalls located in predominantly commercial and industrial land use areas are analyzed for hydrocarbon concentrations. This includes measurements of total aromatic hydrocarbons (TAH) and polycyclic aromatic hydrocarbons (PAH), to allow calculation of total aqueous hydrocarbons (TAqH). Outfalls with watersheds dominated by commercial and industrial land uses are those most likely to contribute petroleum hydrocarbon pollutants to receiving waters. To assess the effectiveness of existing BMPs in improving stormwater quality and reducing petroleum hydrocarbon concentrations, the SWM Program samples two outfalls within commercial and industrial subbasins that contain OGS systems, and two that do not have OGS systems.

Table 3. Parameters Measured at each Selected Outfall

Station ID	Watershed	Contributing Land Use	OGS Present?	Field Parameters						Lab Samples						
				Flow	Conductivity	pH	Temperature	DO	Turbidity	BOD_5	Fecal Coliform	TSS	Hardness	Dissolved Cu	TAH	PAH
SWM03	Campbell	Residential	Yes	x	x	x	x	x	x	x	x	x	x	x		
SWM04	Campbell	Residential	Yes	x	x	x	x	x	x	x	x	x	x	x		
SWM05	Campbell	Commercial and Industrial	Yes	x	x	x	x	x	x	x	x	x	x	x	x	x
SWM06	Chester	Residential	Yes	x	x	x	x	x	x	x	x	x	x	x		
SWM07	Chester	Commercial and Industrial	No	x	x	x	x	x	x	x	x	x	x	x	x	x
SWM08	Chester	Mixed	No	x	x	x	x	x	x	x	x	x	x	x		
SWM09	Chester	Commercial and Industrial	Yes	x	x	x	x	x	x	x	x	x	x	x	x	x
SWM10	Chester	Mixed	No	x	x	x	x	x	x	x	x	x	x	x		
SWM11	Furrow	Residential	No	x	x	x	x	x	x	x	x	x	x	x		
SWM12	Campbell	Commercial and Industrial	No	x	x	x	x	x	x	x	x	x	x	x	x	x

* DO = dissolved oxygen; BOD_5: 5-day biochemical oxygen demand; TSS: total suspended solids; TAH: total aromatic hydrocarbons; TAqH: total aqueous hydrocarbons

2.3 Sampling Events

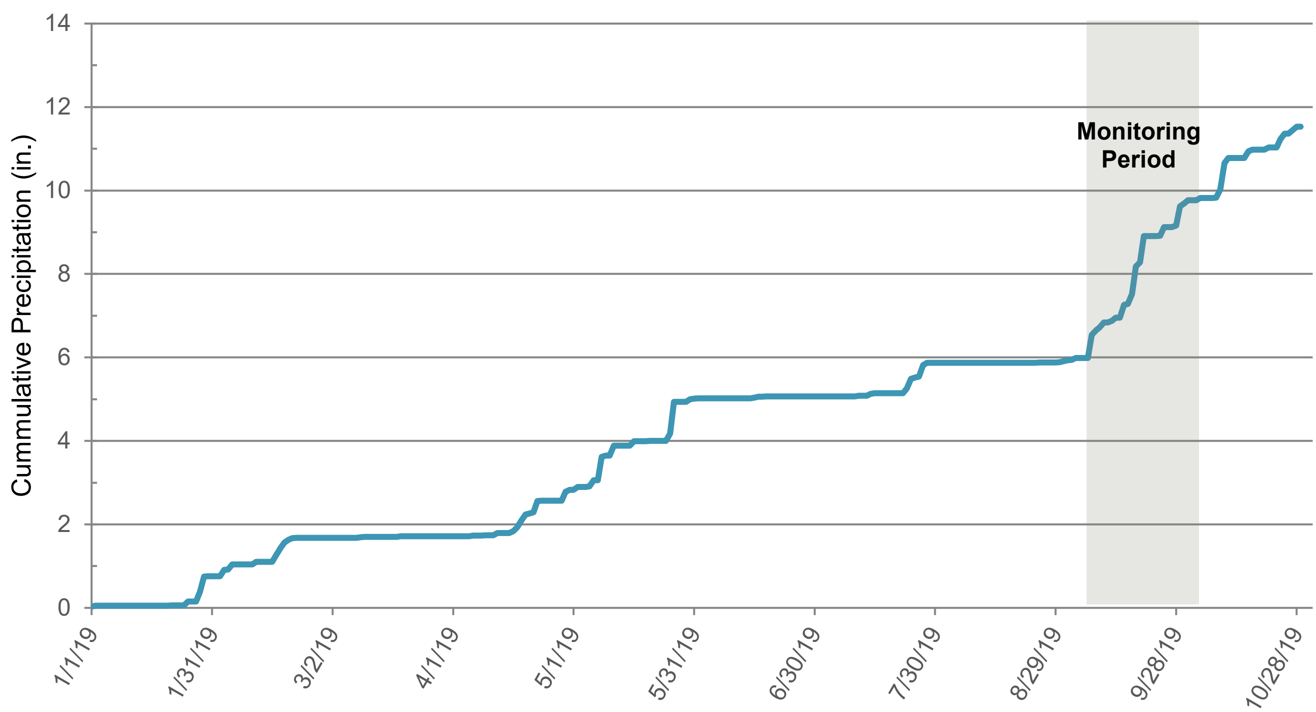
The SWM Program measures pollutants and pollutant indicators in stormwater at the 10 selected outfalls four times each summer. Sampling events are triggered by storms that generate 0.1 inches of precipitation or greater in 24 hours, and are preceded by a period of 24 hours with less than 0.1 inches of precipitation. Rainfall at the National Oceanic and Atmospheric Administration (NOAA) mesonet KTUU-midtown weather station was monitored to determine whether a rainfall event provided sufficient precipitation to trigger a sampling event.

Four stormwater outfall monitoring events were conducted in 2019 as required by the *Stormwater Outfall Monitoring Plan* and the MS4 permit. The 2019 sampling period began on September 7 and concluded on October 1. A lack of rainfall delayed the onset of stormwater outfall monitoring in 2019 compared to previous years. Sampling for the SWM Program typically begins in July and concludes by mid-September. In 2019, there were no storm events suitable for sampling between the first week of July and the first week of September. Sampling events in 2019 took place on September 7, September 18, September 20, and October 1. The monitoring period is shown in conjunction with the cumulative annual precipitation recorded at the Ted TSAIA PANC weather station in Figure 2.

2.3.1 Summer 2019 Drought Conditions

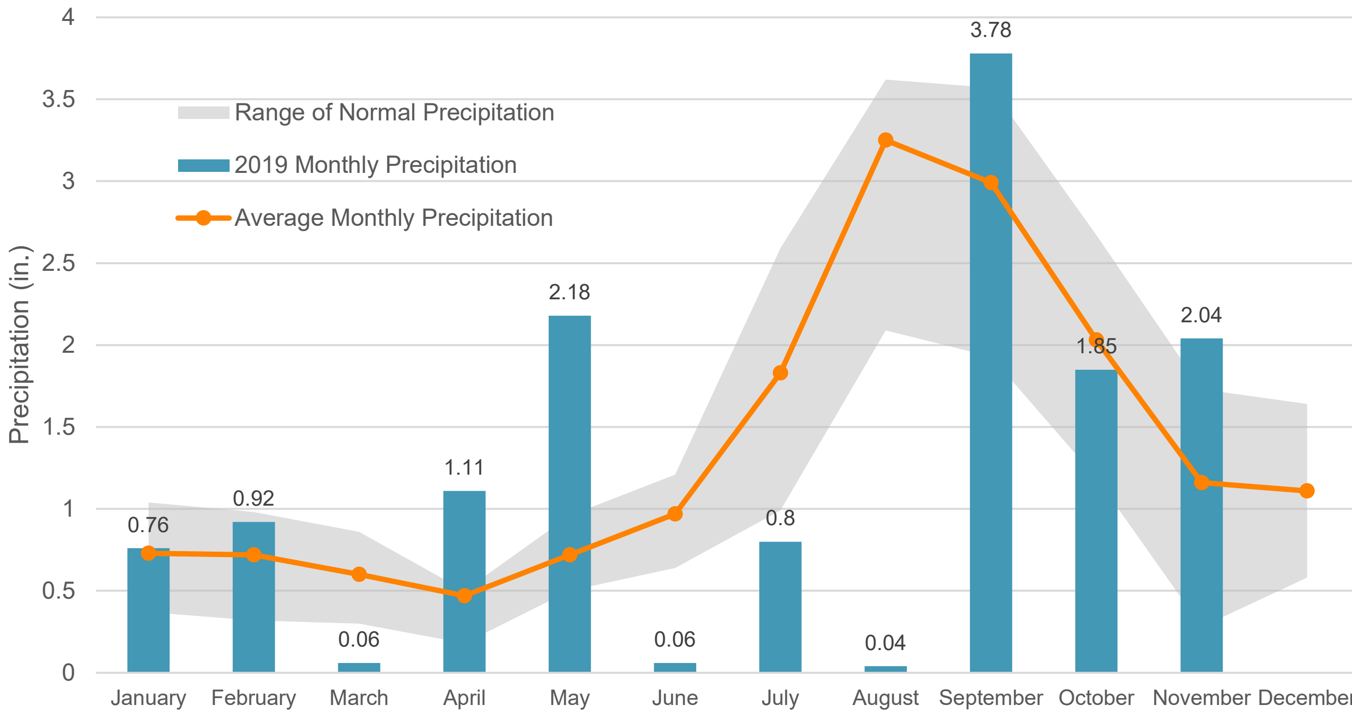
The summer of 2019 in Southcentral Alaska did not follow typical weather patterns. From the beginning of June through the end of August 2019, less than 1 inch of precipitation was measured at the PANC weather station. The average rainfall for this time period is 6.05 inches. In mid-August the U.S. Drought Monitor classified Anchorage as experiencing an "extreme drought" for the first time since the monitoring program began in 2000 (NIDIS 2019). Extreme drought is the second-highest designation assigned by the U.S. Drought Monitor, which assesses conditions related to dryness and drought including observations of how much water is available in streams, lakes and soils compared to usual for the same time of year. Severe drought conditions ended in September, and rainfall in September actually exceeded the range of normal precipitation. The monthly rainfall recorded at the PANC weather station compared to the range of normal precipitation is shown in Figure 3.

Figure 2. 2019 Monitoring Period and Cumulative Precipitation Measured at the PANC Weather Station



Extreme drought conditions during the summer of 2019 were accompanied by extended periods of poor air quality. Nearby wildfires on the Kenai Peninsula resulted in persistent smoke and ash observations for much of the summer, leading to frequent unhealthy air quality warnings in Anchorage. The summer of 2019 was smokiest summer on record as measured at the PANC weather station (ACCAP 2019).

Figure 3. 2019 Monthly Precipitation Measured at the PANC Weather Station Compared to Normal



Note: Normal range of precipitation shown is the range between the 25th and 75th percentiles of monthly precipitation averages recoded at the PANC weather station for the 30 year period from 1981 to 2010. Source: NOAA 2019.

Four tipping bucket rain gauges installed within the monitoring area recorded precipitation throughout the monitoring period. The rain gauges were located along the analysis corridor in order to provide a representation of the actual rainfall within the sampled subbasins. During precipitation events, the collection bucket in the gauge collects precipitation until it reaches the equivalent of 0.01 inch of precipitation whereupon the bucket tips, triggering a reed switch and recording an event with a time stamp. These events are stored in a data logger and downloaded into a computer program where they are summarized over different time intervals or graphed as a time series. The gauges were located off Boniface Parkway between Debarr and East Northern Lights Boulevard ("Nunaka"), near Lake Otis Parkway and Tudor Road ("Thomas"), at the Lynwood Retention Basin at SWM12 ("Lynwood"), and in South Anchorage near Elmore and Huffman Roads ("Spencer") and represent the northern, middle, and southern portions of the study area respectively. Locations of the rain gauges installed in 2019 are shown on Figure 1. Daily rainfall records for the rain gauges are shown in Figure 4 and Figure 5.

Actual rainfall during a single storm event can vary in different locations across the Anchorage Bowl. As in previous years, rainfall data from the PANC weather station at TSAIA were used to supplement the data collected at the rain gauges to provide a time series of rainfall prior to and during the sampled storm events. Rainfall data for each sampling event is presented on a calendar-day basis in Table 5 and demonstrates considerable variability in the geospatial distribution of precipitation throughout the monitoring corridor.

It is important to note that the QAP defines storm events on a 24-hr storm basis rather than a calendar-day basis, as storms often commence in late evening the day before sampling. All four storm events met the criteria of exhibiting greater than 0.1 inch of rain in 24 hours. Sampling for each storm event was completed within 24 hours from the start of a storm. In all sampling events, precipitation recorded at the four project gauges during the preceding 24-hour period was generally less than 0.1 inches. Based on these data, all four storms that were sampled were considered to have met storm event criteria. Table 5 presents rainfall data for each sampling event on a 24-hour basis (as opposed to a calendar day basis).

2.3.2 Timing of Sampling Events

The extreme drought conditions experienced in Anchorage in 2019 resulted in an extended delay in the SWM sampling program. Between June 1st and September 6th, only one weather system provided 0.1 inches or more of precipitation. This small system in late July included two brief rain events that did not provide adequate opportunity for sampling. The first event began in the early evening of July 23, too late to mobilize a sampling crew, and concluded within several hours, such that sampling the following day would not have captured runoff effectively. The second rain event associated with the system occurred on July 28 over the weekend, when sampling is typically not conducted. There were no further rain events for the remainder of July and August.

As result of the extreme drought conditions for much of the summer, as well as the possibility for drought conditions to extend into the foreseeable future, in August the SWM program adopted an aggressive posture to sample all eligible storm events, including storms that would not typically be sampled under normal circumstances. Under the new aggressive strategy, storms to be sampled included storms occurring over the weekend, with the aim of maximizing the likelihood of successfully sampling four events as outlined in the QAP. Sampling over the weekend involves inherent compromises. One of these compromises is that the laboratory, SGS North America, Inc. (SGS), is not open over the weekend to accept samples for delivery. Because the samples collected for BOD_5 and Fecal Coliform have relatively short hold times, outfall monitoring that occurs on weekends cannot test for these parameters.

2.3.3 Sampling Events

The first storm event sampled as part of the 2019 SWM program occurred on Saturday, September 7 (Storm 1). Sampling on September 7 was initiated at 13:45, approximately three hours after the beginning of the storm, and was completed by 18:05. Between 0.14 and 0.30 inches of rain fell across the Anchorage Bowl measured at the project rain gauges in the 24 hour storm period measured through the conclusion of sampling. The total storm precipitation ranged between 0.41 and 0.96 inches across the monitoring corridor. Samples for BOD_5 and Fecal Coliform were not collected during Storm 1, as the lab was not open over the weekend to analyze those samples within the required hold times. This was a necessary compromise as result of the unprecedented drought conditions leading up to the first storm event. BOD and fecal coliform samples were collected and tested for the remaining three storms following the procedures outlined in the QAP.

The second sampled storm event occurred on September 18, 2019 (Storm 2). The storm cycle began several days prior on September 15, which was a Sunday. Based on the forecast for continued wet weather, sampling was deferred in an effort to wait for a weekday sampling event which would allow sampling for BOD_5 and Fecal Coliform. Sampling on September 18 was initiated at 08:30 and was completed by 13:10. Rainfall recorded at the project rain gauges ranged from 0.67 to 0.90 inches in the 24 hour storm period.

The third sampled storm event occurred on September 20 (Storm 3), two days after the second sampled event. There was a 24-hour dry period between the two storm events, during which the KTUU-midtown mesonet weather station recorded less than 0.1 inches of precipitation. After this dry period, the onset of a new storm with more than 0.1 inches of precipitation triggered the third sampling event. Data collected after the conclusion of the SWM Program at the project rain gauges indicated that some sites exceeded the 0.1 inch dry period threshold, and dry period readings ranged from 0.08 to 0.15 inches. However, all readings were sufficiently close to 0.1 inches that the requirement for a 24 hour dry period outlined in the QAP is considered to have been met. Sampling for Storm 3 was initiated at 10:10 and was completed by 14:55. Rainfall recorded at the project rain gauges ranged from 0.80 to 1.18 inches in the 24 hour storm period. The September 20 event was the largest storm sampled during the 2019 SWM Program.

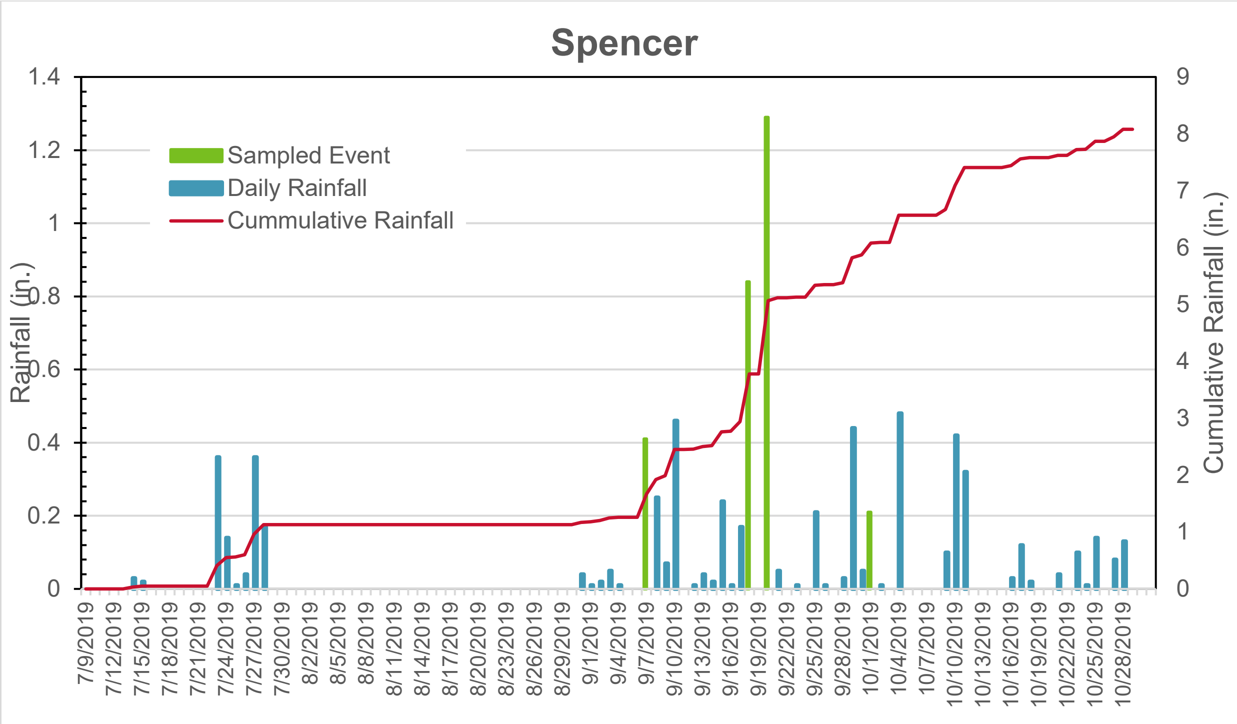
The fourth sampled storm event occurred on October 1 (Storm 4). Sampling for Storm 4 was initiated at 9:15 and was completed by 14:00. Rainfall recorded at the project rain gauges ranged from 0.12 to 0.21 inches in the 24 hour storm period. The October 1 event was the smallest storm sampled during the 2019 SWM Program.

Table 4. Precipitation Recorded During and Prior to Sampling Events (measured per Calendar Day)

	Date	Rainfall Measured (inches)				
		PANC	Lynwood	Nunaka	Spencer	Thomas
	8/31/2019	0.02	0.04	0.03	0.04	0.06
	9/1/2019	0.02	0.04	0.06	0.01	0.07
	9/2/2019	0.01	0.02	0.07	0.02	0.02
	9/3/2019	0.05	0.07	0.07	0.05	0.08
	9/4/2019	0	0	0.02	0.01	0.01
	9/5/2019	0	0	0	0	0.02
	9/6/2019	0	0	0	0	0
Event 1	**9/7/2019**	**0.55**	**0.71**	**0.96**	**0.41**	**0.65**
	≈					
	9/11/2019	0	0	0.01	0	0
	9/12/2019	0.04	0.02	0.01	0.01	0.02
	9/13/2019	0.07	0.07	0.04	0.04	0.05
	9/14/2019	0	0.01	0.01	0.02	0
	9/15/2019	0.31	0.27	0.19	0.24	0.22
	9/16/2019	0.02	0.05	0.04	0.01	0.04
	9/17/2019	0.24	0.33	0.33	0.17	0.3
Event 2	**9/18/2019**	**0.66**	**0.93**	**0.88**	**0.84**	**0.72**
	9/19/2019	0.1	0.16	0.03	0	0.12
Event 3	**9/20/2019**	**0.63**	**1.07**	**1.52**	**1.29**	**1.08**
	≈					
	9/24/2019	0.01	0	0	0	0
	9/25/2019	0.2	0.38	0.34	0.21	0.33
	9/26/2019	0	0	0	0.01	0
	9/27/2019	0	0	0	0	0
	9/28/2019	0.04	0.02	0.03	0.03	0.03
	9/29/2019	0.46	0.65	0.77	0.44	0.57
	9/30/2019	0.07	0.06	0.05	0.05	0.05
Event 4	**10/1/2019**	**0.08**	**0.12**	**0.14**	**0.21**	**0.12**

Table 5. Precipitation Data for Each Sampling Event Presented on a 24 Hour Basis

	Conclusion of Sampling	Time Period	Time Period Range	Rainfall Measured (Inches)			
				Lynwood	Nunaka	Spencer	Thomas
		Preceding 24 hours	16:05 9/5 to 16:05 9/6	0.00	0.00	0.00	0.00
Event 1	**9/7/2019 at 16:05**	**24 Hour Storm Period**	**16:05 9/6 to 16:05 9/7**	**0.30**	**0.22**	**0.14**	**0.27**
	≠		≠				
		Preceding 24 hours	13:10 9:16 to 13:10 9/17	0.09	0.05	0.07	0.05
Event 2	**9/18/2019 at 13:10**	**24 Hour Storm Period**	**13:10 9/17 to 13:10 9/18**	**0.80**	**0.90**	**0.68**	**0.67**
		Preceding 24 hours	14:55 9/18 to 14:55 9/19	0.15	0.08	0.09	0.12
Event 3	**9/20/2019 at 14:55**	**24 Hour Storm Period**	**14:55 9/19 to 14:55 9/20**	**0.81**	**1.18**	**0.89**	**0.80**
	≠		≠				
		Preceding 24 hours	00:00 9/30 to 23:59 9/30	0.06	0.05	0.05	0.05
Event 4	**10/1/2019 at 14:00**	**24 Hour Storm Period**	**00:00 10/1 to 23:59 10/1**	**0.12**	**0.14**	**0.21**	**0.12**



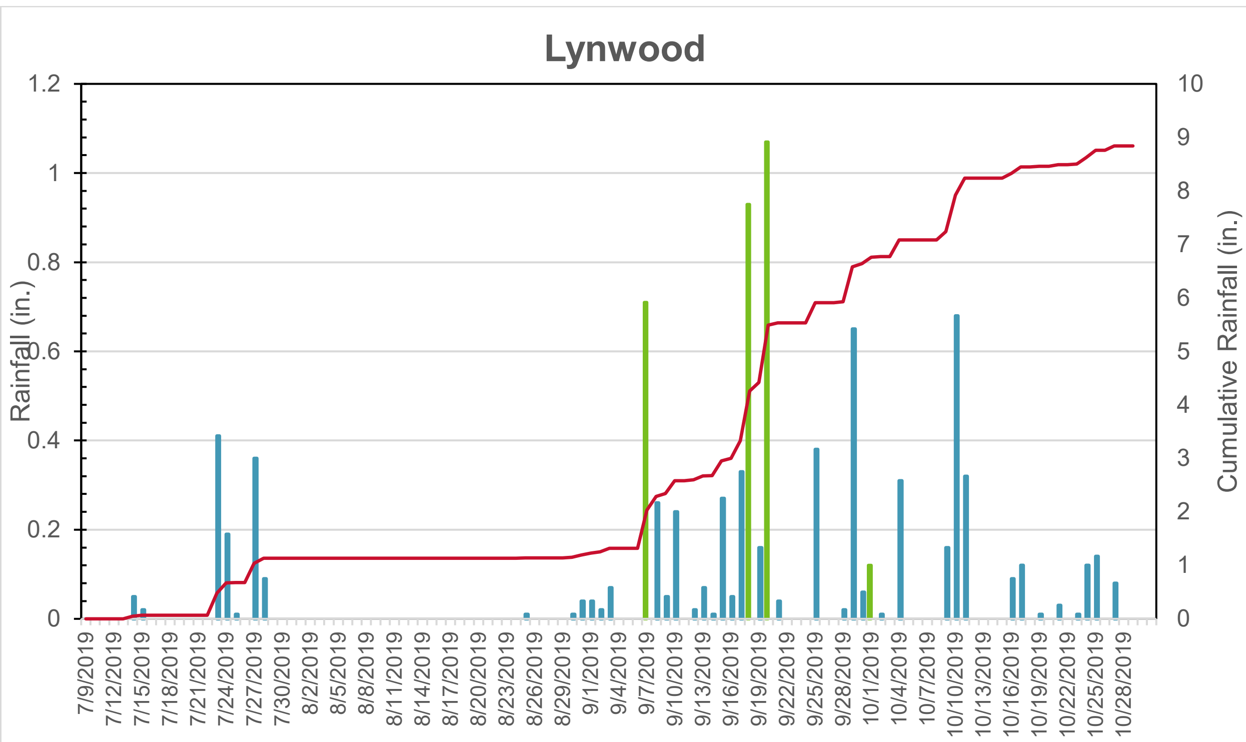
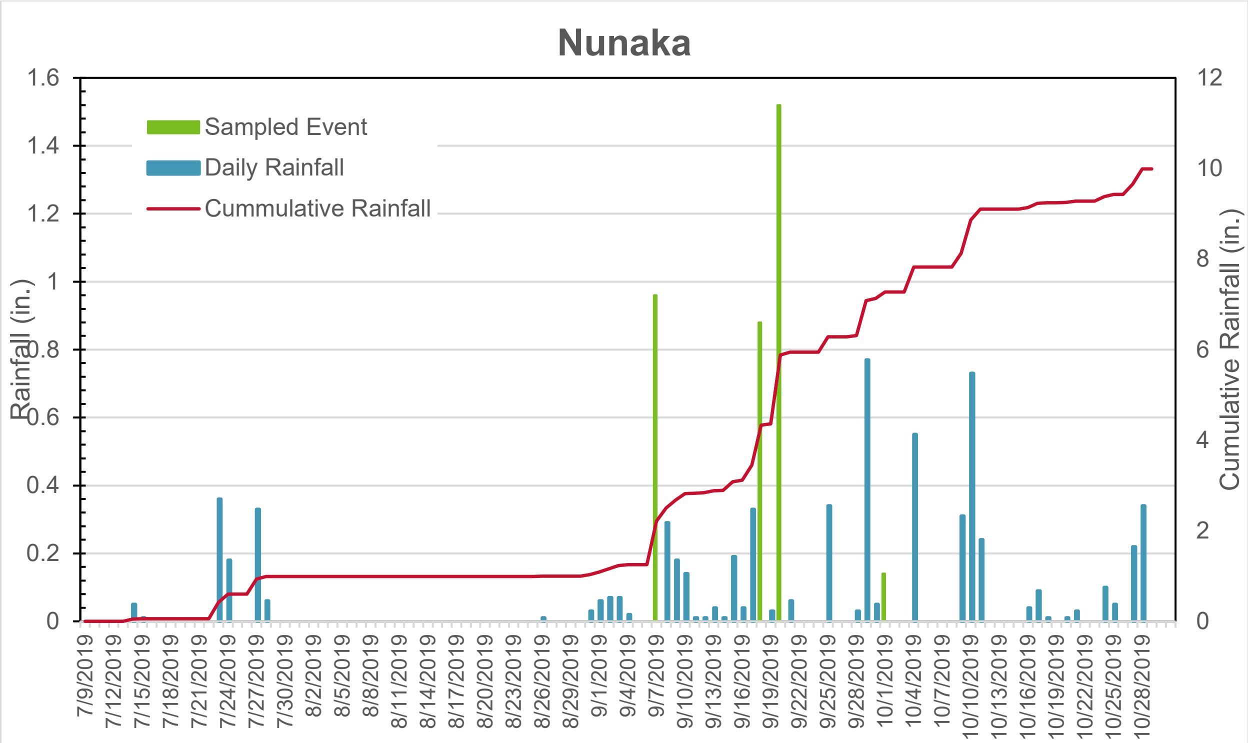


Figure 4. Rainfall Measured at the Spencer and Lynwood Rain Gauges, by Calendar Day



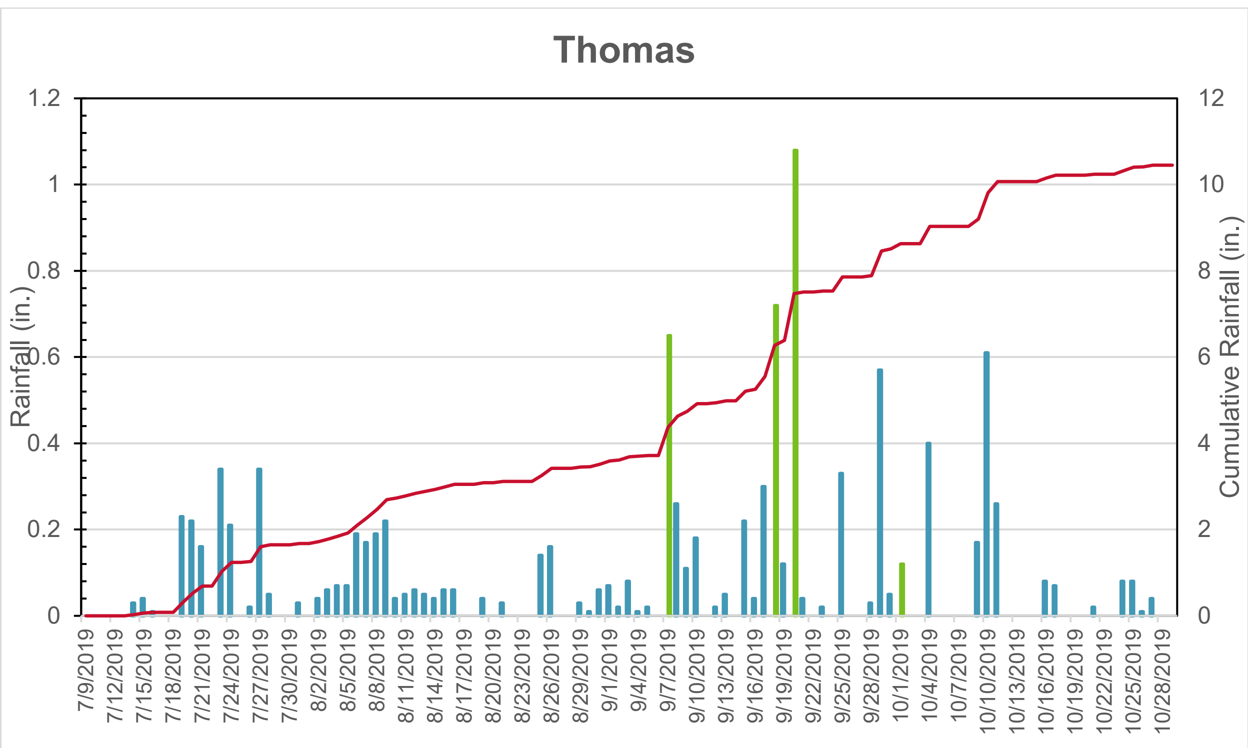


Figure 5. Rainfall Measured at the Nunaka and Thomas Rain Gauges, by Calendar Day

2.4 Field Sampling Procedures

Sampling procedures were carried out in accordance with the methodology outlined in the QAP. No changes from previous years' sampling procedures were required in 2019.

Sampling bottles were prepared before the storm season so that sampling teams could quickly mobilize for sampling. All bottles were labeled with station location, sample number, number of bottles, and analysis type and method. Once a storm event was identified for sampling, the field crew prepared field sampling equipment. All portable water quality measurement instrumentation was calibrated immediately prior to going in the field for each event per the manufacturer's recommendation as outlined in Appendix H of the QAP. Date, time, and sampler's initials were recorded on each sample bottle in the field at the time of sampling.

The field sampling team consisted of two people to address safety concerns and to allow one person to be the designated recorder while the second person performed measurements and conducted the grab sampling. Upon arrival at the outfall, the field team conducted flow measurements and placed the YSI 556 multi-probe into the outfall flow to allow the probes to equilibrate for at least two minutes prior to taking any measurements.

An acoustic doppler flow meter and wading rod were used to collect flow measurements. The flow meter measures the average velocity of the outfall pipe over a twenty second period. The average velocity was used in conjunction with the water depth and pipe diameter to calculate the instantaneous flow of each outfall.

After measuring flow, the field crew measured DO, specific conductivity, pH, and temperature with the YSI 556 multi-probe system. Turbidity was measured in the field by collecting a discrete sample that was analyzed on site with a portable Hach 2100P/Q turbidimeter. All water quality measurements were obtained from the water flowing out of the end of pipe prior to any mixing within the receiving waterbody. All field measurements were recorded on project-specific field log forms that were bound in the project field log books along with field instrument calibration logs (refer to Appendix E).

The field crew obtained the water samples for BOD_5, TSS, fecal coliform, dissolved copper, total hardness, TAH, and PAH in laboratory-provided bottles. The water quality samples were collected from the water flowing from the outfall, and extra care was taken not to disturb any accumulated sediment when collecting a water sample. To avoid having to perform decontamination procedures, all samples, with the exception of TAH, were collected directly into their respective sample containers. In the case of TAH, the sample was first collected into a pre-cleaned and certified 1-Liter (L) PAH bottle that was then used to carefully fill the 40-milliliter (mL) vials for TAH analyses. The PAH bottle was then topped off with additional water from the outfall discharge. Since the PAH bottles were pre-cleaned and certified, it was unnecessary to perform equipment rinsate analyses. Once the water samples were collected, the field crew recorded visual observations at each outfall location.

The field crew conducted replicate field measurements and laboratory analyses at a rate of 15 percent (%) per sampling event. This resulted in replicate field measurements being taken at two monitoring sites per sampling event for all parameters except TAH and PAH. TAH and PAH required one replicate field measurement since they are collected at fewer outfalls. Additional water for TAH and PAH was collected at one station to allow the laboratory to perform matrix spike/matrix spike duplicate (MS/MSD) analyses. TAH analyses also included a trip blank sample, provided by the laboratory that accompanied the sample bottles in the field.

2.5 Sampling Handling and Chain of Custody Procedures

BOD_5, TSS, fecal coliform, dissolved Cu, hardness, TAH, and PAH samples were collected, preserved, and cooled for delivery to the laboratory as described in the QAP. SGS is located in Anchorage, so no special sample shipping or packaging was required. Upon sample collection, all samples were kept chilled to 6 °C with gel ice and delivered to the laboratory by the field crew following the sample collection effort. All samples were transferred to the laboratory under chain of custody (COC) procedures as outlined in the QAP. Copies of all completed COCs are included with the laboratory data reports in Appendix C.

2.6 Laboratory Analyses

The water quality constituents selected for this program were established based upon the requirements of the MS4 permit. All analyses were conducted by SGS, which is certified to conduct such analyses. All analytical methods (refer to Table 2) were based on approved EPA methodology and included all necessary QA/QC procedures and analyses as outlined in the QAP.

The laboratory QA/QC activities provide information needed to assess potential laboratory contamination, analytical precision and accuracy, and representativeness. Analytical quality assurance for this program included:

- Employing analytical chemists trained in the required procedures and analytical methods
- Adherence to documented procedures, EPA methods, and laboratory standard operating procedures
- Calibration of analytical instruments
- Use of quality control samples, internal standards, surrogates, and standard reference materials (SRMs)
- Complete documentation of sample tracking and analysis

Internal laboratory control checks included the use of internal standards, method blanks, MS/MSDs, duplicates, laboratory control spikes and duplicates (LCS/LCSD), and SRMs as required by the sample analysis methodology. For additional detail on laboratory QA/QC procedures, refer to the QAP.

2.7 Deviation from the QAP

There were no deviations from the QAP during the 2019 monitoring year with respect to field sampling procedures, sample handling, sample chain of custody, laboratory analysis, QA/QC, and data validation.

As discussed in Section 2.3, the extreme drought conditions experienced in Anchorage in the summer of 2019 presented a challenge for the SWM program. As result of limited opportunities for sampling, weekend sampling was required for the first storm to maximize the probability of sampling four events within the monitoring period. The laboratory contracted for the SWM program, SGS, was not open over the weekend to accept samples for delivery. Because the samples collected for BOD and Fecal Coliform have relatively short hold times, outfall monitoring that occurs on weekends cannot test for these parameters. As result, BOD and fecal coliform data were not collected for the first storm event. Full data, including BOD and fecal coliform, were collected for the second, third, and fourth storm events.

2.8 QA/QC and Data Validation

QA/QC procedures were followed according to the QAP (MOA 2016). The procedures included analytical checks (field replicates, trip blanks, MS/MSDs); instrument calibration; and procedures to assess data for precision, accuracy, representativeness, comparability, and completeness.

Verification analyses for laboratory parameters were conducted by SGS. The data review focused on criteria for the following QA and QC parameters and their overall effects on the data:

- Sample handling (chain of custody)
- Temperature blank
- Holding time compliance
- MS/MSD and LCS/LCSD results
- Field replicate comparison
- Data validation

SGS is certified by the EPA and the Alaska Drinking Water Program and has an approved QA/QC program. Analytical methods and testing procedures were in adherence with EPA-approved protocols and guidelines. The analyses for the fecal coliform, BOD_5, TSS, dissolved copper, total hardness, PAH, and TAH were reported with appropriate method detection limits and report detection limits.

Sample custody was maintained for the samples. The coolers transporting the samples remained at ambient temperatures or were cooled to less than 6 °C before being delivered to the laboratory within a few hours of each sampling event.

The QA/QC officer validated all data reported by the laboratory. Data that was determined to be either biased low or high was flagged based on low or high recovery rates from laboratory control samples. Any data that was considered suspicious was also rejected and flagged as such. For a more detailed summary of field and laboratory data validation results, refer to Appendix D. Other QA/QC procedures in 2019 included the requirement that all field team members read the QAP. Each team consisted of one ADEC-qualified sampler and one sampler in training. The field team was also required to QC all data at the end of each event to insure all data were collected and sampling information was complete.

3.0 Results and Discussion

3.1 Field Measurements

Insitu field measurements taken as part of the 2019 SWM program are presented in Figures 6 through 11 and in Table 6. Reported measurements include flow, turbidity, DO, conductivity, pH, and temperature. Where relevant, *insitu* measurements are compared against Alaska Water Quality Standard (AWQS) benchmarks (refer to Table 9 for AWQS benchmarks used for comparisons). It should be noted that these AWQS benchmarks apply to the receiving waters, and for stormwater should be considered for comparison purposes only.

Outfall flow rates are reported in Figure 6 and in Table 6. The flow rates were highly variable between sites and storm events, reflecting both the range in subbasin characteristics as well as the spatial and temporal variability that was seen in the precipitation records throughout the monitoring corridor. Outfall SWM08 had the highest mean flow rate (9.07 CFS), as well as the maximum measured flow rate (22.57 CFS during Storm 3) of the 10 outfalls observed during the 2019 SWM program. Outfall SWM09 had the lowest mean flow rate (0.17 CFS) of the outfalls sampled, with a minimum observed flow of 0.01 CFS during Storm 4.

Measured turbidity levels are reported in Figure 7 and Table 6. Like flow rates, turbidity levels were variable between storms and across the sampling corridor, with some outfalls demonstrating consistently low turbidity readings while others exhibited spikes in turbidity during one or more of the sampling events. Mean turbidity levels recorded during the 2019 SWM program at outfalls SWM03, SWM04, SWM05, SWM06, SWM10, and SWM 11 were all below 50 Nephelometric Turbidity Units (NTU). Turbidity values at these outfalls measured as low as 4.13 NTU. In contrast, outfalls SWM07, SWM09, and SWM12 had mean turbidity levels above of 100 NTU. At SWM09 and SWM12, elevated mean turbidity was driven by a single spike in the data for one of the four sampled storms. For example, the turbidity measured at SWM09 during Storm 2 was 399 NTU, the highest turbidity level observed during the 2019 SWM program. Excluding this spike, mean turbidity at SWM09 was 47.5 NTU for the other three sampling events. SWM07 was the only outfall with consistently elevated turbidity, with measured turbidity above 135 NTU for three of the four sampled storm events. The observed variability in turbidity measurements across outfalls and sampling events was expected as turbidity is highly dependent on specific drainage basin characteristics such as land use, land permeability, drainage slope, precipitation intensity, precipitation history, and other factors, all of which vary considerably site-to-site. Turbidity generally tracked with TSS measurements from laboratory analysis, which are reported in Table 7.

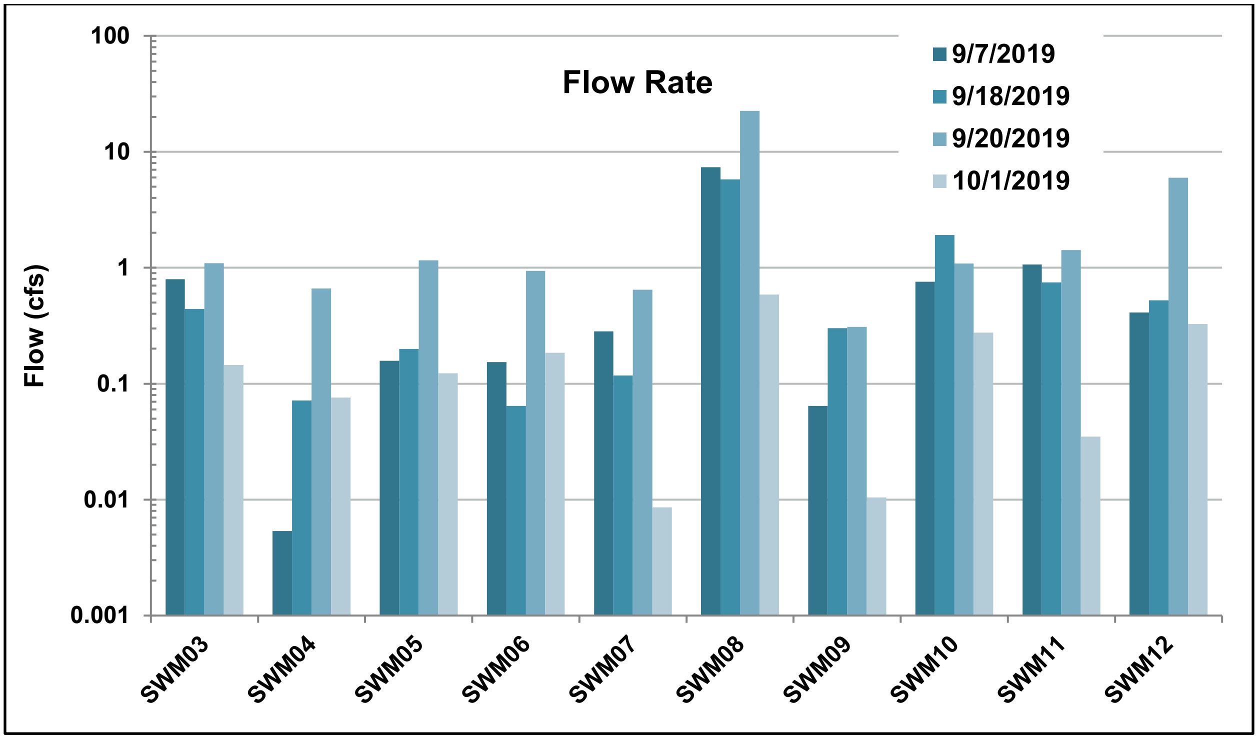


Figure 6. Flow Rates Measured at Monitoring Sites during All Four Events

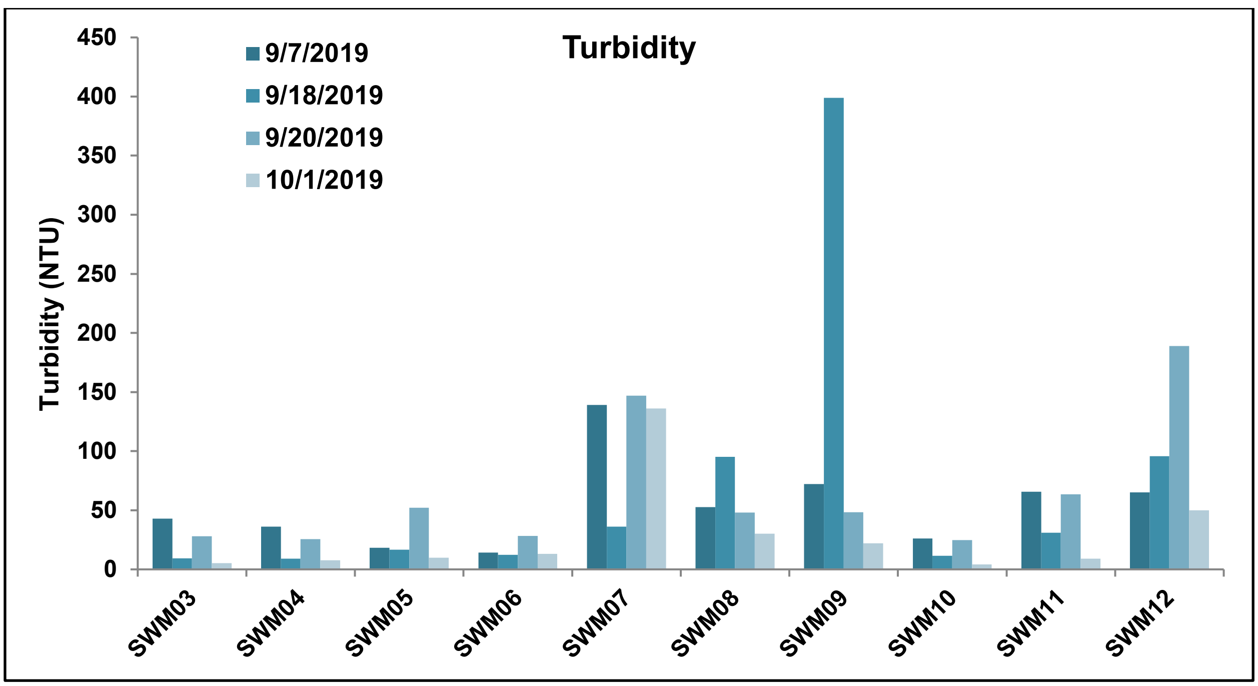


Figure 7. Turbidity Measured in Stormwater Sampled at Monitoring Sites during All Four Events

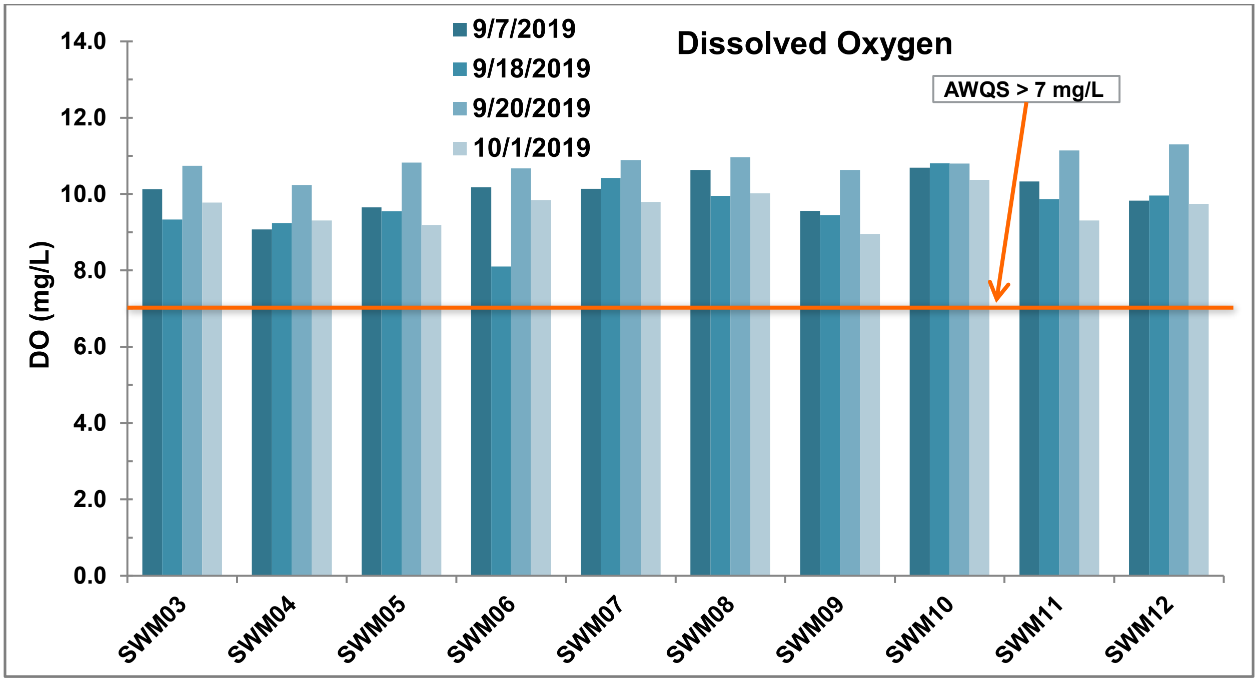


Figure 8. Dissolved Oxygen Measured in Stormwater Sampled at Monitoring Sites during All Four Events. (AWQS Criterion >7 mg/L.)

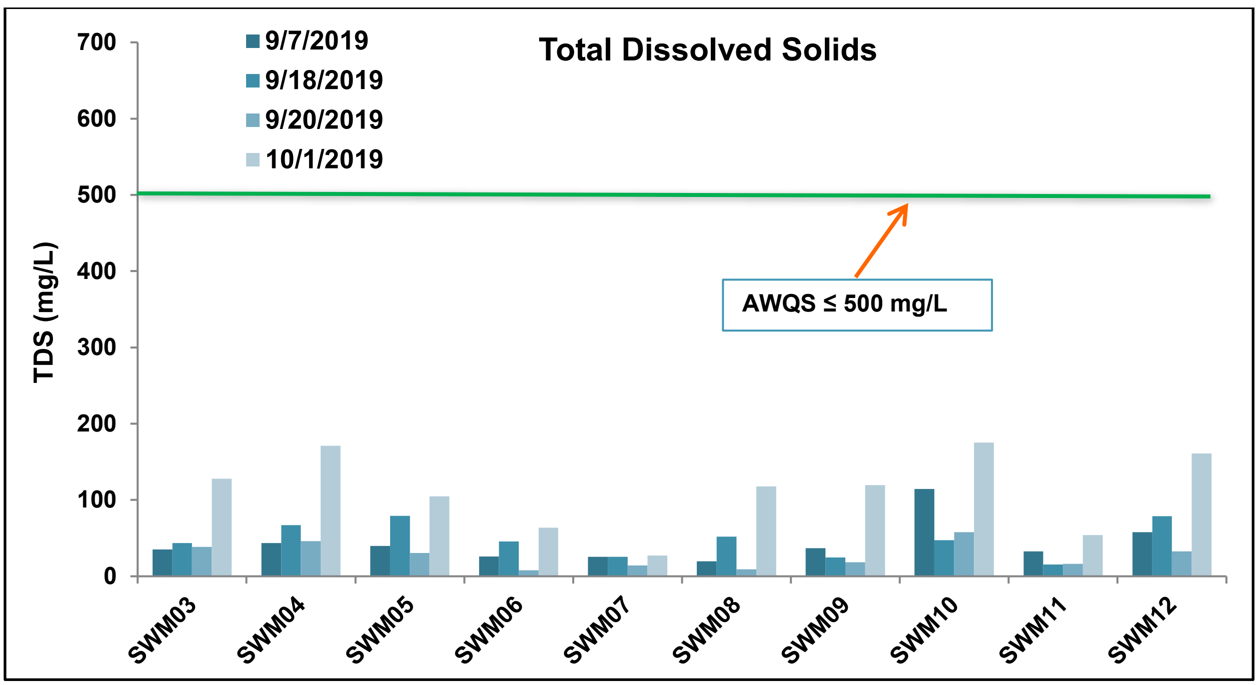
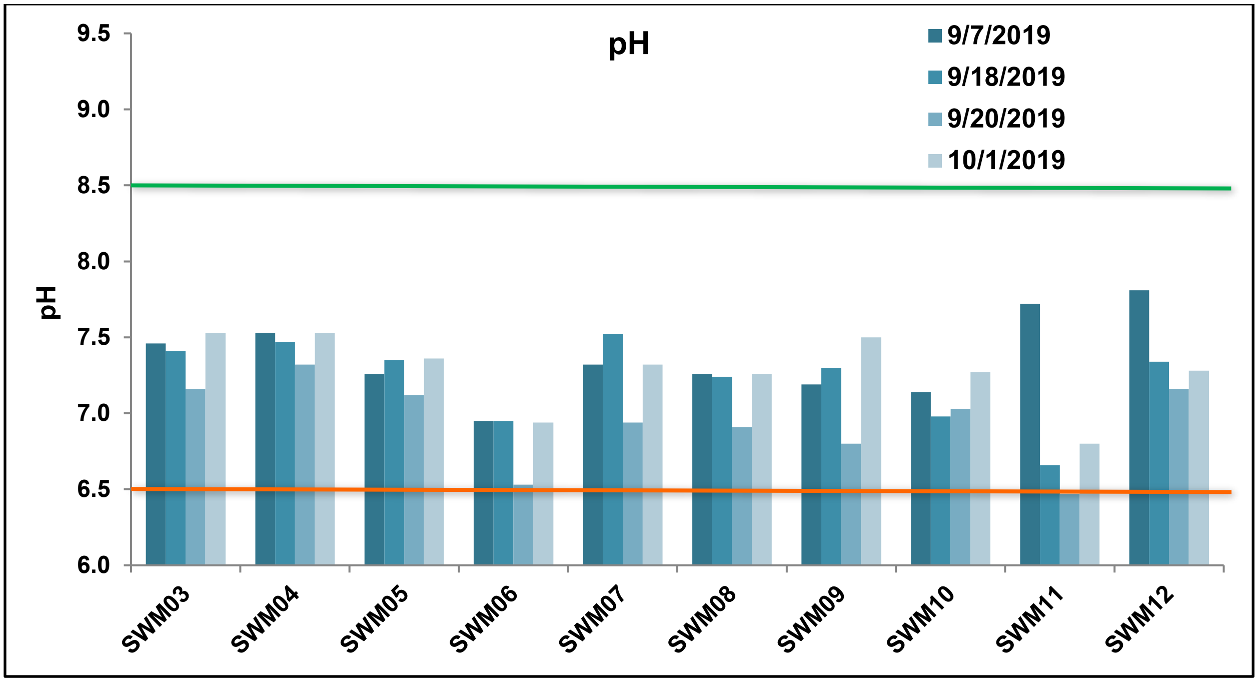
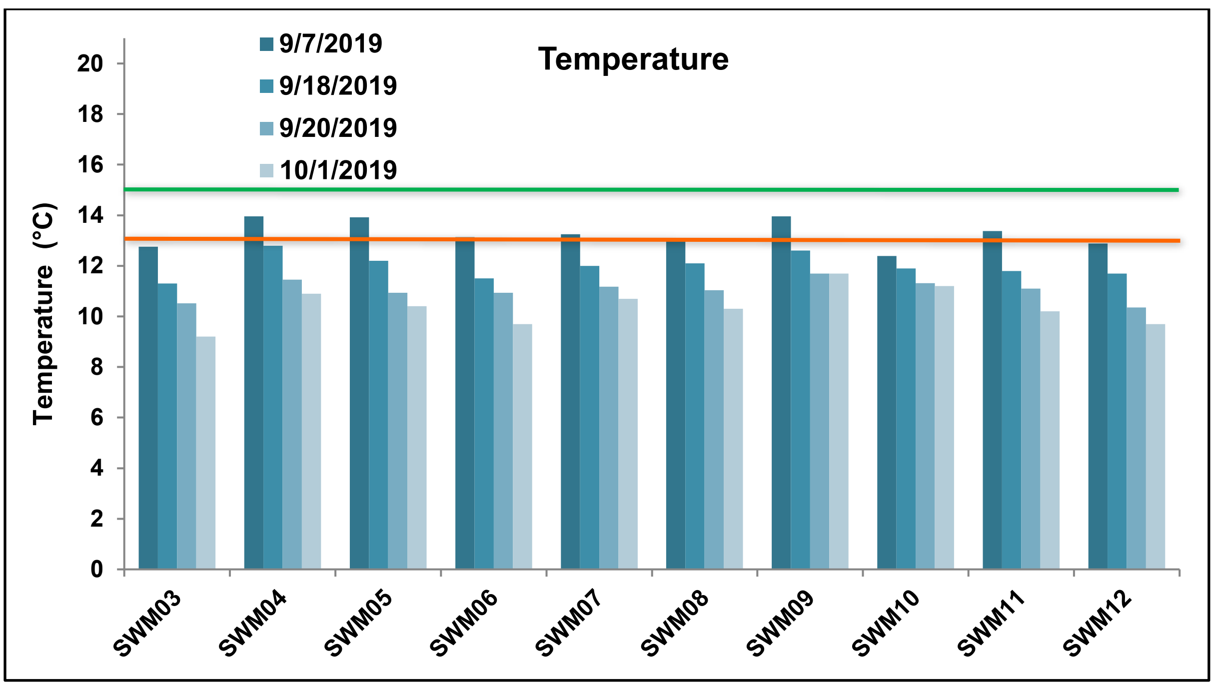


Figure 9. Total Dissolved Solids Measured in Stormwater Sampled at Monitoring Sites during All Four Events. (AWQS Criterion ≤500 mg/L.)



Green line indicates the upper AWQS pH limit of 8.5 and red line indicates the lower AWQS pH limit of 6.5.

Figure 10. pH (units) Measured in Stormwater Sampled at Monitoring Sites during All Four Events



Red line indicates the upper AWQS limit of 13°C for spawning and egg/fry incubation and green line indicates the upper AWQS limit of 15°C for migration and rearing areas.

Figure 11. Temperature (°C) Measured in Stormwater Sampled at Monitoring Sites during All Four Events

Table 6. *Insitu* Parameters Measured at Monitoring Sites during All Four Sampling Events

Station	Storm 1 7-Sep-2019	Storm 2 18-Sep-2019	Storm 3 20-Sep-2019	Storm 4 1-Oct-2019	Mean
Flow Rate (CFS)					
SWM03	0.79	0.44	1.10	0.15	0.62
SWM04	0.01	0.07	0.66	0.08	0.20
SWM05	0.16	0.20	1.16	0.12	0.41
SWM06	0.15	0.06	0.94	0.19	0.34
SWM07	0.28	0.12	0.65	0.01	0.26
SWM08	7.35	5.79	22.6	0.59	9.07
SWM09	0.06	0.30	0.31	0.01	0.17
SWM10	0.76	1.92	1.09	0.28	1.01
SWM11	1.07	0.75	1.42	0.04	0.82
SWM12	0.41	0.52	5.97	0.33	1.81
Turbidity (NTU)					
SWM03	42.9	9.28	27.9	5.39	21.4
SWM04	36.2	8.97	25.6	7.59	19.6
SWM05	18.3	16.6	52.2	10.0	24.3
SWM06	14.1	12.2	28.2	13.2	16.9
SWM07	139.0	36.2	147.0	136.0	114.6
SWM08	52.7	95.1	48.2	30.1	56.5
SWM09	72.1	399.0	48.3	22.0	135.4
SWM10	26.1	11.5	24.7	4.13	16.6
SWM11	65.6	31.0	63.4	9.04	42.3
SWM12	65.2	95.8	189.0	50.0	100.0

Table 6. (continued)

Station	Storm 1 7-Sep-2019	Storm 2 18-Sep-2019	Storm 3 20-Sep-2019	Storm 4 1-Oct-2019	Mean
Dissolved Oxygen (mg/L)					
SWM03	10.13	9.33	10.74	9.78	10.0
SWM04	9.07	9.24	10.24	9.31	9.5
SWM05	9.65	9.55	10.82	9.19	9.8
SWM06	10.18	8.10	11.53	9.84	9.9
SWM07	10.14	10.42	10.89	9.79	10.3
SWM08	10.63	9.95	10.97	10.02	10.4
SWM09	9.56	9.45	10.63	8.96	9.7
SWM10	10.69	10.81	10.80	10.37	10.7
SWM11	10.33	9.87	11.14	9.31	10.2
SWM12	9.83	9.96	11.30	9.74	10.2
Total Dissolved Solids (mg/L)					
SWM03	35.1	43.6	38.4	128.1	61.3
SWM04	43.6	67.0	46.2	171.0	81.9
SWM05	39.7	79.3	30.6	104.7	63.5
SWM06	26.0	45.5	7.8	63.7	35.8
SWM07	25.4	25.4	14.3	27.3	23.1
SWM08	19.5	52.0	9.1	117.7	49.6
SWM09	37.1	24.7	18.2	119.6	49.9
SWM10	114.4	47.5	57.9	175.5	98.8
SWM11	32.5	15.6	16.3	54.0	29.6
SWM12	57.9	78.7	32.5	161.2	82.6

Table 6. (continued)

Station	Storm 1 7-Sep-2019	Storm 2 18-Sep-2019	Storm 3 20-Sep-2019	Storm 4 1-Oct-2019	Mean
pH					
SWM03	7.46	7.41	7.16	7.53	7.16 – 7.53
SWM04	7.53	7.47	7.32	7.53	7.32 – 7.53
SWM05	7.26	7.35	7.12	7.36	7.12 – 7.36
SWM06	6.95	6.95	6.53	6.94	6.53 – 6.95
SWM07	7.32	7.52	6.94	7.32	6.94 – 7.52
SWM08	7.26	7.24	6.91	7.26	6.91 – 7.26
SWM09	7.19	7.30	6.80	7.50	6.80 – 7.50
SWM10	7.14	6.98	7.03	7.27	6.98 – 7.27
SWM11	7.72	6.66	6.47	6.80	6.47 – 7.72
SWM12	7.81	7.34	7.16	7.28	7.16 – 7.81
Temperature (°C)					
SWM03	12.8	11.3	10.5	9.2	10.9
SWM04	14.0	12.8	11.5	10.9	12.3
SWM05	13.9	12.2	10.9	10.4	11.9
SWM06	13.1	11.5	10.9	9.7	11.3
SWM07	13.3	12.0	11.2	10.7	11.8
SWM08	13.1	12.1	11.0	10.3	11.6
SWM09	14.0	12.6	11.7	11.7	12.5
SWM10	12.4	11.9	11.3	11.2	11.7
SWM11	13.4	11.8	11.1	10.2	11.6
SWM12	12.9	11.7	10.4	9.7	11.2

Footnotes: Range rather than mean provided for pH.

Table 7. Concentrations of Microbiological and Conventional Parameters

Station	Storm 1 7-Sep-2019	Storm 2 18-Sep-2019	Storm 3 20-Sep-2019	Storm 4 1-Oct-2019	Mean
Biochemical Oxygen Demand (mg/L)					
SWM03	*	**2U**	2.61	**2U**	1.54
SWM04	*	**2U**	**2U**	**2U**	1.00
SWM05	*	**2U**	2.29	**2U**	1.43
SWM06	*	2.62	2.01	3.70	2.78
SWM07	*	6.13	2.99	6.16	5.09
SWM08	*	5.56	2.62	4.50	4.23
SWM09	*	7.81	2.07	4.01	4.63
SWM10	*	3.49	**2U**	**2U**	1.83
SWM11	*	3.55	3.18	**2U**	2.58
SWM12	*	4.06	3.69	6.60	4.78
Total Suspended Solids (mg/L)					
SWM03	47.5	6.29	39.7	5.98	24.9
SWM04	36.5	4.95	26.9	13.0	20.3
SWM05	9.60	8.75	41.2	3.43	15.7
SWM06	9.00	5.76	33.6	6.21	13.6
SWM07	93.8	125	113	47.3	94.8
SWM08	42.8	80.4	49.4	15.0	46.9
SWM09	46.8	317	41.0	7.25	103.0
SWM10	11.6	130	25.1	2.40	42.3
SWM11	53.8	23.9	58.2	4.31	35.1
SWM12	41.8	51.0	146	30.7	67.4

Footnotes: U = not detected at detection limit (shown). Mean calculations utilize 1/2 the detection limit

* = BOD not sampled for Storm 1

Table 7. (continued)

Station	Storm 1 7-Sep-2019	Storm 2 18-Sep-2019	Storm 3 20-Sep-2019	Storm 4 1-Oct-2019	Geometric Mean
Fecal Coliform (FC/100 mL)					
SWM03	*	3300	4400	1640	2877
SWM04	*	1930	1730	91	672
SWM05	*	2470	2000	**0.50U**	608
SWM06	*	1950	2600	182	974
SWM07	*	2430	2000	3100	2470
SWM08	*	3300	2200	2800	2729
SWM09	*	5870	3800	273	1826
SWM10	*	3970	2100	**0.50U**	724
SWM11	*	4730	3600	727	2313
SWM12	*	3670	5700	1360	3053

Footnotes: U = not detected at the associated detection limit shown. Mean calculations used geometric mean for fecal coliform and utilized 1/2 the detection limit where analyte was not detected.

* = Fecal Coliform not sampled for Storm 1

Dissolved oxygen (DO) levels are reported in Figure 8 and in Table 6. Measured dissolved oxygen (DO) levels were typical for Alaska streams, with all measurements above the AWQS threshold of 7 milligrams/liter (mg/L) (Table 10). Mean DO concentrations across the four sampled storm events ranged from a low of 9.5 mg/L at SWM04 to a high of 10.7 mg/L at SWM10. The highest measured DO concentrations occurred during the third storm event, which was the largest storm sampled during the 2019 SWM program. The elevated DO during Storm 3 is probably a reflection of the higher turbulent flows resulting from the magnitude of the storm.

Although not required by the monitoring plan, specific conductivity was recorded at each site since it was available on the portable multi-parameter meter and is considered useful for interpretation of stormwater data. Specific conductivity was converted to total dissolved solids (TDS) concentrations so that comparisons could be made with the AWQS criterion. TDS concentrations are reported in Figure 9 and in Table 6. TDS concentrations were generally low with mean concentrations below 100 mg/L at each of the ten outfalls across the four sampling events. These concentrations are substantially reduced from prior years when mean TDS concentrations occasionally exceeded 200 mg/L. The maximum TDS concentrations observed during the 2019 SWM monitoring program were measured during Storm 4, which also had the lowest flows of the four sampling events. Even the maximum observed TDS concentration (175.5 mg/L at SWM10 during Storm 4) does not exceed the AWQS criterion of 500 mg/L (Table 10).

Measurements for pH are reported in Figure 10 and Table 6, and generally fall within AWQS criteria. Rainfall is often slightly acidic, and the National Atmospheric Deposition Program (NADP) indicates that rainfall in Alaska typically falls with a pH of 5.1 to 5.2 (NADP 2019). Measured pH levels during the 2019 SWM program were generally at their lowest during Storm 3, which was also the largest storm event sampled. The minimum recorded pH value occurred at SWM11 during Storm 3, and was 6.47, slightly below the AWQS guideline of 6.5 (Table 10) for the Growth and Propagation of Fish, Shellfish, other Aquatic Life and Wildlife. The maximum observed pH value of 7.81 was recorded during Storm 1 at SWM12, and fell within AWQS guidelines (maximum of 8.5).

Temperature measurements are reported in Figure 11 and in Table 6. At each outfall site, temperature decreased with each consecutive monitoring event reflecting the progressively cooler fall weather. The majority of temperature values were found to be less than the AWQS criteria (Table 10) of 13°C for fish spawning and egg/fry incubation areas, and all were below the AWQS criterion of 15°C for fish migration routes and rearing areas.

In addition to the standard field measurements, the field crew also recorded observations of any odor and visible water color, clarity, floatables, deposits or stains, sheens, and debris. A faint hydrocarbon odor was noticed at SWM08 during the first sampling event as well as at SWM07 during the fourth sampling event. Observations of water color and clarity were consistent and matched those outfalls where high turbidity and TSS were observed. No floatables were noted in the field logs. Some stains (rust) were observed at SWM10, which may be an indication of corrosion of the stormwater piping or simply the result of high iron content that is often seen in Anchorage streams. Other observations included a small amount of scum at one site, some garbage-type debris, leaves, sticks, and algae. Other than hydrocarbons and turbidity, no attempt has been made to correlate any of the visual observations with the conventional or pollutant measurements.

3.2 Conventional Parameters (BOD5 and TSS)

Biochemical oxygen demand (BOD_5) concentrations from the 2019 SWM program are reported in Figure 12 and in Table 7. BOD_5 concentrations were found to be fairly low at all locations for all four storm events. Concentrations ranged from a low of not detected (ND, or <2 mg/L) at many sites to a high of 7.81 mg/L measured at SWM09 during the second storm event. For comparison, the maximum recorded BOD_5 concentration in 2018 was 21.8 mg/L, nearly three times greater than the 2019 maximum recorded value. It should be noted that for the 2019 SWM program, BOD_5 and fecal coliform data were not collected for the first storm event. As discussed in Section 2.3, this was due to extreme drought conditions in the summer of 2019 which necessitated weekend sampling while the testing laboratory was closed. The limited hold times for BOD_5 and fecal coliform made it impossible to capture data for the first storm event (sampled on Saturday September 7, 2019).

Measurements for concentrations of total suspended solids (TSS) are presented in Figure 13 and in Table 7. As noted earlier, TSS levels are correlated with turbidity measurements. As with turbidity, TSS concentrations were variable between storms and across the sampling corridor, with some outfalls demonstrating consistently low TSS readings while others exhibited spikes in TSS concentrations. Outfalls SWM03, SWM04, SWM05, SWM06, SWM08, SWM10, and SWM11 all have mean TSS concentrations below 50 mg/L across the four storm events sampled. In contrast, outfalls SWM07, SWM09, and SWM12 had the highest mean TSS concentrations with mean concentrations of 65 mg/L or greater. At outfalls SWM09 and SWM12, these elevated mean TSS readings are driven by a single spike in the data. For example, at SWM09, the TSS measurement for Storm 2 was 317 mg/L, the highest single measurement recorded for TSS during the 2019 SWM program. Excluding this spike, the mean TSS for the other three storms sampled at SWM09 was 31.7 mg/L. SWM07 was the only outfall with consistently elevated TSS values, with TSS concentrations greater than 90 mg/L for three of the four sampled events.

3.3 Fecal Coliform

Fecal Coliform measurements are presented in Figure 14 and in Table 7. The highest measured fecal coliform concentration measured as part of 2019 SWM program was 5,870 colony forming units per 100 mL (CFU/100mL) at outfall SWM09 during Storm 2. By comparison, during the 2018 SWM program, eight outfalls exceeded measurements of 10,000 CFU/100mL. Overall, peak concentrations found in 2019 were substantially decreased from those seen in prior years.

Geometric mean concentrations for fecal coliform measured as part of the 2019 SWM program ranged from 608 CFU/100mL to 3053 CFU/100mL. The station with the lowest geometric mean fecal coliform concentration was SWM05 with a concentration of 608 CFU/100mL; stations SWM04, SWM06 and SWM10 also exhibited geometric mean fecal coliform levels below 1000 CFU/100mL. SWM05 and SWM10 both had individual samples test below the detection limit of 0.5 CFU/100mL during Storm 4. For these samples, one half of the detection limit was used in the calculation of geometric means. The highest geometric mean fecal coliform concentrations were found at outfalls SWM03, SWM08, and SWM12, with measurements of 2877, 2729, and 3053 CFU/100mL respectively.

Despite the general decrease in measured fecal coliform concentrations during the 2019 SWM program, fecal coliform measurements were still found to exceed the AWQS benchmark of 200 CFU/100 mL. While the AWQS criterion does not technically apply to stormwater, the limit of 200 CFU/100 mL is adopted as the most relevant benchmark based on comparable water use categories referenced in the AWQS definitions (refer to Table 10). Studies conducted by the EPA in the early 1980s indicate that the median concentration of fecal coliform in cold climate urban runoff is typically in the 1,000 CFU/100 mL range, which is comparable to levels seen during the 2019 SWM program (EPA 1983).

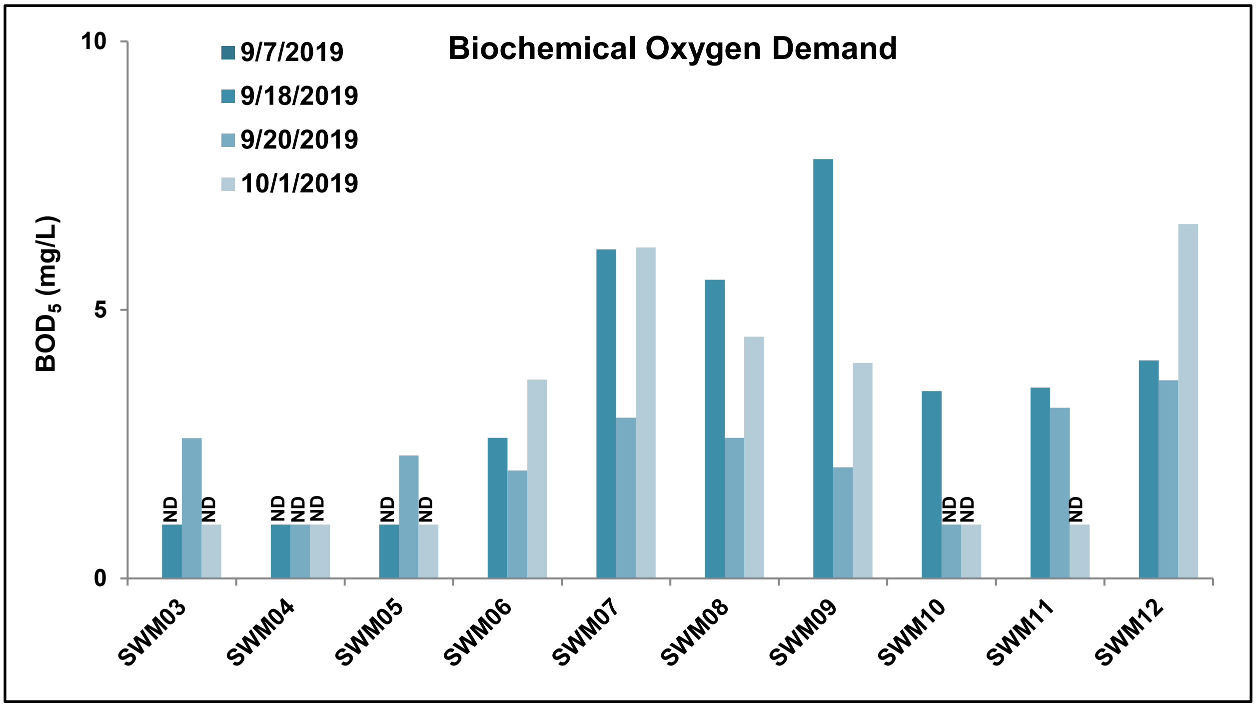


Figure 12. BOD$_5$ (mg/L) Measured in Stormwater Sampled at Monitoring Sites during All Four Events (Note: ND ≤2 mg/L)

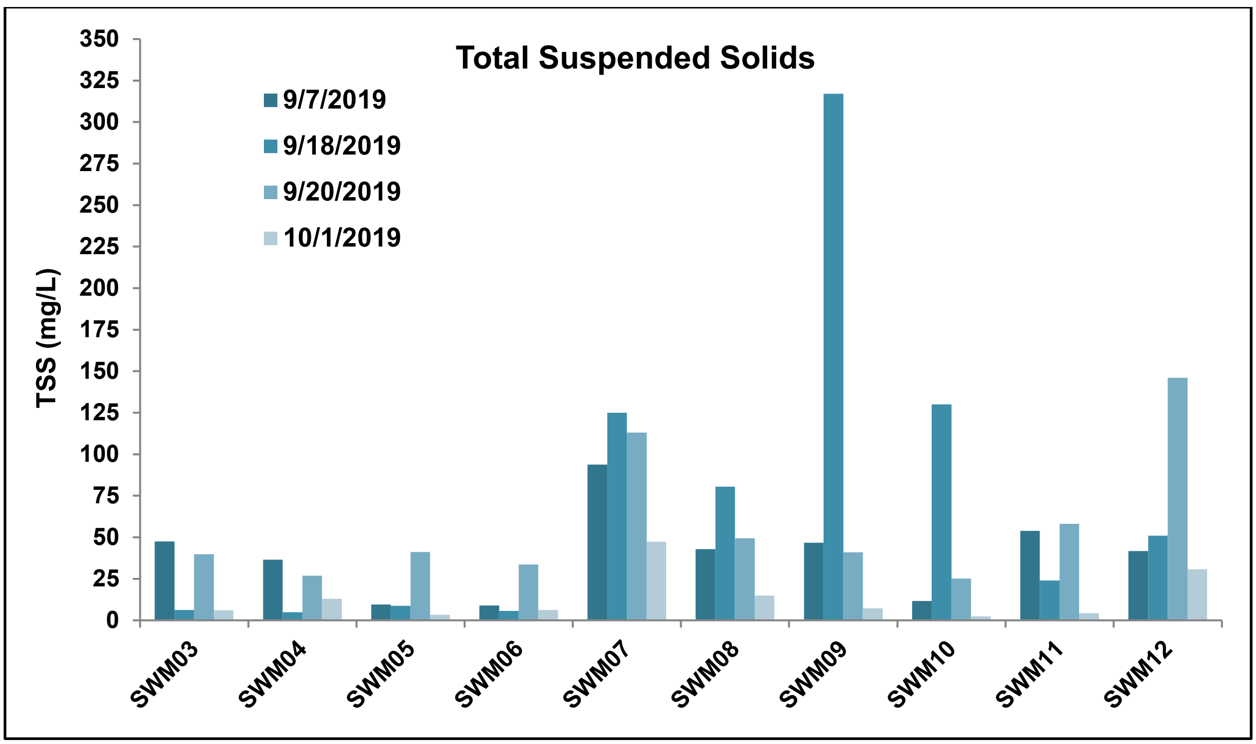


Figure 13. Total Suspended Solids Measured in Stormwater Sampled at Monitoring Sites during All Four Events

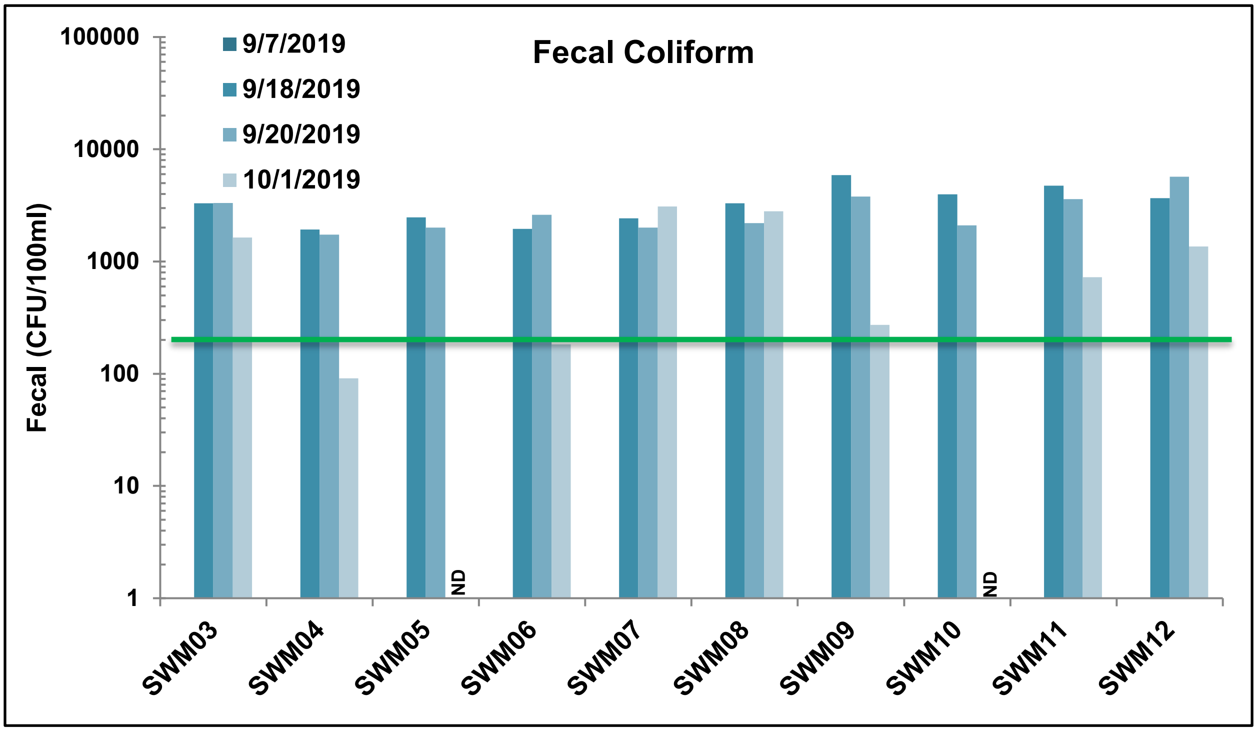


Figure 14. Fecal Coliform (FC/100 mL) Measured in Stormwater Sampled at Monitoring Sites during All Four Events (green line indicates AWQS benchmark of less than 200 CFU/100 mL)

It should be noted that, as discussed in detail in Section 2.3, samples for fecal coliform were not collected during the first sampling event on September 7. Fecal coliform samples were collected and tested for the remaining three storms following the procedures outlined in the QAP.

It should also be noted that as result of the extreme drought conditions experienced in Anchorage in the summer of 2019, the sampling period occurred significantly later in the year than normal. The first sampling event typically occurs in July, but as result of the drought, the 2019 SWM monitoring program began in September. Sampling later in the year likely has an impact on fecal coliform concentrations, and could explain some of the decrease observed in 2019 peak fecal coliform levels. The dry hot weather in the summer of 2019 could also have had an impact on peak fecal coliform concentrations. A previous analysis of fecal coliform in Anchorage streams indicated that the highest loads would most likely occur in August/September in association with peak runoff and rainfall (MOA 2003). Multi-year data collected as part of this SWM program so far has not supported that conclusion and suggests that the highest fecal coliform levels might actually be expected in July. Yearly and seasonal trends are discussed in further detail in Section 3.7.

Despite the fact that the adopted fecal coliform benchmark of 200 CFU/100mL was exceeded during most storms at most outfalls, overall mean concentrations were not alarming when compared to typical concentrations seen in warmer urban areas which can range from the 10,000s to 100,000s CFU/100mL (EPA 1983). However, the high year-to-year variability in fecal coliform measurements suggests the need to continue monitoring this parameter over a relatively extended time period to better assess the performance of control measures.

3.4 Metals and Hardness

Monitoring of dissolved copper and total water hardness were added to the program in 2016 for all locations and storms. The monitoring conducted in years prior to 2016 did not include these two parameters.

Hardness measurements are presented in Table 8 and Figure 15. The highest hardness values at each of the ten outfalls resulted from Storm 4, the smallest storm event. Mean hardness concentrations ranged from a low of 14.4 mg/L at SWM07 to a high of 61.7 mg/L at SWM10. Typically, within the same waterbody, hardness is inversely correlated to turbidity and TSS. This relationship was evident in the 2019 data, where all ten sites had their highest hardness values during the fourth storm event, and most of these same sites also experienced their lowest turbidity and TSS levels during the fourth storm. Hardness is an important parameter for freshwater since it interacts with dissolved metals such as copper to affect metal toxicity thresholds.

Dissolved copper measurements are presented in Table 8 and Figure 16. Dissolved copper concentrations were quite variable and ranged from 0.616 micrograms/liter (µg/L) at SWM10 during Storm 4 to a high of 41.7 µg/L at SWM11 during the first storm. Nine of the ten outfalls had their highest concentrations of dissolved copper during the first storm, which was the first major precipitation event after the extreme drought during the summer of 2019. SWM07 and SWM11 had the highest mean concentrations of copper at 11.2 and 12.1 µg/L respectively. These values were largely driven by the spike in copper concentrations seen in runoff from the first storm after the prolonged period of drought. Excluding the first storm, mean dissolved copper concentrations for SWM07 and SWM11 are 5.5 and 2.3 µg/L respectively, indicating a return to lower levels after the first flushing event. Compared with previous years, some outfalls such as SWM05 and SWM12 saw decreased mean dissolved copper concentrations, while others, such as SWM07 and SWM11 saw increased concentrations, which again, were largely driven by the first storm event.

The AWQS criteria for copper are determined in conjunction with water hardness measurements. For the State of Alaska, the acute water quality criteria for copper ranges from a concentration of 6.99 µg/L at a hardness of 50 mg/L to a concentration of 13.44 µg/L at a hardness value of 100 mg/L. The AWQS criteria applies to the receiving waters, and is used for comparison purposes only when evaluating stormwater.

Table 8. Concentrations of Hardness and Dissolved Copper.

Station	Event 1 11-Jul-2018	Event 2 25-July-2018	Event 3 22-Sept-2018	Event 4 28-Sept-2018	Mean
Hardness (mg/L)					
SWM03	32.1	36.2	26.2	111	51.4
SWM04	33.4	47.7	29.1	124	58.6
SWM05	26.1	53.4	19.6	81.5	45.2
SWM06	5	35.1	6.58	53.5	25.0
SWM07	5	20.6	10.7	21.3	14.4
SWM08	5	19.6	6.68	82	28.3
SWM09	28	34.2	13.1	87.2	40.6
SWM10	80.5	30	32.4	104	61.7
SWM11	5	12.7	14	45.8	19.4
SWM12	39.9	47	24.6	125	59.1
Dissolved Copper (µg/L)					
SWM03	7.11	2	1.81	2.15	3.3
SWM04	3.91	2.55	1.6	4.58	3.2
SWM05	9.3	5.64	3.4	4.13	5.6
SWM06	4.66	2.25	0.717	2.53	2.5
SWM07	28.3	5.8	3.05	7.55	11.2
SWM08	7.7	6.79	1.77	2.04	4.6
SWM09	6.55	2.18	1.21	1.39	2.8
SWM10	2.04	0.842	1.3	0.616	1.2
SWM11	41.7	2.56	1.71	2.48	12.1
SWM12	10.7	5.18	3.83	4.77	6.1

Footnotes: U = not detected at the associated reporting limit that is shown. Mean calculations utilized 1/2 the dectection limit where analyte was not detected.

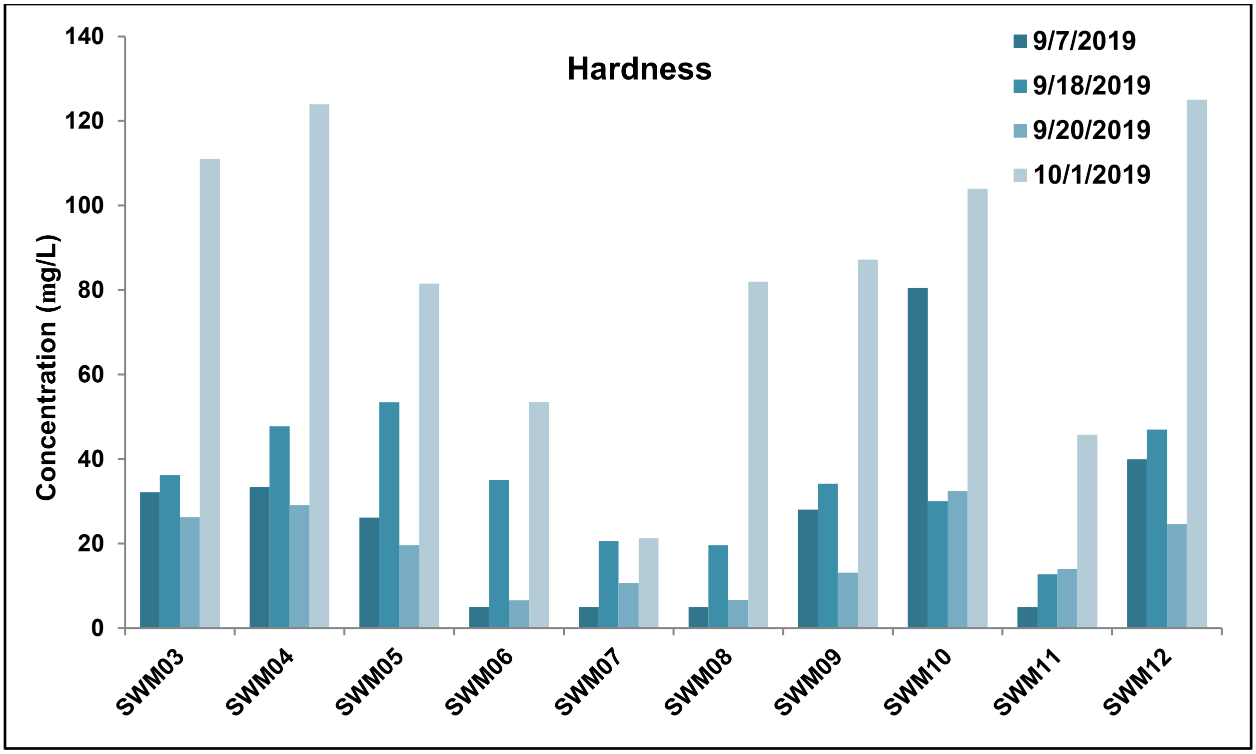


Figure 15. Water Hardness (mg/L) Measured in Stormwater Samples

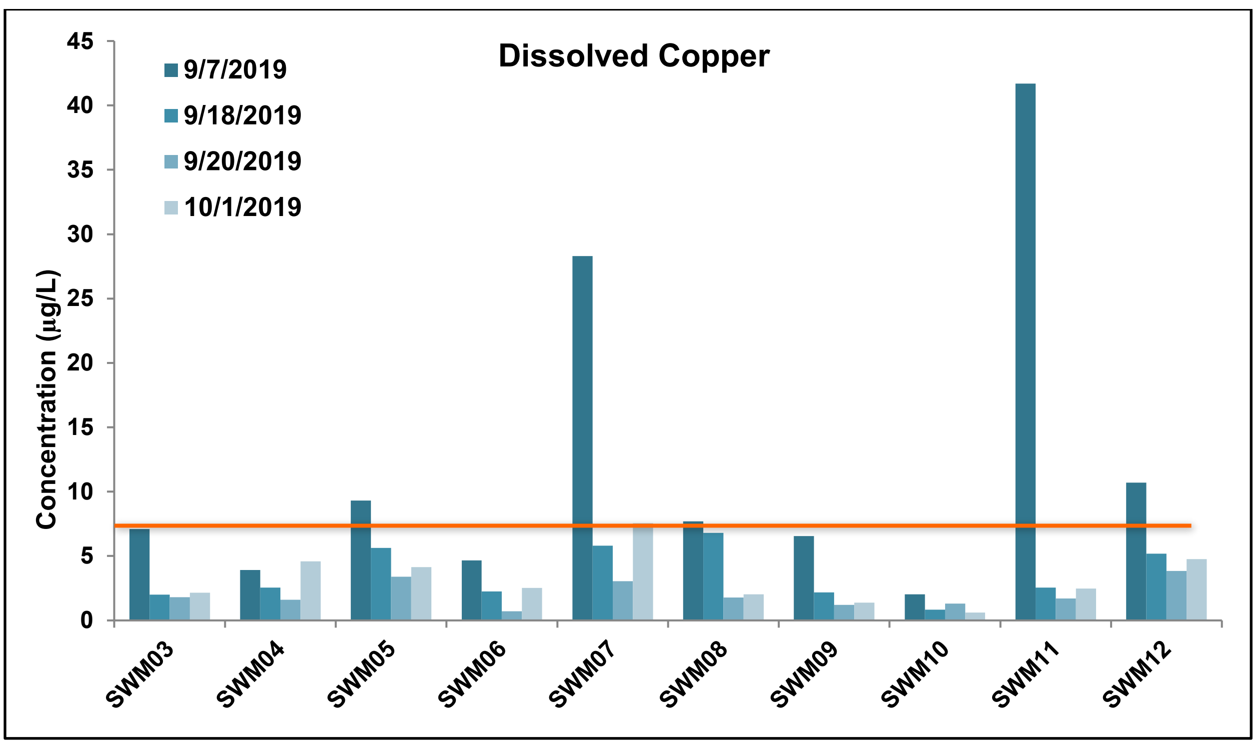


Figure 16. Dissolved Copper (µg/L) Measured in Stormwater Samples (Acute AWQS based on hardness value of 50 mg/L in the receiving water)

3.5 Hydrocarbons

Total aromatic hydrocarbons (TAH) and total polycyclic aromatic hydrocarbons (TPAH) were measured at four of the monitoring sites: SWM05, SWM07, SWM09, and SWM12. For this study TAHs were measured as benzene, ethylbenzene, toluene, and xylenes (BTEX). Dichlorobenzene and Chlorobenzene were not analyzed for in 2019 due to reclassification of these parameters by ADEC. Hydrocarbon measurements are presented in Figure 17 and in Table 9. All samples collected were within the AWQS criteria (Table 10) of 10 µg/L for TAH and 15 µg/L for total aqueous hydrocarbons (TAqH), representing the summation of TAH and TPAH.

TAH (BTEX) was detected in a total of seven samples at three of the four sites. BTEX concentrations ranged from undetected to a high of 7.14 µg/L at SWM07 during Storm 4. BTEX was detected at outfall SWM05 during Storms 1 and 2, SWM07 during Storms 1, 3, and 4, and SWM09 during Storms 1 and 2. Toluene was the most commonly detected constituent, though ethylbenzene and xylene were also detected in one of the samples at SWM07. Only SWM12 had no BTEX detected during the 2019 monitoring period. While all samples met AWQS criteria, 2019 marked a notable shift from prior monitoring years. In the period of 2012-2018, only two of the 111 collected samples reported measurable BTEX concentrations, as opposed to seven of 16 samples collected in 2019. This change may be related to the extreme drought conditions experienced during the summer of 2019.

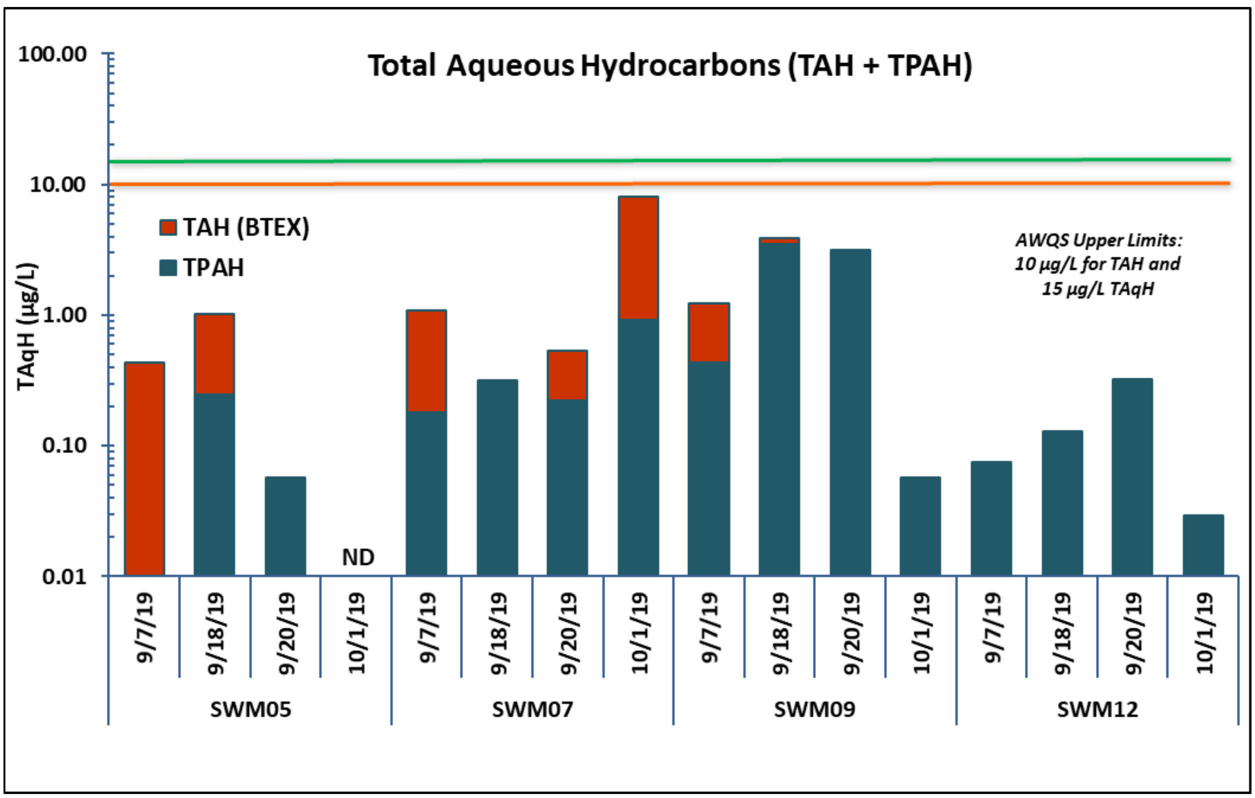


Figure 17. Total Aqueous Hydrocarbons (TAqH = TAH + TPAH) Measured in Stormwater Sampled at Monitoring Sites during All Four Events. (AWQS ≤ 10 µg/L for TAH and ≤ 15 µg/L for TAqH.)

TPAH concentrations varied between storm events and between the four outfalls tested. SWM05 had the lowest mean TPAH concentration across the four storm events sampled, with no detectible TPAH components during Storm 1 and Storm 4. SWM09 had the highest mean TPAH across the four storm events, with a maximum value of 3.516 µg/L during Storm 2. In addition to having the greatest mean TPAH concentration, SWM09 also had by far the greatest diversity of detected analytes. During the third storm event, 13 of the 16 tested PAH analytes were detected at SWM09, and on average, SWM09 had over twice the number of unique analytes detected as did the other sites. Across all outfalls, the most commonly detected TPAH compounds were combustion-related compounds including pyrene, fluoranthene and phenanthrene.

Two of the outfalls tested for hydrocarbons, SWM05 and SWM09, have OGS units, while SWM07 and SWM12 do not. There does not appear to be any correlation between the presence of an OGS unit and measured hydrocarbon concentrations. In addition to the laboratory measurements of TPAH and BTEX, field observations were taken. A hydrocarbon odor was observed at SWM07 during the fourth storm event, corresponding to the maximum TAqH concentration observed during the 2019 monitoring period.

Table 9. Hydrocarbon Concentrations Measured in Stormwater at Four Sites during All Four Storm Events.

	SWM05 - OGS (Yes)				SWM07 - OGS (No)				SWM09 - OGS (Yes)				SWM12 - OGS (No)			
	9/7/2019	9/18/2019	9/20/2019	10/1/2019	9/7/2019	9/18/2019	9/20/2019	10/1/2019	9/7/2019	9/18/2019	9/20/2019	10/1/2019	9/7/2019	9/18/2019	9/20/2019	10/1/2019
Polycyclic Aromatic Hydrocarbons (µg/L)																
Acenaphthene	0.007UJ-	0.0326U	0.00645U	0.00625UJ-	0.0071UJ-	0.0322U	0.00645U	0.00685UJ-	0.00665UJ-	0.007U	0.0068U	0.00645UJ-	0.00685UJ-	0.00685U	0.0066U	0.00665UJ-
Acenaphthylene	0.007U	0.0326U	0.00645U	0.00625U	0.0071U	0.0322U	0.00645U	0.00685U	0.00665U	0.007U	0.0068U	0.00645U	0.00685U	0.00685U	0.0066U	0.00665U
Anthracene	0.007UJ-	0.0326U	0.00645U	0.00625UJ-	0.0071UJ-	0.0322U	0.00645U	0.00685UJ-	0.00665UJ-	**0.023=**	**0.023=**	0.00645UJ-	0.00685UJ-	0.00685U	0.0066U	0.00665UJ-
Benzo(a)anthracene	0.007UJ-	0.0326U	0.00645UJ-	0.00625UJ-	0.0071UJ-	0.0322U	0.00645UJ-	0.00685UJ-	**0.0151J-**	**0.204=**	**0.198J-**	0.00645UJ-	0.00685UJ-	0.00685U	0.0066UJ-	0.00665UJ-
Benzo(a)pyrene	0.00281UJ-	0.013U	0.00258UJ-	0.0025UJ-	0.00284UJ-	0.0129U	0.00258UJ-	0.00275UJ-	0.00266UJ-	**0.283=**	**0.249J-**	0.00258UJ-	0.00275UJ-	0.00275U	0.00263UJ-	0.00266UJ-
Benzo(b)fluoranthene	0.007UJ-	0.0326U	0.00645UJ-	0.00625UJ-	0.0071UJ-	0.0322U	0.00645UJ-	0.00685UJ-	**0.0514J-**	**0.513=**	**0.483 J-**	0.00645UJ-	0.00685UJ-	0.00685U	0.0066UJ-	0.00665UJ-
Benzo(g,h,i)perylene	0.007UJ-	0.0326U	0.00645UJ-	0.00625UJ-	0.0071UJ-	0.0322U	**0.0357J-**	0.00685UJ-	**0.0294J-**	**0.314=**	**0.264J-**	0.00645UJ-	0.00685UJ-	0.00685U	**0.0496J-**	0.00665UJ-
Benzo(k)fluoranthene	0.007UJ-	0.0326U	0.00645UJ-	0.00625UJ-	0.0071UJ-	0.0322U	0.00645UJ-	0.00685UJ-	0.00665UJ-	**0.176**	**0.124 J-**	0.00645UJ-	0.00685UJ-	0.00685U	0.0066UJ-	0.00665UJ-
Chrysene	0.007UJ-	0.0326U	0.00645UJ-	0.00625UJ-	0.0071UJ-	0.0322U	0.00645UJ-	0.00685UJ-	**0.0512J-**	**0.395=**	**0.332J-**	0.00645UJ-	0.00685UJ-	0.00685U	**0.065J-**	0.00665UJ-
Dibenzo(a,h)anthracene	0.00281UJ-	0.013U	0.00258UJ-	0.0025UJ-	0.00284UJ-	0.0129U	0.00258UJ-	0.00275UJ-	0.00266UJ-	**0.0621=**	**0.0557J-**	0.00258UJ-	0.00275UJ-	0.00275U	0.00263UJ-	0.00266UJ-
Fluoranthene	0.007UJ-	**0.134=**	**0.0309=**	0.00625UJ-	**0.05J-**	**0.109=**	**0.0603=**	**0.033J-**	**0.0947J-**	**0.612=**	**0.567=**	**0.0256J-**	**0.0328J-**	**0.042=**	**0.0763=**	**0.0147J-**
Fluorene	0.007UJ-	0.0326U	0.00645U	0.00625UJ-	0.0071UJ-	0.0322U	0.00645U	**0.018J-**	0.00665UJ-	0.007U	**0.012J**	0.00645UJ-	0.00685UJ-	0.00685U	0.0066U	0.00665UJ-
Indeno(1,2,3-cd)pyrene	0.007UJ-	0.0326U	0.00645UJ-	0.00625UJ-	0.0071UJ-	0.0322U	**0.0185J-**	0.00685UJ-	**0.0229J-**	**0.261=**	**0.233J-**	0.00645UJ-	0.00685UJ-	0.00685U	0.0066UJ-	0.00665UJ-
Naphthalene	0.0141U	0.065U	0.0129U	0.0125UJ-	**0.0171J-**	0.0645U	0.0129U	**0.773J-**	**0.0644=**	0.0141U	0.0136U	0.0129UJ-	0.0138U	**0.00946J**	0.0132U	0.0133UJ-
Phenanthrene	0.0281UJ-	0.13U	0.0257U	0.025UJ-	**0.0348J-**	**0.0665J**	**0.0363J**	**0.0442J-**	**0.0392J-**	**0.179=**	**0.157=**	**0.0113J-**	0.0274UJ-	**0.0333J**	**0.0416J**	0.0266UJ-
Pyrene	0.0281UJ-	**0.112J**	**0.0257J**	0.025UJ-	**0.0795J-**	**0.138J**	**0.0704=**	**0.0544J-**	**0.0639J-**	**0.494=**	**0.443=**	**0.0202J-**	**0.0425J-**	**0.0453J**	**0.0913=**	**0.0148J-**
Volatile Aromatic Hydrocarbons (µg/L)																
Benzene	0.2U	0.2U	0.2U	0.2U	0.2U	0.2U	0.2U	0.2U	0.2U	0.2U	0.2U	0.2U	0.2U	0.2U	0.2U	0.2U
Ethylbenzene	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U	**0.718J**	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U
o-Xylene	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U	**1.83=**	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U
P&M-Xylene	1U	1U	1U	1U	1U	1U	1U	**3.69=**	1U	1U	1U	1U	1U	1U	1U	1U
Toluene	**0.43J**	**0.77J**	0.5U	0.5U	**0.91J**	0.5U	**0.31J**	**0.904J**	**0.81J**	**0.34J**	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U
Hydrocarbon Summary Parameters (µg/L)																
TPAH	ND	**0.246**	**0.0566**	ND	**0.1814**	**0.3135**	**0.2212**	**0.9226**	**0.4322**	**3.5161**	**3.1407**	**0.0571**	**0.0753**	**0.13006**	**0.3238**	**0.0295**
TAH as BTEX	**0.43**	**0.77**	ND	ND	**0.91**	ND	**0.31**	**7.142**	**0.81**	**0.34**	ND	ND	ND	ND	ND	ND
TAqH (TPAH + TAH)	**0.43**	**1.016**	**0.0566**	ND	**1.0914**	**0.3135**	**0.5312**	**8.0646**	**1.2422**	**3.8561**	**3.1407**	**0.0571**	**0.0753**	**0.13006**	**0.3238**	**0.0295**

Footnotes: U = not detected at the reporting limit. ND = no concentration detected in any analyte tested. J- = Estimated value biased low due to matrix interferences. J=estimated

All detected concentrations are shown in bold. Hydrocarbon summary parameters only include detected concentrations.

Table 10. Pertinent Numeric Alaska Water Quality Standard (AWQS) Criteria

Designated Use	Description of Standard
Fecal Coliform Bacteria	
(A) Water Supply (i) drinking, culinary and food processing	In a 30-day period, the geometric mean may not exceed 20/FC/100 ml, and not more than 10% of the samples may exceed 40 FC/100 ml.
(A) Water Supply (ii) agriculture, including irrigation and stock watering	The geometric mean of samples taken in a 30-day period may not exceed 200 FC/100 ml, and not more than 10% of the samples may exceed 400 FC/100 ml. For products not normally cooked and for dairy sanitation of unpasteurized products, the criteria for drinking water supply, (1)(A)(i), apply.
(A) Water Supply (iii) aquaculture	For products normally cooked, the geometric mean of samples taken in a 30-day period may not exceed 200 FC/100 ml, and not more than 10% of the samples may exceed 400 FC/100 ml. For products not normally cooked, the criteria for drinking water supply, (1)(A)(i), apply.
(A) Water Supply (iii) Industrial	Where worker contact is present, the geometric mean of samples taken in a 30-day period may not exceed 200 FC/100 ml, and not more than 10% of the samples may exceed 400 FC/100 ml.
(B) Water Recreation (iv) contact recreation	In a 30-day period, the geometric mean of samples may not exceed 100 FC/100 ml, and not more than one sample or more than 10% of the samples if there are more than 10 samples, may exceed 200 FC/100 ml.
(B) Water Recreation (ii) secondary contact	In a 30-day period, the geometric mean of samples may not exceed 200 FC/100 ml, and not more than 10% of the total samples may exceed 400 FC/100 ml.
(C) Growth and Propagation of Fish, Shellfish, other Aquatic Life and Wildlife	Not applicable.
Dissolved Oxygen (most restrictive shown)	
(A) Water Supply (iii) aquaculture (C) Growth and Propagation of Fish, Shellfish, other Aquatic Life and Wildlife	DO must be greater than 7mg/L in surface waters. The concentration of total dissolved gas may not exceed 110% of saturation at any point of sample collection.
pH	
(A) Water Supply (i) drinking, culinary and food processing	May not be less than 6.0 or greater than 8.5.
(A) Water Supply (ii) agriculture, including irrigation and stock watering, & (iv) Industrial	May not be less than 5.0 or greater than 9.0.

Table 10 (continued). Pertinent Numeric Alaska Water Quality Standard (AWQS) Criteria

Designated Use	Description of Standard
pH (continued)	
(A) Water Supply (iii) aquaculture	May not be less than 6.5 or greater than 8.5. May not vary more than 0.5 pH unit from natural conditions.
(B) Water Recreation (iv) contact recreation	May not be less than 6.5 or greater than 8.5. If natural condition pH is outside this range, substances may not be added that cause an increase in the buffering capacity of the water.
(B) Water Recreation (ii) secondary contact	Same as (6)(A)(iv)
(C) Growth and Propagation of Fish, Shellfish, other Aquatic Life and Wildlife	May not be less than 6.5 or greater than 8.5. May not vary more than 0.5 pH unit from natural conditions.
Petroleum Hydrocarbons	
(A) Water Supply (iii) aquaculture & (C) Growth and Propagation of Fish, Shellfish, Other Aquatic Life, and Wildlife.	TAqH in the water column may not exceed 15 µg/L. TAH in the water column my not exceed 10 µg/L. Surface waters and adjoining shorelines must be virtually free from floating oil, film, or discoloration.
Dissolved Inorganic Substances (most restrictive shown)	
(A) Water Supply (i) drinking, culinary, and food processing	Total dissolved solids (TDS) from all sources may not exceed 500 mg/L.
Temperature (most restrictive shown)	
(A) Water Supply (iii) aquaculture & (C) Growth and Propagation of Fish, Shellfish, Other Aquatic Life, and Wildlife.	The following maximum temperatures may not be exceeded, where applicable: Migration routes and rearing areas: 15°C Spawning areas, egg & fry incubation: 13°C

Table 10 (continued). Pertinent Numeric Alaska Water Quality Standard (AWQS) Criteria

Turbidity	
(A) Water Supply (i) drinking, culinary, and food processing	May not exceed 5 nephelometric turbidity units (NTU) above natural conditions when the natural turbidity is 50 NTU or less, and may not have more than 10% increase in turbidity when the natural turbidity is more than 50 NTU, not to exceed a maximum increase of 25 NTU.
(A) Water Supply (ii) agriculture, including irrigation and stock watering	May not cause detrimental effects on indicated use.
(A) Water Supply (iii) aquaculture	May not exceed 25 NTU above natural conditions. For all lake waters, may not exceed 5 NTU above natural conditions.
(A) Water Supply (iv) industrial	May not cause detrimental effects on established water supply treatment levels.
(B) Water Recreation (i) contact recreation	May not exceed 5 NTU above natural conditions when the natural turbidity is 50 NTU or less, and may not have more than 10% increase in turbidity when the natural turbidity is more than 50 NTU, not to exceed a maximum increase of 15 NTU. May not exceed 5 NTU above natural turbidity for all lake waters.
(B) Water Recreation (ii) secondary recreation	May not exceed 10 NTU above natural conditions when natural turbidity is 50 NTU or less, and may not have more than 20% increase in turbidity when the natural turbidity is greater than 50 NTU, not to exceed a maximum increase of 15 NTU. For all lake waters, turbidity may not exceed 5 NTU above natural turbidity.
(C) Growth and Propagation of Fish, Shellfish, Other Aquatic Life, and Wildlife	Same as (12)(A)(iii).

Dissolved Copper (µg/L)

Metal	m_A	b_A	m_C	b_C	**Freshwater Conversion Factors (CF)**	
					Acute (CMC)	**Chronic (CCC)**
Copper	0.9422	-1.700	0.8545	-1.702	0.960	0.960

Hardness-dependent criteria may be calculated from the following for freshwater metals:

Acute (dissolved) = $\exp\{m_A[\ln(\text{hardness})] + b_A\}$ (CF)

Chronic (dissolved) = $\exp\{m_C[\ln(\text{hardness})] + b_C\}$ (CF)

3.6 Multi-Year Site Trends

Review of the SWM program data record reveals persistent differences between outfalls with regards to measured parameters. This section discusses site trends for each parameter, and where applicable, statistical analysis is used to further study these trends.

The stormwater outfall sampling conducted in 2019 represented the ninth year of sampling under the SWM program. These nine years of sampling provide a data record for investigation of differences between the monitoring sites included in the program. General site differences were investigated through statistical analysis where applicable for parameters that follow normal or log-normal distributions. Box plots have been prepared for visualization of the data record for each parameter tested (Figures 18-26). The box plots depict the minimum, maximum, median, 25th-percentile, and 75th-percentile of the data collected over the nine year monitoring period. It should be noted that outfalls SWM11 and SWM12 were added to the SWM program in 2017 and therefore have shorter data records than the other outfalls.

Statistical analysis of the SWM program data record indicates that there are significant differences in outfall temperature across at least some of the 10 outfalls tested. Cursory observation of the box plot data (Figure 18) indicates that temperature readings tend to be lower at SWM03 and SWM10 than at the other outfalls. Similarly, SWM04 appears to trend warmer than other outfalls, and has a median temperature over two degrees Celsius higher than do SWM03 and SWM10. These differences were found to be statistically significant (single factor ANOVA P-value of 0.000045), supporting the conclusion that there are significant, persistent differences in temperature between at least some of the outfalls.

Figure 18. Station Box Plot of Temperature by Outfall, All Data 2011 through 2019

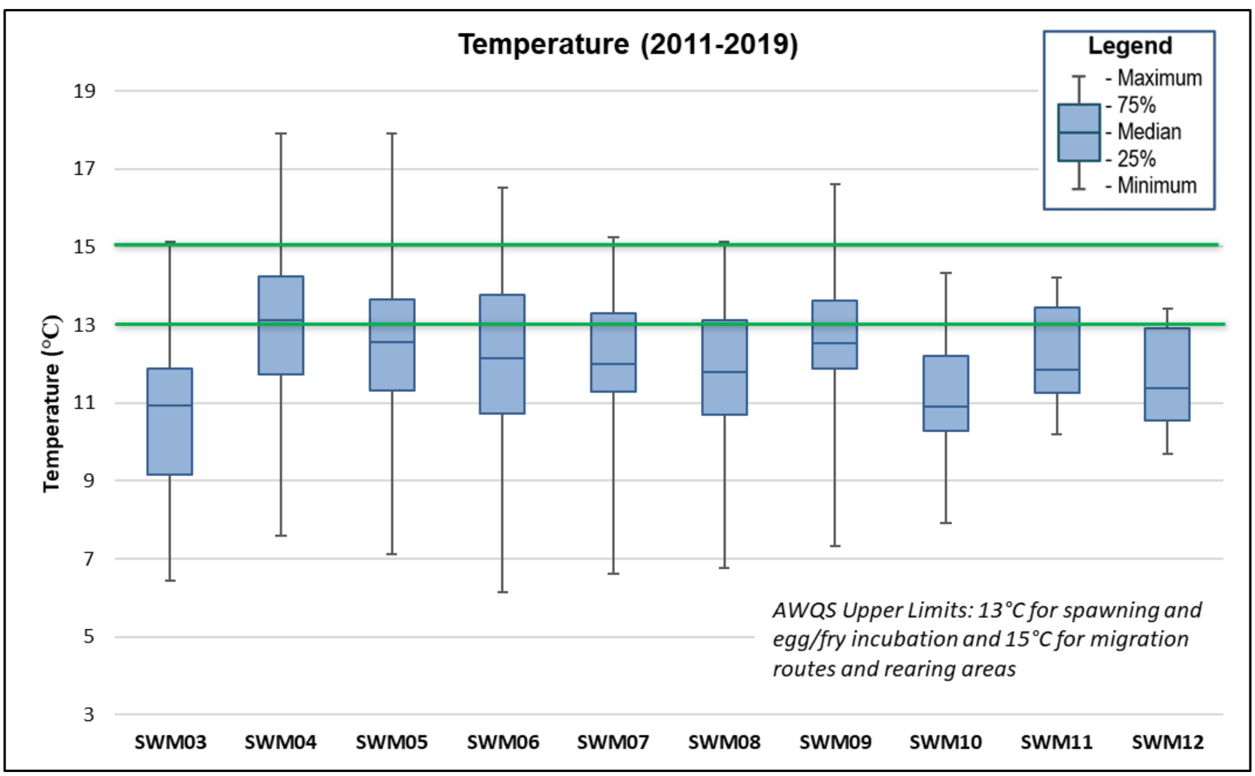


Figure 19. Station Box Plot of Dissolved Oxygen by Outfall, All Data 2011 through 2019

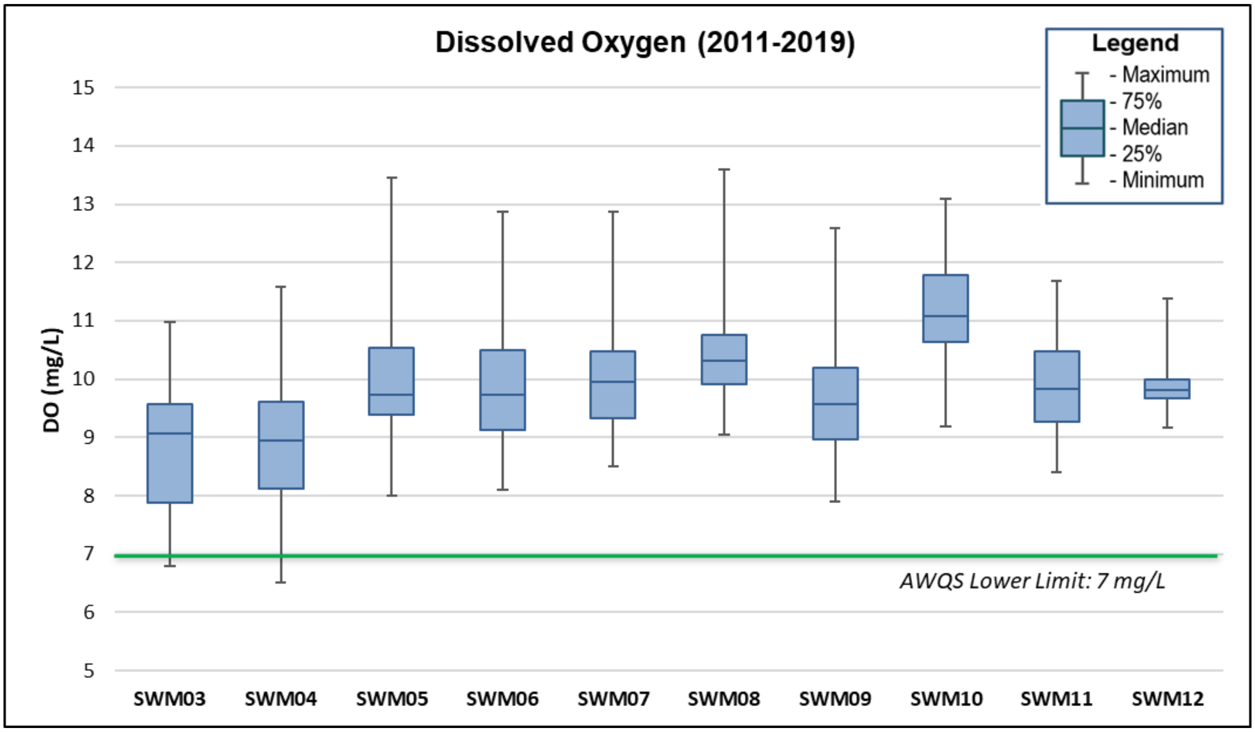


Figure 20. Station Box Plot of pH by Outfall, All Data 2011 through 2019

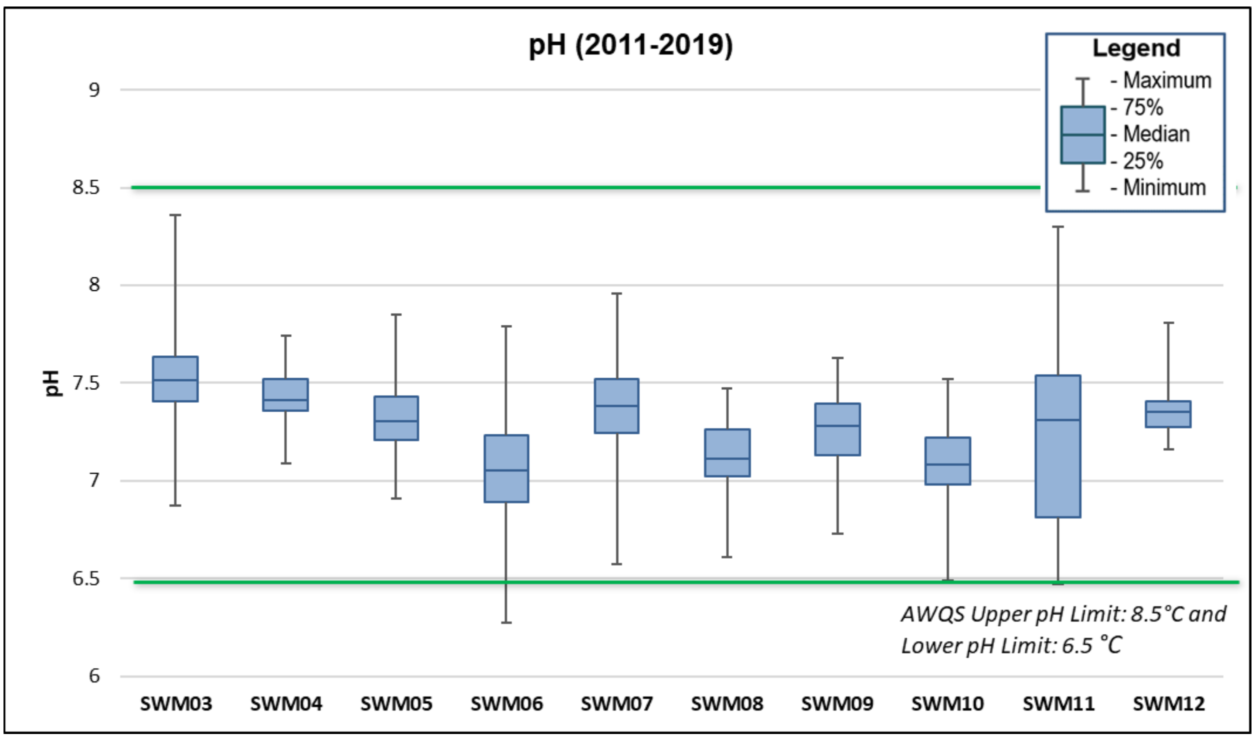


Figure 21. Station Box Plot of Total Dissolved Solids by Outfall, All Data 2011 through 2019

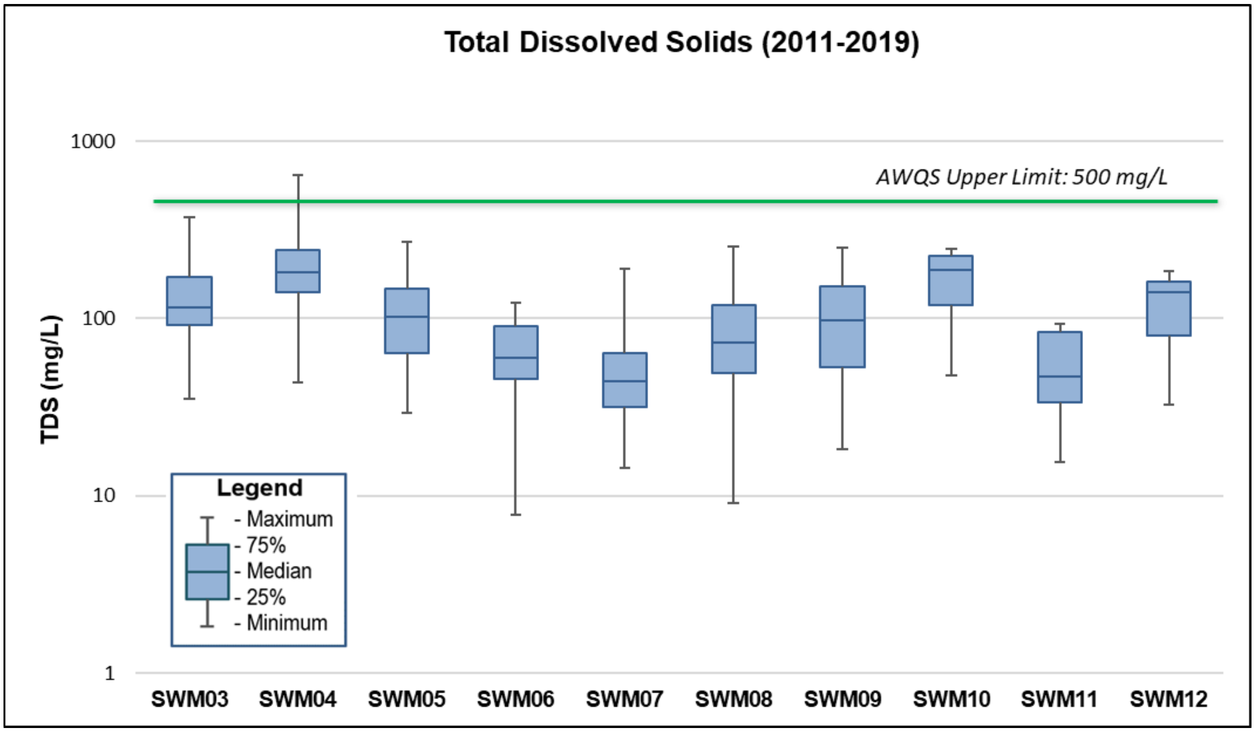


Figure 22. Station Box Plot of Total Suspended Solids by Outfall, All Data 2011 through 2019

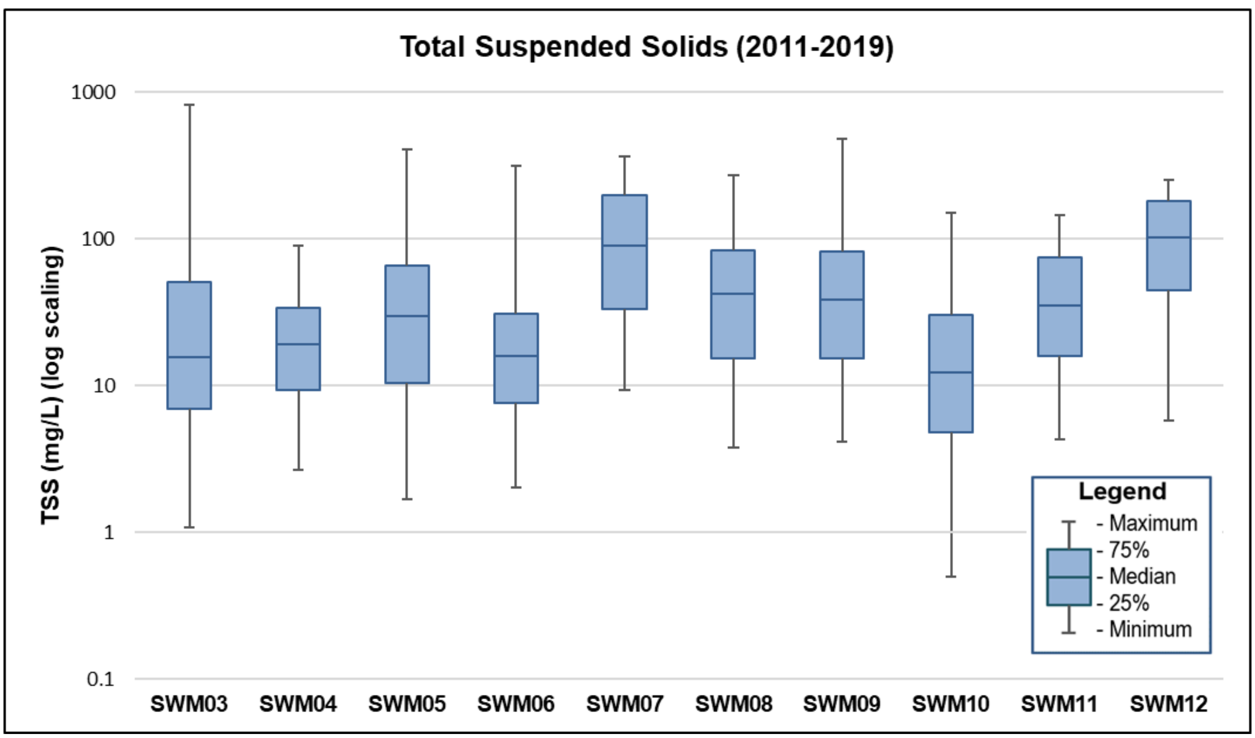


Figure 23. Station Box Plot of Turbidity by Outfall, All Data 2011 through 2019

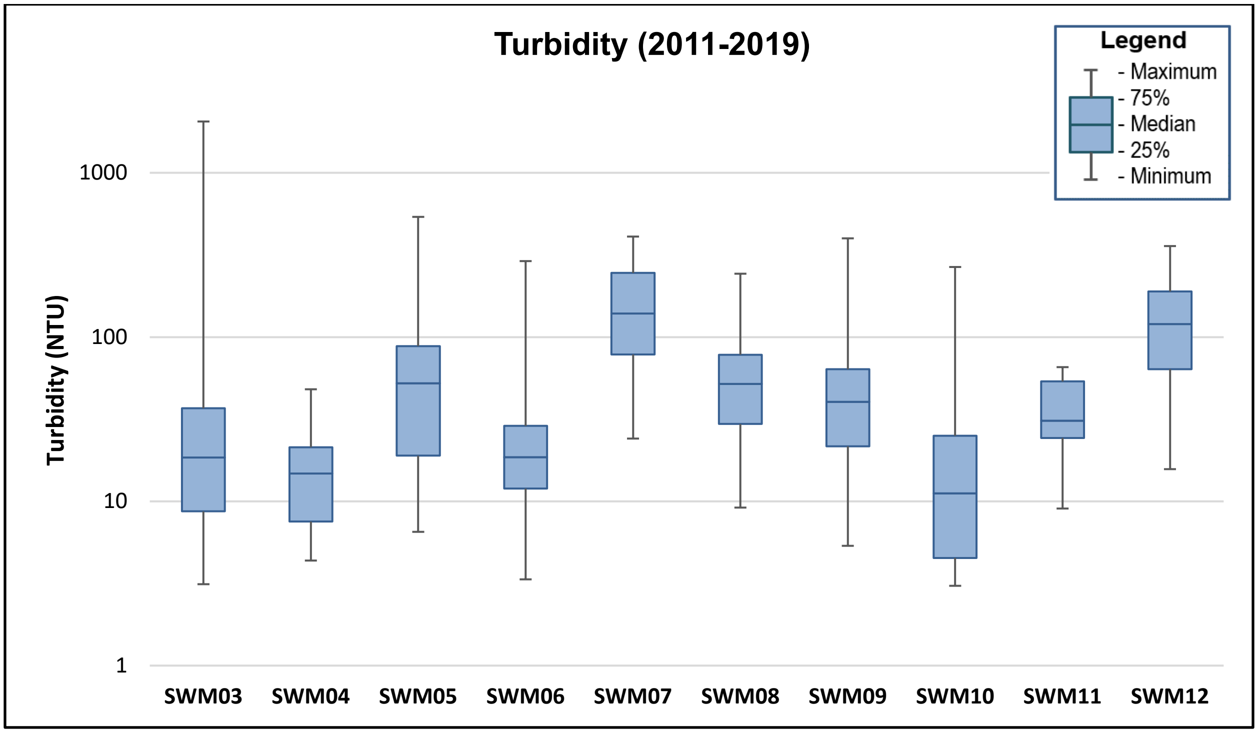


Figure 24. Station Box Plot of BOD_5 by Outfall, All Data 2011 through 2019

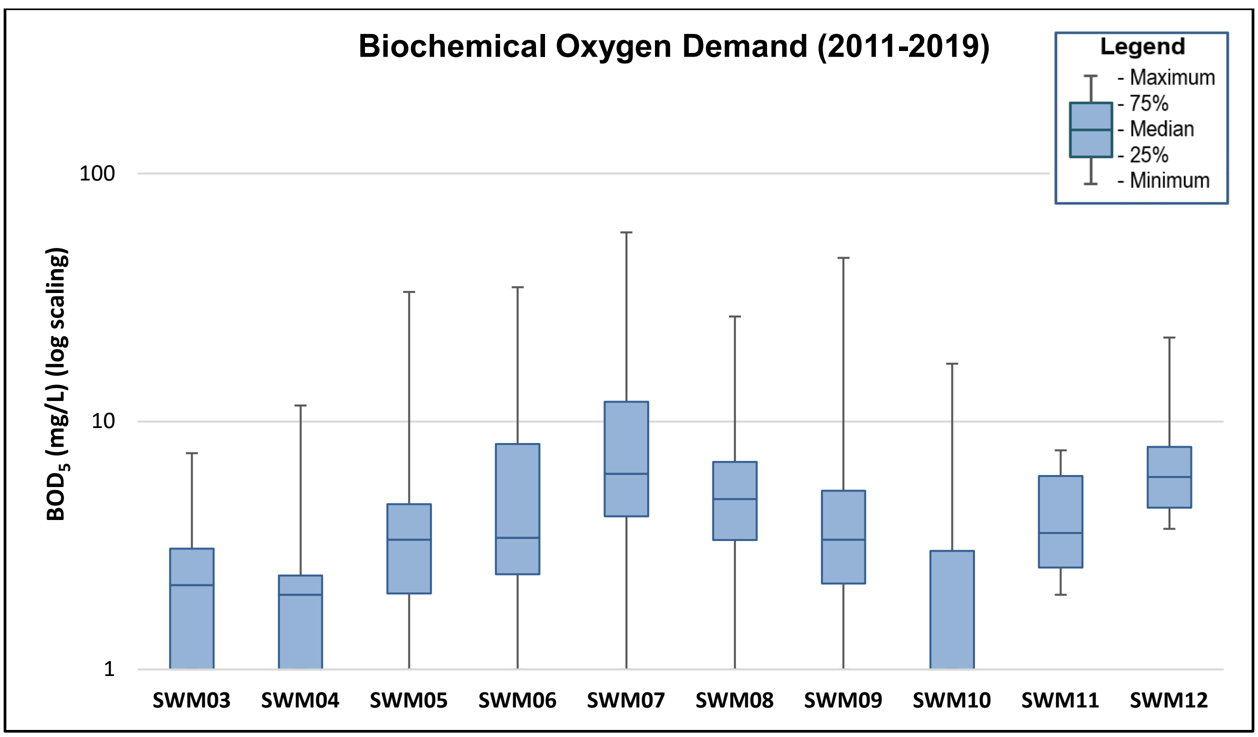


Figure 25. Station Box Plot of Fecal Coliform Bacteria by Outfall, All Data 2011 through 2019

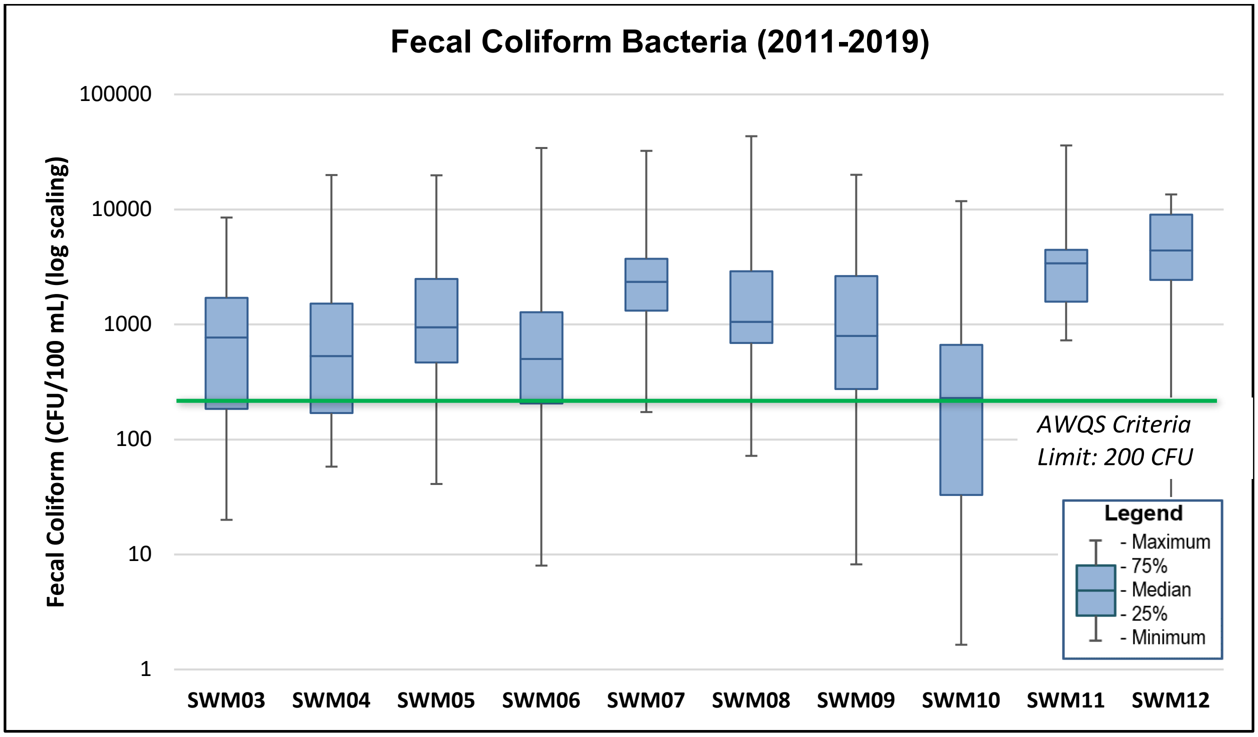


Figure 26. Station Box Plot of Flow Rate by Outfall, All Data 2011 through 2019

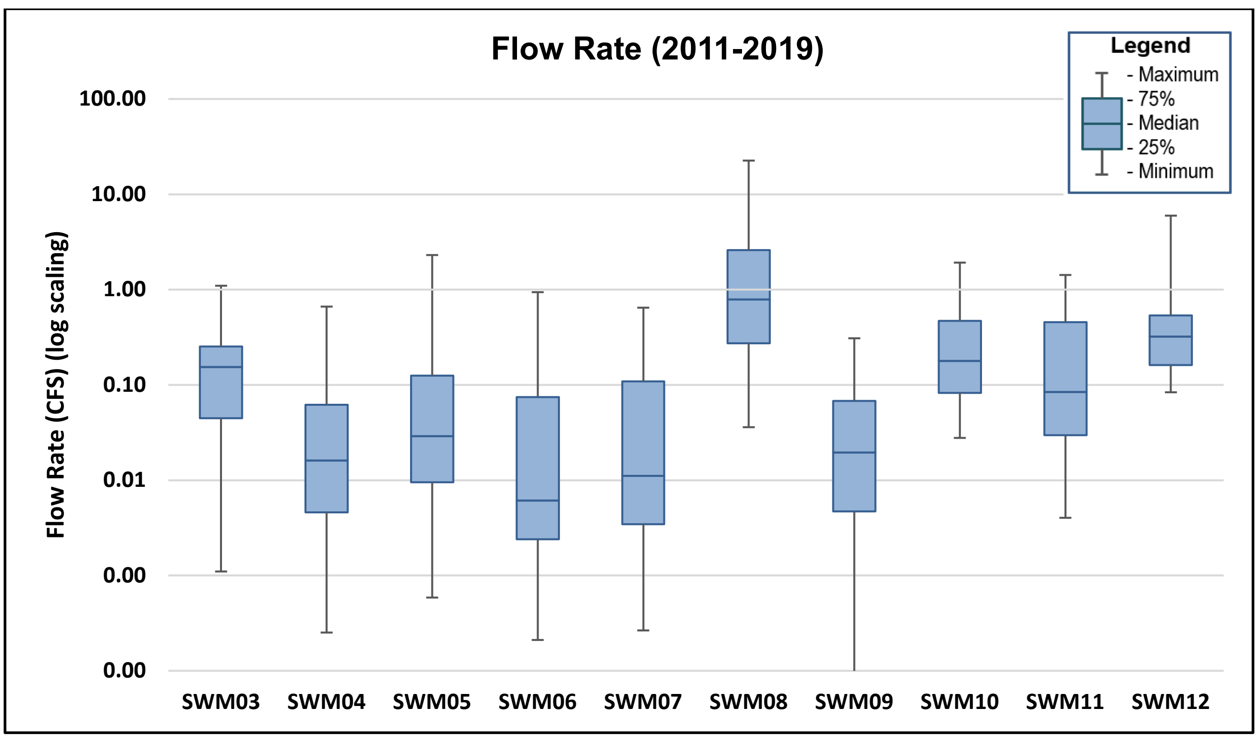


Figure 27. Station Box Plot of Hardness by Outfall, All Data 2016 through 2019

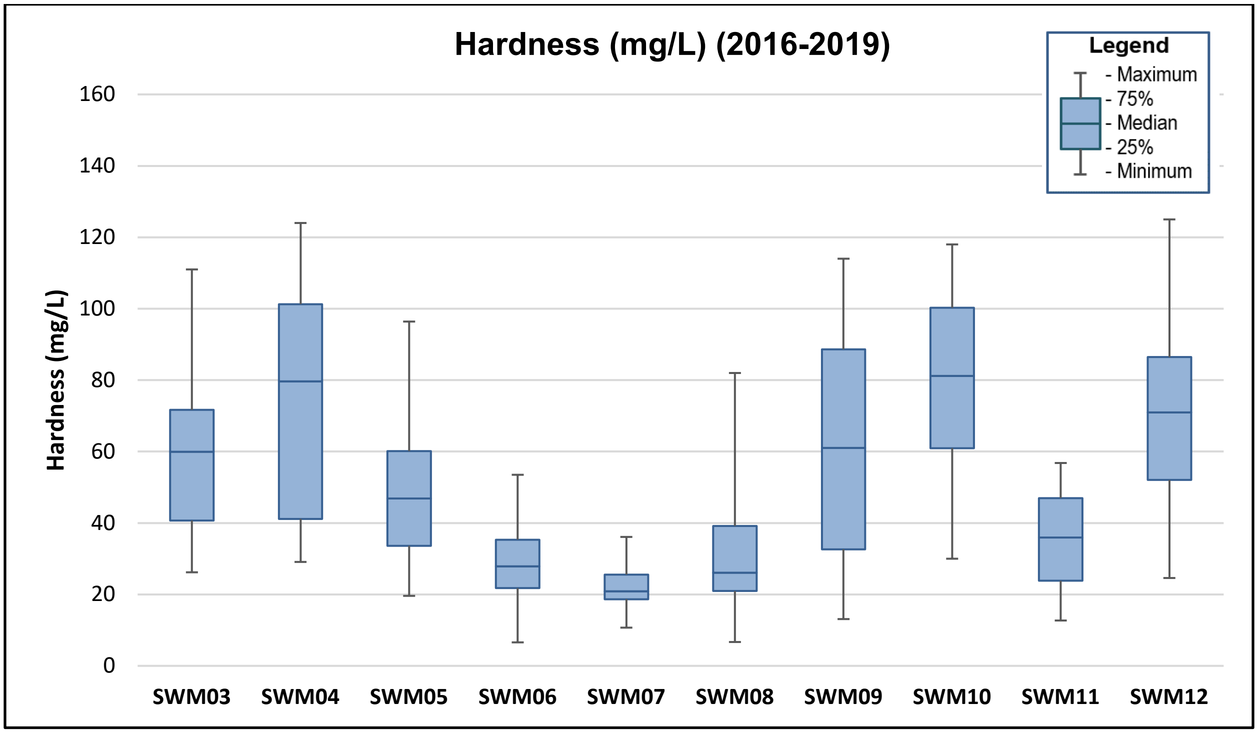
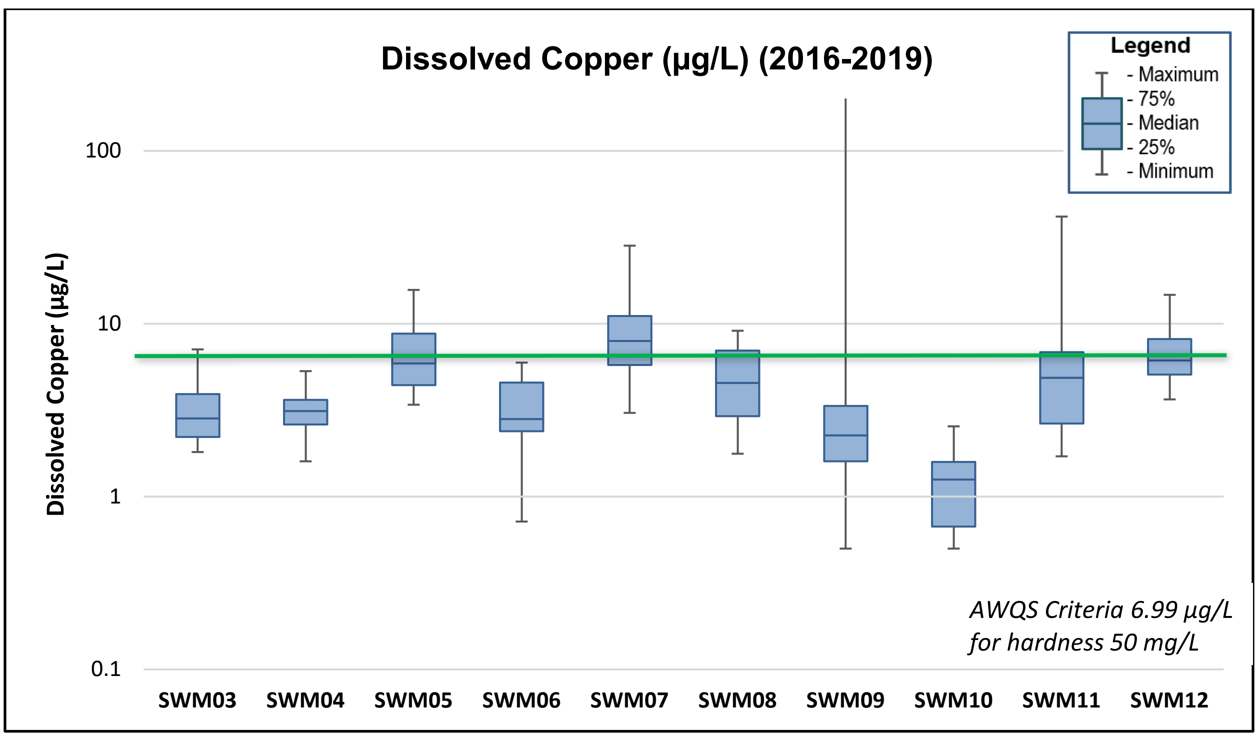


Figure 28. Station Box Plot of Dissolved Copper by Outfall, All Data 2016 through 2019



The box plot data record for DO is presented in Figure 19. Like temperature, DO concentrations are assumed to follow a normal distribution at each site. There is statistically significant variation between outfall sites (ANOVA p-value of $1.45*10^{-22}$), but all sites generally are above the AWQS limit of 7mg/L. Throughout the data record, SWM10 has the greatest median DO concentration of 11.1 mg/L and is statistically distinct from each of the other outfall sites. The elevated DO at SWM10 is potentially due to turbulent flow in the outfall pipe prior to discharge.

While SWM10 had the highest median DO concentrations, it is one of the locations with the lowest BOD_5 concentrations (Figure 24). This potential inverse correlation between DO and BOD_5 did not necessarily hold true for the other outfalls. SWM07, which had a median DO level of ~10 mg/L, slightly above the average across outfall sites, also had the highest median BOD_5 concentration seen throughout the data record. SWM12 was a close second and also demonstrated elevated BOD_5 concentrations. In fact, historic mean BOD_5 concentrations at SWM07 and SWM12 are statistically indistinguishable (P value 0.47). The drainage areas for both outfalls include a high percentage of streets, parking lots, and other impervious surfaces. The elevated BOD_5 records at these outfalls may be a result of vehicle cooling liquid inputs (glycols) from streets and driveways.

The pH at outfalls SWM06, SWM8, and SWM10 tended to test lower than at other outfalls with median pH values ranging from 7.055 to 7.115 (Figure 20). These three outfalls are statistically indistinguishable from one another with regards to mean pH (single factor ANOVA returning a P value of 0.54) and are statistically distinct from outfalls SWM3, SWM4, SWM5, and SWM7 per Tukey's honest Significant Difference (HSD) post-hoc testing. There were several isolated individual measurements in the data record below the AWQS lower limit of 6.5 pH units, including one measurement in 2019 at SWM11 with a pH of 6.47. These excursions in the data appear to be incidental and not part of a broader trend. Outfall SWM03 had the highest median pH concentration (pH 7.515) in the data record. None of samples collected in the data record exceed the upper AWQS pH criterion of 8.5 pH units.

The data record for TDS is presented in Figure 21. TDS levels are highest at SWM04 and SWM10 with median values of 181.7 and 188.3 mg/L respectively. These outfalls are statistically similar with regard to TDS levels (paired t-test p value of 0.08) and statistically distinct from outfalls SWM05, SWM06, SWM07, SWM08, SWM09 and SWM11 per Tukey's HSD post-hoc testing. It should be noted that median TDS levels for both SWM04 and SWM10 fall well below the AWQS criterion of 500mg/L. Only a single sample in the data record, collected in 2013 at SWM04, has ever exceed the AWQS threshold. The comparatively elevated TDS at SWM04 and SWM10 may be an indication of pollutants such as fertilizer, salts, or other organic ions flushing from the contributing drainage basins. Both outfalls drain primarily residential areas. Potential sources could be magnesium chloride that MOA uses on the city streets for de-icing purposes, residential/commercial use of deicing salts on walkways and driveways, and/or residential use of fertilizers.

The box-plots for TSS and turbidity are presented in Figure 22 and Figure 23, respectively. Both TSS and turbidity were highly variable between storms and locations, although there is a general positive correlation between TSS and turbidity visible in the box plots. The highest median TSS and turbidity concentrations were detected at SWM07 and at SWM12, with median TSS and turbidity concentrations over double those of any of the other outfalls in the data record. Further statistical analysis was not performed. Outfall SWM10 has consistently exhibited among the lowest TSS and turbidity levels.

The box-plot data record for fecal coliform is presented in Figure 25. Outfall sites SWM07, SWM11, and SWM12 have the highest median fecal coliform concentrations of the ten monitoring sites, with median concentrations between 2350 and 5100 CFU/100mL. Fecal coliform concentrations are assumed to follow a log-normal distribution, and these three sites are statistically indistinguishable from one-another with regard to mean fecal coliform concentrations (log-normal ANOVA p-value of 0.14). SWM07 and SWM12 represent commercial/industrial land use basins, while SWM11 represents a residential land use basin. The sources of the higher concentrations seen at SWM07, SWM11, and SWM12 are unknown, but it is likely that the factors contributing to elevated fecal coliform measurements differ at each site. The data record for SWM11 and SWM12 is only three years long, as opposed to nine years for the other outfalls, and further sampling will be required to monitor the trends at these outfalls. Other locations with elevated fecal coliform concentrations include SWM05 and SWM08. SWM10 consistently has the lowest fecal coliform concentrations, with a median concentration of 230 CFU/100mL.

The box-plot for the flow rate data record is presented in Figure 26. Flow rate was highly variable between locations and between events, reflecting variability in both precipitation and basin characteristics throughout the monitoring corridor. For some outfalls, particularly for those with small drainage basins, flow rates responded rapidly to changes in precipitation. Outfall SWM08 drains the largest basin and had consistently higher flow rates than the other locations.

Box plots for hardness and dissolved copper concentrations are presented in Figure 27 and Figure 28 respectively. Hardness and copper were first added to the SWM program in 2016, and as result these box plots represent a shorter four-year data record. There is a general inverse relationship visible between hardness and dissolved copper concentrations. SWM10 has the highest median hardness concentration and the lowest median dissolved copper concentrations among the 10 outfalls included in the SWM program. Conversely, SWM07 had the lowest median hardness and the highest dissolved copper concentrations. No statistical analyses was performed on the basis of the shorter data record, and further monitoring will be required to see if these trends continue.

3.7 Seasonal and Yearly Trends

The SWM program data record was examined for seasonal and yearly trends. The timing of outfall monitoring varies year-to-year depending on weather conditions and the timing of suitable storm events, and parameters can vary with season. Typically, sampling for the SWM program begins in July and continues through September. The 2019 SWM program was unique due to the extreme drought conditions that impacted the Anchorage area for most of the summer. The 2019 sampling program began on September 7th and concluded on October 1st. While the 2019 program started later than usual, the sampling program in prior years has concluded as late as October 16th. All four 2019 sampling events therefore occurred within the sampling window of previous years.

Figure 29 presents the seasonal patterns for key parameters for the data record from 2011 through 2019, plotted against the day of the year. As expected, temperature fluctuates with season and was highest across all locations in July and August. DO fluctuates inversely to temperature, with the lowest DO concentrations during the summer months when temperatures are highest and increasing DO concentrations in the fall as water temperatures cool. Fecal coliform concentrations are not as highly correlated with season as are temperature and DO. It appears that fecal coliform concentrations may decrease in the fall months, though more data is needed to support this conclusion. Seasonal pattern regression values are presented on each plot where the data have been fitted to a third-order polynomial.

There are significant year-to-year fluctuations for various parameters tested, but there do not appear to be any significant broader trends evident in the data. For example, fecal coliform concentrations vary each monitoring year, with spikes in the data occurring seemingly at random at many of the outfalls throughout the data record. For example, there are spikes in the data (greater than 10,000 CFU/100mL) at two of the outfalls in 2016, six outfalls in 2017, five outfalls in 2018, and zero outfalls in 2019. There is significant variability year to year in fecal coliform concentrations that can only partially be explained by seasonal patterns and does not appear to fit any longer-term trends. The lack of any spikes in fecal coliform in 2019 is likely a product of both the high variability in this parameter as well as the sampling period shifted later in the season.

One parameter that was notable elevated in 2019 and will need to be closely monitored in future years is TAH (BTEX). In the period of 2012-2018, only two samples reported measurable BTEX concentrations out of 111 samples collected. In 2019, seven of 16 samples collected detected measurable BTEX constituents across multiple outfalls and storm events. It is theorized that this notable change may be related to the extreme drought conditions experienced during the summer of 2019. Future monitoring will need to determine whether 2019 was indeed an anomaly as theorized, or whether the findings in 2019 are indicative of a larger trend.

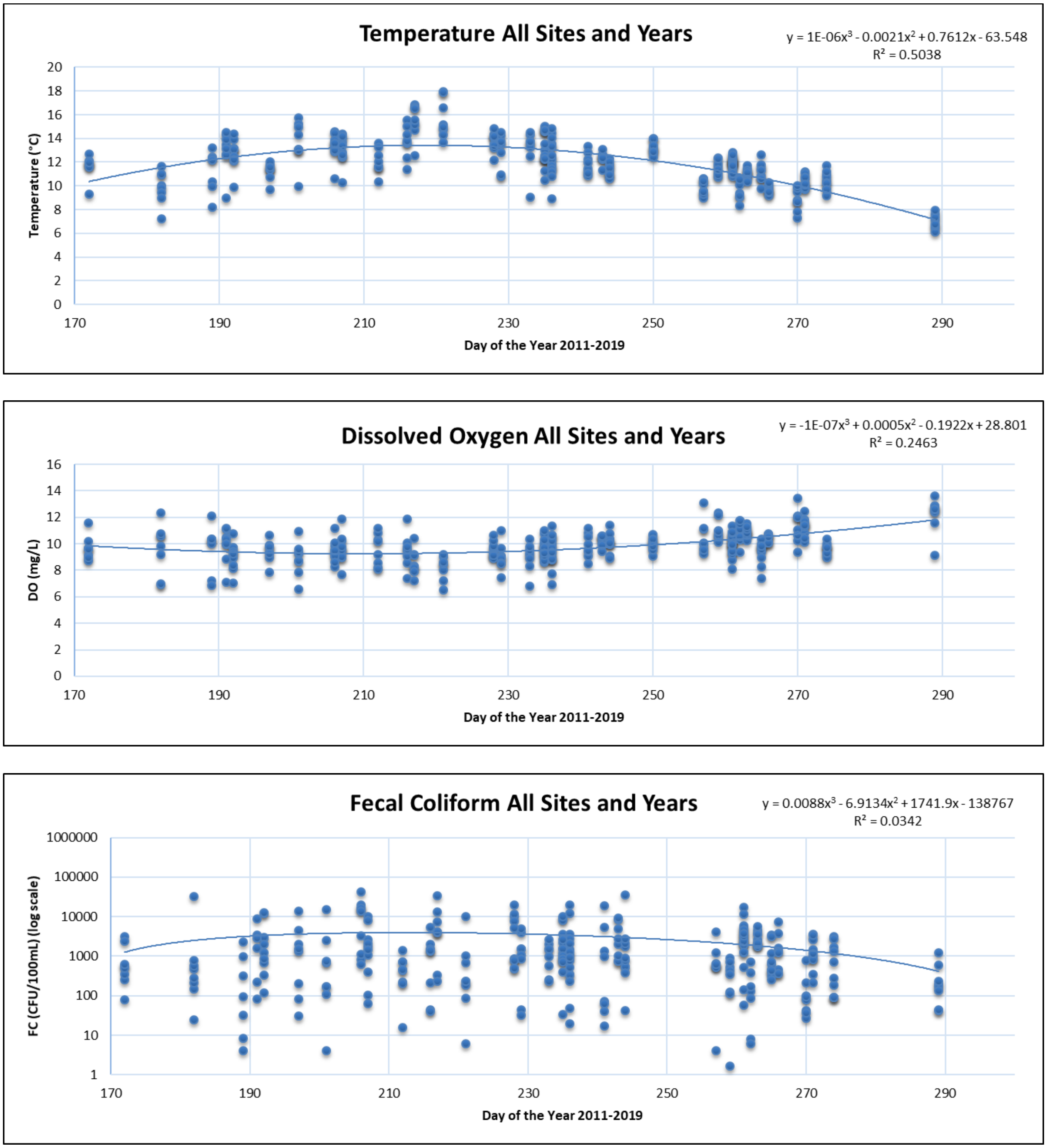


Figure 29. Seasonal Patterns for Temperature, DO, and Fecal Coliform, All Sites and All Years.

3.8 Annual Loading

Annual loadings for fecal coliform and hydrocarbons are presented in Figure 30 and Figure 31. These annual loadings are calculated using the Simple Method, which was developed under an EPA grant to provide Phase II communities with tools to protect their local watersheds (SMRC 2010). The Simple Method estimates stormwater runoff pollutant loads for urban areas based on the following parameters: subbasin drainage area and percent impervious cover, flow-weighted or event-mean stormwater runoff pollutant concentrations, and annual precipitation. With the Simple Method, calculations can be based on specific land use areas such as residential, commercial, industrial, and roadway to calculate annual pollutant loads for each type of land use. The method can also be used for more generalized pollutant comparisons by land uses such as new suburban areas, older urban areas, central business districts, and highways. Equations and calculation methodology utilized for the Simple Method are detailed in Attachment B-1 of the QAP (MOA 2016).

A major limitation for this method is using a single grab sample for each storm event rather than using flow-weighted data. Available documentation (SMRC 2010) for this method does not address its applicability to organic compounds such as petroleum hydrocarbons, even though comparisons are provided in this report. Loading data are considered estimates that can provide useful information for making general comparisons, but do not provide the precision required for detailed comparisons.

Annual loading estimates were determined for fecal coliform and hydrocarbons. Fecal coliform loading calculations (Figure 30) utilized the annual geometric mean for each location to account for the high variability in fecal coliform counts. For hydrocarbons, both TPAH and TAH as BTEX were examined. 2019 was the first year that BTEX was included in the hydrocarbon loading analysis. In previous years only TPAH was included in the analysis since most BTEX samples were non-detected. In 2019, nearly 50% of the samples collected returned measurable BTEX concentrations, warranting inclusion in the annual hydrocarbon loading analysis. Hydrocarbon loading calculations (Figure 31) utilized the annual arithmetic mean for each location.

The fecal coliform loading estimates generated through application of the Simple Method indicate that SWM07 continues to stand out as the subbasin with the highest annual fecal coliform loading. SWM07 represents a commercial/industrial land use basin and had the highest fecal coliform loading of the basins evaluated in 2019, with an estimated annual loading of 23.74 billion colonies/year. SWM07 has also has the distinction of having the highest fecal coliform loading of the ten outfalls in seven of the past nine years. Other outfalls with elevated annual loading estimates for fecal coliform (greater than 10 billion colonies/year) include SWM03 (residential), SWM08 (mixed), and SWM12 (commercial/industrial). These locations represent all three of the different land use categories examined in the study (refer to Table 1). The lowest fecal loading estimates were at SWM04 (residential), SWM05 (commercial/industrial), and SWM10 (mixed).

Figure 30. Fecal Coliform Annual Loading by Monitoring Site

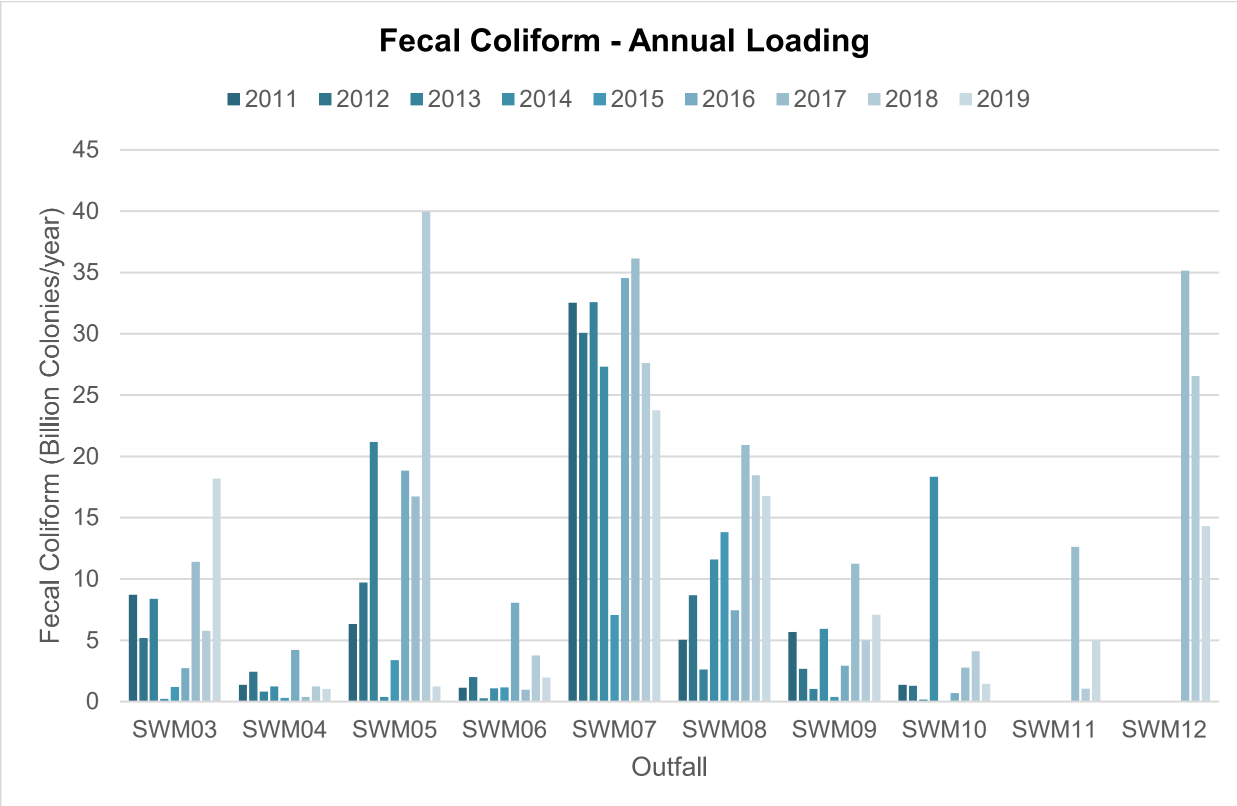
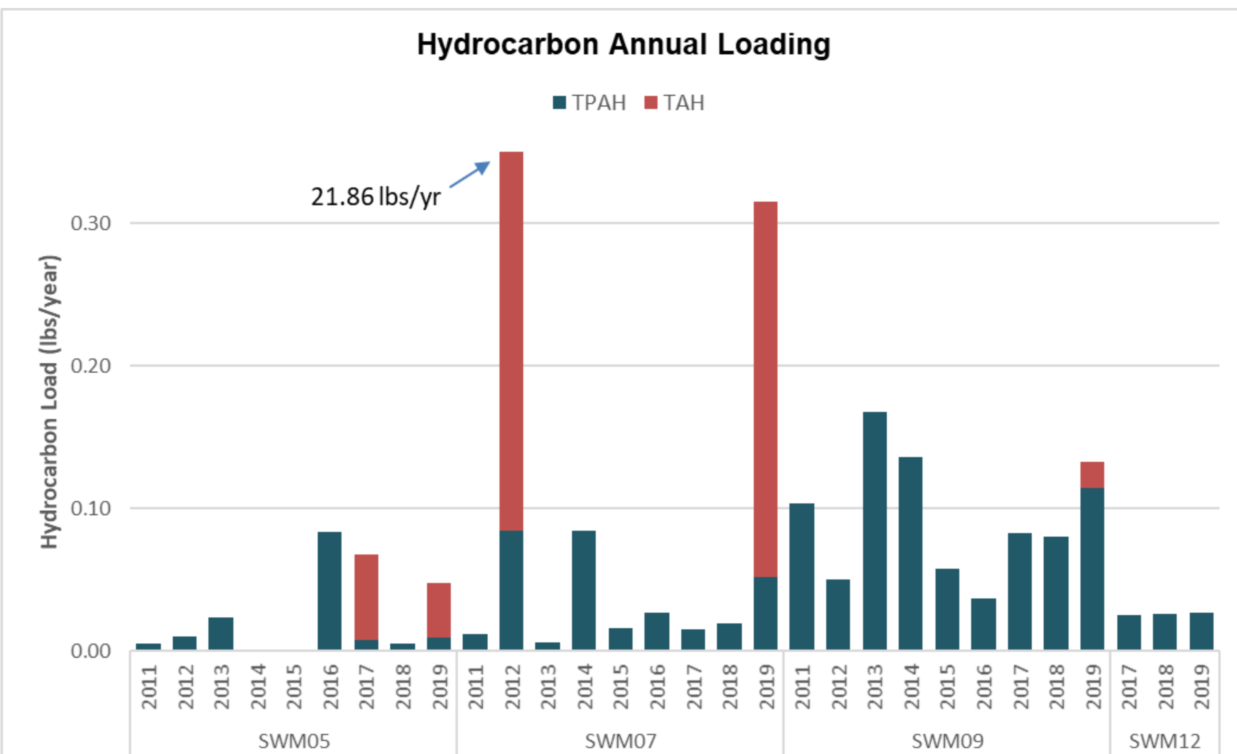


Figure 31. Hydrocarbon Annual Loading by Monitoring Site



Annual hydrocarbon loading, as determined by TAH and TPAH measurements, was elevated at three of the four outfalls studied for hydrocarbons. As stated previously, a notable change was that TAH constituents were detected in 7 of the 16 samples collected for hydrocarbons as part of the 2019 monitoring program. In previous years, TAH had been excluded from the annual loading analysis because its constituents are so rarely detected. TAH constituents have been detected in only two prior samples in the SWM program data record, once in 2012 at SWM07 (with an exceptionally high concentration) and once in 2017 at SWM05. It was noteworthy that there were seven positive samples in 2019, and this warranted the inclusion of TAH in the annual loading analysis.

The increase in both the frequency of detection as well as the overall TAH loading may potentially be related to the extreme drought conditions experienced in Anchorage in the summer of 2019. Between June 1 and September 6, almost no rain fell in the City of Anchorage. Hydrocarbons from fuels, oils, and solvents dripping from passenger vehicles and other sources likely accumulated over the course of the drought. Furthermore, any illicit discharges within the basins, either to the land or directly into the storm sewer, likely stood stagnant or absorbed into the substrate and were never flushed. The return of rain in September may have mobilized and flushed many months of accumulated hydrocarbons through the storm sewer. This period of flushing coincided with the monitoring period for the 2019 SWM program. Future years of monitoring data will be required to test this hypothesis. It will be important to confirm that the increase in BTEX detection in 2019 was a spike in the data and not representative of a broader trend from some unknown cause.

4.0 Summary and Conclusions

This report detailed the findings of the 2019 Municipality of Anchorage stormwater monitoring program, satisfying the requirements of the current municipal MS4 permit (Permit No. AKS-052558). The Anchorage MS4 permit establishes control measures and requires the development of programs designed to prevent contaminants from entering the storm sewer system. The permit further identifies monitoring objectives, including stormwater outfall monitoring (Section 4.1.7 of the MS4 permit). The stormwater outfall monitoring program monitors 10 priority outfall locations that represent a variety of major land use areas within the Anchorage Bowl. The program tests these outfall locations at least four times each year during storm events for specific physical and chemical parameters. The stormwater sampling conducted during 2019 represents the ninth year of outfall monitoring under the current program.

The 2019 stormwater monitoring program successfully sampled four storm events at the 10 priority outfall locations despite extreme drought conditions that persisted for much of the summer. In most years, sampling under the program begins in July. In 2019, the sampling period was shifted later into the year due the lack of suitable precipitation events from early June through early September. The 2019 sampling events occurred on September 7, September 18, September 20, and October 1.

Overall, sample results fell generally within AWQS criteria and in line with the results of previous monitoring years. None of the samples tested present any immediate concerns for any of the tested parameters. The data record was investigated to look for systemic differences between outfall sites, and for seasonal and multi-year trends.

Dissolved copper concentrations were elevated at several outfall locations during the first sampling event of the 2019 monitoring program. It is possible that the elevated copper concentrations seen during the first storm reflect the first major flush after the extended period of drought preceding the first sampling event. Dissolved copper concentrations returned to previously seen levels during subsequent monitoring events.

Fecal coliform levels measured in the 2019 SWM program were generally lower than in recent years. There were no significant spikes in the fecal coliform data, and for the first time since 2015, none of the samples tested above 10,000 CFU/100mL. Levels may have been biased low due to sampling later in the year, though fecal coliform spikes have been observed during September sampling events in prior years.

There was a general increase in hydrocarbon concentrations measured during the 2019 SWM program, though all samples met AWQS criteria for both TAH and TAqH. Seven samples tested with detectible quantities of TAH BTEX constituents, marking a notable shift from prior years. Over the eight years of prior monitoring, only two previous samples contained detectable quantities of BTEX. It is possible that this increase across multiple outfalls may be related to the extended period of extreme drought experienced in Anchorage during the summer of 2019. Future sampling under the outfall monitoring program will establish if the increased TAH detection in 2019 reflects a short-term spike in the data or a longer-term change in conditions.

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