Lower Duwamish Waterway Source Control: Brandon Combined Sewer Basin Study

Data Report

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Final

King County

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Lower Duwamish Waterway Source Control

Brandon Combined Sewer Basin Study

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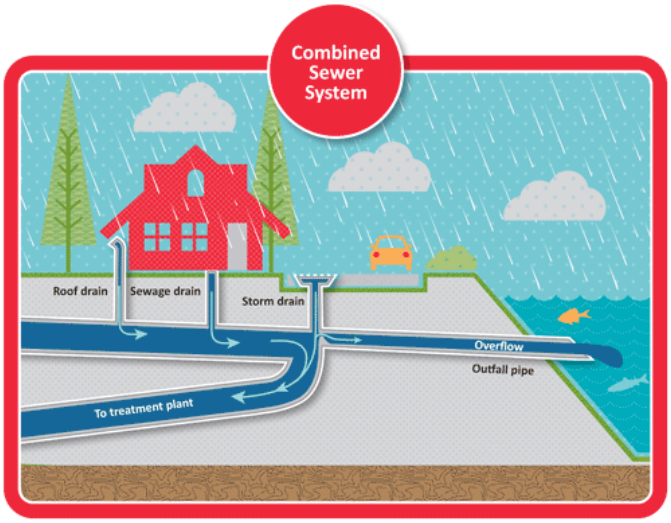
Pilot Study on Pathways of Pollution to Combined Sewer Sewer Basins

King County is committed to doing its part to clean up the Duwamish River and keep it clean. Understanding how pollution gets into the river is key to keeping it out of the river.

Background

King County has been conducting a series of studies to improve our understanding of how contamination is entering the Lower Duwamish Waterway.

Like many cities around the country, the older parts of King County's wastewater system rely on a single set of pipes to carry untreated sewage (domestic and industrial wastewater) and stormwater to a treatment plant. Wastewater from many areas along the Lower Duwamish Waterway normally flows to the West Point treatment plant. During very large storms, the system includes safety valves called "combined sewer overflows" that can route excess sewage and stormwater flow directly into the Waterway to prevent sewer backups into homes and streets. King County is required to control all of its CSOs by 2030. The study described here was a pilot effort to identify the primary pathway of chemical pollution into combined systems.



Pollution can enter combined systems through three **pathways** (sewage, stormwater, and groundwater infiltration). This pilot study attempts to determine the amount of chemicals contributed by each pathway, or the "chemical load", to the Brandon Combined Sewer Basin. A greater understanding of the chemical loads to a combined sewer basin can help King County and other government agencies focus their efforts to best decrease the amount of pollution entering the system and local waters before CSO control goals are met in 2030.

Pathway is defined as the route or mechanism by which contaminated media are transported.

Study Objective

How much pollution is entering the Brandon Combined Sewer Basin pipes during a rainstorm, and does it primarily come from sewage, stormwater, or groundwater?

To answer this question, researchers collected wastewater samples from the combined system during different weather conditions to help estimate the chemical load entering the pipes for each pathway:

- Sewage (domestic and industrial wastewater present in pipes year-round)
- Stormwater (runoff entering into pipes during storms only)
- Groundwater (groundwater seeping into pipes during the rainy season)

Chemicals studied

The following chemicals were targeted in this study because they are chemicals of concern for the Lower Duwamish Waterway:

- ***Polychlorinated biphenyls (PCBs)***
- ***Metals and mercury***
- ***Polycyclic aromatic hydrocarbons (PAHs)***
- ***Phthalates***
- ***Dioxin/furans***

Pathway Analysis

Researchers analyzed the chemical concentrations from the samples in combination with flow data (the amount of wastewater flowing through the pipe at the time the sample was taken) to estimate the chemical load for each pathway. They then compared these chemical loads to determine whether groundwater, sewage, or stormwater was the pathway contributing the greatest amount of chemicals flowing to the treatment plant during storms.

- **Groundwater** seeping into pipes did not seem to add to the chemical load, but more research is needed to fully understand the chemical contribution from groundwater.
- **Sewage alone** in the pipes had a smaller chemical load than when mixed with stormwater.
- **Stormwater** was the major contributor to the chemical load for most chemicals found in the system, including some metals (like copper and zinc), PCBs, dioxin/furans, and PAHs.
- For some other metals and phthalates, the chemical load did not vary greatly between sewage and stormwater.

Conclusions

A clear finding of this study is that stormwater contributes the largest chemical input into the Brandon Combined Sewer Basin during periods of rainfall compared to sewage alone for most of the chemicals studied. While efforts are underway to control CSOs in King County, large storms can currently cause untreated CSO discharges to the Lower Duwamish Waterway. The study results suggest efforts to reduce or control chemical pollution in stormwater before it enters a CSO basin would be the most effective way to reduce the amount of chemical pollution released into the Lower Duwamish Waterway during an untreated CSO event.

How will this study be used?

This study will be used to guide pollution control needs within combined sewer basins prior to the completion of King County's CSO control plan. For example, these results would shape decisions about whether stormwater or sewer inputs should be targeted as the main source of a particular chemical in the basin. Results from this pilot study will be compared to results from a similar study in another combined sewer basin to assess if primary pathways of chemicals to a combined sewer system during storm events are consistent across different basins.

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Lower Duwamish Waterway Source Control: Brandon Combined Sewer Basin Study

Data Report

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Acronyms

µg/L	micrograms per liter
AWWF	average wet weather flow
AXYS	AXYS Analytical Services
CSO	combined sewer overflow
CVAA	Cold Vapor Atomic Absorbance
DOC	dissolved organic carbon
EBI	Elliott Bay Interceptor
Ecology	Washington Department of Ecology
EPA	U.S. Environmental Protection Agency
FOD	frequency of detection

FSU	Field Sciences Unit
GC/MS	Gas Chromatography/Mass Spectrometry
hr	hour
HPAHs	high molecular weight polycyclic aromatic hydrocarbons
HRGC/HRMS	high-resolution gas chromatography/high-resolution mass spectroscopy
ICP-MS	inductively coupled plasma-mass spectrometry
ID	Identification
KCEL	King County Environmental Laboratory
L	liter
LDC	Laboratory Data Consultants
LDW	Lower Duwamish Waterway
LIMS	Information Management System
LMCLs	lowest method calibration limits
LPAHs	low molecular weight polycyclic aromatic hydrocarbons
MDL	method detection limit
mg/L	milligrams per liter
mg	milligram
mL	milliliter
ng	nanogram
NPDES	National Pollutant Discharge Elimination System
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
pg/L	picograms per liter
QC	quality control
RDL	reporting detection limit
RSD	relative standard deviation
SAP	sampling and analysis plan
SIM-LVI	selected ion monitoring and large volume injection
SDL	specific detection limit
SMS	Sediment Management Standards
SOP	standard operating procedure
SVOCs	Semi-volatile organic compounds

TEQ	Toxicity Equivalents
TOC	total organic carbon
TSS	total suspended solids

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EXECUTIVE SUMMARY

This report summarizes a pilot study to examine pathways[1] of contaminant sources to combined sewer basins in the Lower Duwamish Waterway (LDW). A combined sewer basin is a drainage basin typically in an older area of Seattle where the sewer system receives both sewage and stormwater. Under most weather conditions, the combined sewer systems that are within the LDW drainage basin send all the collected sewage (domestic and industrial wastewater) and stormwater to the West Point Treatment Plant where it is treated prior to being discharged to Puget Sound. Under large storm conditions, some flows that cannot be accommodated in the collection system are diverted to combined sewer overflow (CSO) outfalls[2], which discharge to the LDW.

This pilot study was conducted in the Brandon combined sewer basin, chosen mainly because it is a relatively small combined sewer basin comprised primarily of commercial and industrial facilities. This study aims to better understand the present-day pathways for loadings of select chemicals into combined sewer basins. Specifically, the study aims to identify primary pathways of LDW contaminants of concern within combined sewers; that is, whether contaminants entering the combined sewer system are primarily from stormwater, sewage, or groundwater infiltration entering the system. The results of this study are intended to be useful in guiding any basinwide source tracing efforts in combined basins prior to CSO control[3] by estimating the primary pathway of contaminant sources during stormflow conditions (i.e., storm events, when sewage and stormwater are both present in the system), which could lead to CSO discharge during large storm events.

It is important to emphasize that this study does not estimate loadings to the LDW from CSO outfalls during CSO discharge events. Most of the flows entering the system (and the associated contaminants) go to the West Point Plant to be treated, and by 2022, CSO discharges from the Brandon CSO outfall will be controlled through the construction of a wet weather treatment plant. However, if prior to CSO control, additional source control activities are needed, understanding relative pathway contributions to a combined sewer system will help focus source control efforts on the most likely pathway, improving the chances of finding and controlling the source.

[1] Pathway is defined as the route or mechanism by which contaminated media are transported to a particular location. Source is defined as the entity or activity that first releases a contaminant into the environment (e.g., maintenance or repair activity or spills or leaks at a residence or business that results in a release of a contaminant that could enter a stormwater or sewer system from their property).

[2] The regional wastewater system includes CSO "relief points" in the combined sewer area of Seattle to prevent backups in homes and streets from stormwater volumes greater than the system can convey.

[3] CSO discharges are "controlled" by Washington State standards when one untreated discharge event or less, on average, occurs per year.

Objective and Design Questions

The pilot study objective was to assess the relative magnitude of pollutant loads that reach the combined sewer system via three distinct pathways to better inform LDW source control activities prior to CSO control. The pathways investigated in this study are:

1. Sewage, which includes industrial and domestic wastewater (present year-round)
2. Groundwater infiltration (may be present during wet season), and
3. Stormwater, runoff from properties that reaches the system (present during rain events).

To address the study objective and guide study design, a total of five questions were evaluated. The first three provide estimates of the mass of chemical flowing within the combined sewer system of the Brandon Basin during three different conditions:

1. What are chemical loadings in the Brandon combined sewer basin during dry season baseflow conditions (which represents the sewage component[4]),
2. What are chemical loadings in the Brandon combined sewer basin during wet season baseflow conditions (which represents both the sewage and infiltration components), and
3. What are the chemical loadings in the Brandon combined sewer basin during storm events (i.e., "stormflow", when sewage and stormwater components are both present in the collection system[5]),

These results were then used to mathematically estimate the relative contributions to the combined sewer system from infiltration and stormwater, as noted below in the following two questions:

4. What are the chemical loadings to the combined sewer system within the Brandon Basin from infiltration to the system pipes?

   This was estimated as the average wet season baseflow loadings (sewage and infiltration components) minus the average dry season baseflow loadings (sewage component).

5. What are the chemical loadings to the combined sewer system within the Brandon Basin from stormwater?

   This was estimated as the average stormflow loadings (sewage and stormwater components) minus the average baseflow loadings (sewage component).

[4] Sewage also includes permitted industrial discharges.

[5] Significant infiltration is not expected in the combined sewer system during stormflow conditions due to the hydrostatic pressure gradient.

Methods

To address the five questions above, wastewater samples were collected from three locations within the Brandon combined sewer basin under various flow conditions between 2011 and 2012. (Because the study focuses on pathways into the combined sewer basin rather than what reaches the LDW, CSO discharges were not sampled). The first location was the Brandon Regulator station, which includes flow from the entire Brandon Basin (244 acres), and the next two locations, Utah and East Marginal, include flow from two different subbasins (31 and 85 acres, respectively) within the Brandon Basin (see Figure ES-1). Flow monitoring was also conducted at each sample location.

At each site, between five and six flow-weighted samples were collected during both dry baseflow (non-storm events July-October), and wet baseflow (non-storm events November-June) conditions in 2011 and 2012. Between eight and 14 storm event samples were also collected at each site between November 2011 and June 2012. Samples were analyzed for conventional parameters, total and dissolved metals and mercury, polycyclic aromatic hydrocarbons (PAHs), phthalates, polychlorinated biphenyls (PCBs) and dioxin/furans. Loading rates (mass per time) were estimated for each sample and parameter by multiplying the parameter concentration by the average flow measured during the sampling period.

The loading rate estimates represent chemical loads that, under most conditions, would all be transferred to the West Point Treatment Plant, via the Elliott Bay Interceptor, for treatment. Generally, only very large storms result in some discharges to the LDW through the Brandon CSO Outfall. The estimates, therefore, do not represent discharges to the waterway nor do they represent historical discharges to the LDW.

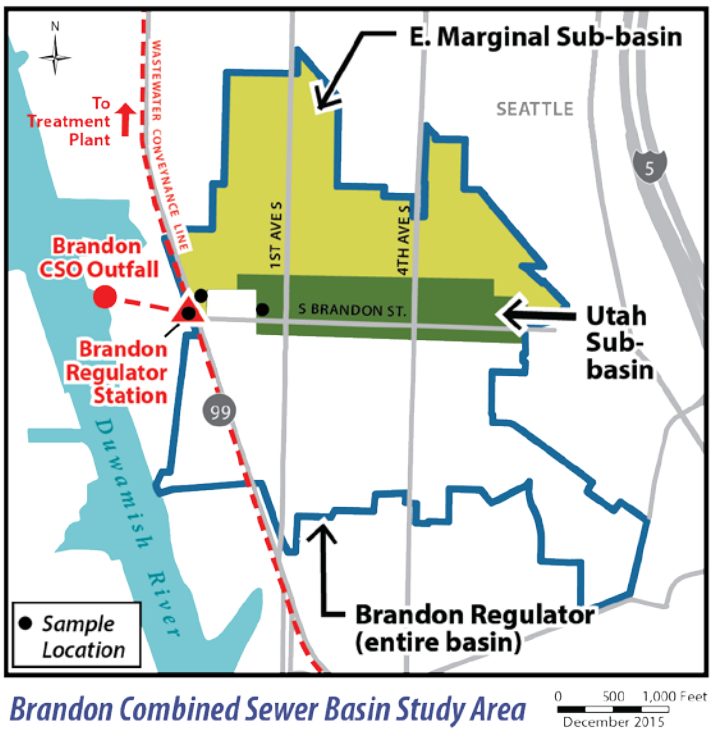

Figure ES-1. Brandon Combined Sewer Basin Study Area

Findings

Estimates of chemical loadings during different weather conditions (Study Questions 1–3): The study results indicate that dry season and wet season baseflow loading rates into the combined system may differ for some chemicals, but often the ranges overlapped. For almost all parameters, the highest calculated loading rate estimates were measured during storm events (i.e., when both sewage and stormwater are present within the combined system).

Chemical loadings from infiltration (Study Question 4): The statistical analysis to evaluate the potential influence of infiltration (groundwater or other non-sewage flows seeping into pipes) indicated differences in average flow at Utah and East Marginal locations, but not at the Brandon Regulator location. However, the difference in average flow at these two locations did not translate to consistent differences in chemical loadings between dry and wet season baseflow samples. Thus, while there may be infiltration of groundwater, or other non-sewage flows, into the combined sewer system during the wet season, any potential loads from infiltration are difficult to distinguish from the variability in loading rates observed from sewage inputs alone.

Chemical loadings from stormwater (Study Question 5): For all parameters evaluated, median and average estimated loading rates were greater during stormflow sampling (i.e., when both sewage and stormwater are present within the combined system) when compared to baseflow. This suggests stormwater contributes a significant load of each parameter during storm events.

Relative magnitude of pathway loading rates for each contaminant: Based on the average loading rates evaluated for study questions 1-3, the relative magnitudes of pathway loading rates into the combined system (sewage versus stormwater) was determined. The average "baseflow" loading rate is comprised of the sewage fraction, whereas the stormwater loading rate was generated by subtracting baseflow (sewage fraction) from stormflow (combined sewage and stormwater). Because there were few differences between dry and wet baseflow loading rates (and variability was high), infiltration loading rates could not be estimated. For this reason, infiltration was not included in the pathway assessment for the Brandon Basin. The sewage and stormwater loading rates were then compared to assess the primary pathway during storm events.

Stormwater (rather than sewage) was estimated to be the primary pathway for almost all contaminants during storm events. The most notable exceptions were total and dissolved arsenic and chromium at Brandon Regulator where sewage was estimated to be the primary pathway. However, this finding was heavily influenced by a single wet baseflow sample with elevated arsenic and chromium concentrations and flow[6]. Table ES-1

[6] Total and dissolved arsenic concentrations in this sample were 30% and 50% higher than any other baseflow concentrations and total and dissolved chromium concentrations that were 25% and 85% higher than any other baseflow concentrations. When the primary pathways for these metals were estimated using medians instead of averages, stormwater was found to contribute more of the chemical load than sewage. Based on the low sample size (n=6), it is difficult to estimate how frequently these elevated concentrations might occur in the basin.

summarizes the analysis of the primary pathway of contaminant sources at the three sampling locations.

Table ES-1. Primary pathways of contaminant sources within the Brandon Basin during storms

Group	Analyte	Utah	East Marginal	Brandon Regulator
Conventionals	Total Organic Carbon			
	Dissolved Organic Carbon			
	Total Suspended Solids			
Total Metals	Arsenic			A
	Cadmium			
	Chromium			A
	Copper			
	Lead			
	Nickel			
	Silver			
	Vanadium			
	Zinc			
	Mercury			
Dissolved Metals	Arsenic			A
	Cadmium	N/C	N/C	
	Chromium			A
	Copper			
	Lead			
	Nickel			
	Silver	N/C	N/C	N/C
	Vanadium			
	Zinc			
PAHs	Phenanthrene		N/C	
	Fluoranthene		N/C	
	Total HPAHs			
Phthalates	Benzyl Butyl Phthalate			
	Bis(2-ethylhexyl)phthalate			
	Diethyl Phthalate			
PCBs and Dioxin/Furans	Total PCBs			
	Total Dioxin/Furans			
	Total Dioxin TEQs			

= primarily sewage (>60%);

= primarily stormwater (>60%);

= even mix of sewage and stormwater (ranged from 40-60% for both sources)

= hash marking indicates moderate to high uncertainty in primary source estimate (as defined in Section 7.4.3)

A = relative magnitudes of pathways for arsenic and chromium at Brandon Regulator were highly influenced by one baseflow sample with elevated loading rates

N/C = not calculated – relative magnitude of pathways was only estimated for parameters with greater than 75% frequency of detection at a given site.

Uncertainty Assessment

The loading rate estimates indicate whether sewage or stormwater is the primary pathway of contaminants to the combined sewer system for a given parameter during storm events. However, to better understand the confidence in the results, an uncertainty assessment for the loading rates and primary pathway estimates was conducted. The results of this uncertainty assessment should be considered when looking for the main sources of a particular chemical in the basin.

Overall, there was greater uncertainty in average loading rates for the Brandon Regulator location compared to the results for Utah and East Marginal sampling locations. In general, there was greater certainty in source contribution estimates from the sewage fraction because baseflow was directly sampled. Because the stormwater loading rates were generated by subtracting baseflow (sewage only) from stormflow (combined sewage and stormwater), stormwater loading rate estimates were influenced by the variability of both data sets.

Among the parameters evaluated the greatest uncertainty in the primary pathway estimates were for: dissolved organic carbon, total arsenic and dissolved arsenic, cadmium, chromium, and vanadium at the Brandon Regulator location; dissolved organic carbon and diethyl phthalate at the East Marginal location; and benzyl butyl phthalate at the Utah location. There was moderate uncertainty associated with the estimates for total organic carbon, total suspended solids, a few metals and diethyl phthalate at either Brandon Regulator or East Marginal. For other chemicals, the uncertainty assessment provided some assurance that the primary pathway estimate was reasonable based on the range of loading rates estimated for this study.

Conclusions

A clear finding of the study is that, for most of the contaminants, stormwater contributes more of the chemical input into the Brandon combined sewer basin than sewage during periods of rainfall.

This would appear to suggest that efforts to reduce pollution in stormwater runoff to a CSO basin would reduce the amount of pollution that could be released to the waterway during an untreated CSO event. However, it should be noted that the stormflow loading rates presented in this study are only applicable to estimate the contaminant loading rates to the West Point Treatment Plant from the Brandon Basin during mild to moderate storm events. They are not representative of typical CSO discharge conditions that are generally associated with larger storm events. In addition, this study did not sample CSO discharges from the basin, only flows within the combined sewer collection system. The study estimates are therefore not representative of CSO loading rates to the LDW.

In summary, this project is a pilot effort to better understand the chemical inputs to a combined sewer system associated with sewage (domestic and industrial wastewater), stormwater, and to the extent possible, groundwater infiltration. However, land use patterns in each combined basin vary, and it is possible results could be different in other combined basins. Therefore, a similar study is being conducted in the Michigan combined sewer basin, a larger basin with more diverse land use. Results from the Brandon basin will be compared to results from the Michigan basin to assess if primary pathways of

contaminants to a combined sewer system during storm events under present-day conditions are consistent.

This and other studies in the Green/Duwamish Watershed provide valuable information to support source control efforts prior to the completion of CSO control measures and that will support the LDW sediment cleanup effort.

In addition to King County's commitment to controlling CSOs, this and other studies in the Green/Duwamish Watershed undertaken by King County provide valuable information to on-going and future source control efforts in support of the LDW sediment cleanup effort.

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1.0. INTRODUCTION

Sources of chemical contaminants to the Lower Duwamish Waterway (LDW) Superfund site include both historical and current sources. Current sources can be transported through various pathways to the LDW including inputs from the Green River, direct discharge of stormwater, combined sewer overflows (CSOs), atmospheric deposition, spills and leaks of contaminated material, groundwater, and bank erosion or leaching of contaminants from materials. King County is conducting several studies to characterize contaminants in some of these pathways identified for the LDW (AECOM 2012; EPA 2014). These include studies of atmospheric deposition in the Green/Duwamish Watershed and characterizing LDW contaminants of concern in the Green River Watershed and combined sewer basins.

This report discusses a pilot study conducted in the Brandon Combined Sewer Basin (Brandon Basin). The study was designed to better understand the present-day loadings of select chemicals within a combined sewer system so that primary pathways of LDW contaminants of concern could be identified. The results of this study are intended to be useful in guiding any combined sewer basinwide source tracing efforts prior to CSO control by estimating whether sewage, stormwater, or groundwater infiltration is the primary pathway for select contaminants to the combined sewer system during stormflow conditions (i.e., storm events, when sewage and stormwater are both present in the system).

It is important to emphasize that this study does not estimate loadings to the LDW from CSO outfalls during CSO discharge events. Most of the flows entering the system (and the associated contaminants) go to the West Point Plant to be treated, and by 2022, CSO discharges from the Brandon CSO outfall will be controlled through the construction of a wet weather treatment plant. However, if prior to CSO control, additional source control activities are needed, the results of this study will help focus source control efforts on the most likely pathway, improving the chances of finding and controlling the source.

This report is organized as follows: study background and study area (Section 1.0); field sampling methods (Section 2.0); laboratory methods (Section 3.0); data and loading analysis methods (Section 4.0); results (Section 5.0); loading analysis results (Section 6.0); discussion (Section 7.0); and conclusions and recommendations (Section 8.0). Supporting appendices include chain of custody forms, laboratory data results, and chemistry data validation reports.

1.1 Study Background

King County is a member of the Source Control Work Group for the LDW Superfund site. Other members include: the Washington Department of Ecology (Ecology) as lead agency, U.S. Environmental Protection Agency (EPA), the City of Seattle, and the Port of Seattle. The Source Control Work Group collaborates to understand potential sources of chemicals to the LDW Superfund site and works to control and reduce present-day sources that can contaminate sediments and resident fish and shellfish in the waterway. King County wants

to better understand the potential present-day sources and pathways of contaminants of concern identified in the LDW Superfund site.

The LDW Superfund site is about 5 miles long, encompassing 441 acres, and consists of the downstream portion of the Duwamish River, excluding the East and West Waterways. Over 200 outfalls, including public and private storm drains and CSOs, drain into the LDW (Windward 2010). Of these, King County's Wastewater Treatment Division has eight CSOs and two emergency overflows discharging into the LDW. Of these eight CSOs, currently 4 are controlled and the remaining four will be controlled by 2025 (King County 2012b).

The LDW Remedial Investigation (Windward 2010) identified four human health risk driver contaminants: polychlorinated biphenyls (PCBs), arsenic, carcinogenic polycyclic aromatic hydrocarbons, and dioxins/furans. Furthermore, 41 of the 47 chemicals (including total PCBs and arsenic), for which Washington State Sediment Management Standards (SMS) criteria are available (WAC 173-204-320), are contaminants of concern for benthic invertebrates. PCBs were also identified as a contaminant of concern for river otters, one of the wildlife receptors evaluated in the Ecological Risk Assessment.

Based on information presented in the LDW feasibility study (AECOM 2012), the Green River contributes by far the majority of solids/sediments to the LDW. Therefore, King County has been characterizing contaminant levels within the Green River watershed in both sediment and water (King County 2013a; 2014a; 2014b; 2015a). King County has also conducted atmospheric deposition studies in the Green/Duwamish River watershed (King County 2013b and 2015b) to further understand the inputs from this pathway.

Stormwater within the area directly draining to the LDW contributes the majority of the directly discharged chemical pollutants to the LDW (AECOM 2012, King County 2014). However, in a portion of the LDW drainage basin, stormwater is captured in combined sewer systems and sent to the West Point treatment plant where it is treated along with sewage (domestic and industrial wastewater) prior to being discharged to Puget Sound. Under most conditions, these combined sewer systems reduce the overall stormwater inputs to the LDW, but under sufficient storm conditions, flows that cannot be accommodated in the collection system (i.e., pipes) are diverted to CSO outfalls, which discharge to the LDW. In comparison to the Green River and separated stormwater discharges, CSOs contribute only a fraction of the chemical pollutants entering the LDW (King County 2014).

In support of the LDW Feasibility Study and source control evaluations, King County has previously completed chemical analysis of whole water samples from multiple County CSOs within the Duwamish River Basin (King County 2011a) and has been characterizing solids within the combined sewer structures and lines that discharge to the LDW (King County 2011b). The combined sewer basin study presented here is intended to complement King County's other efforts conducted in the combined sewer basins, as well as contribute to source control information for present-day discharges developed from King County's various Green/Duwamish River Watershed studies.

The Brandon Combined Sewer Basin (Brandon Basin) includes inputs from three main pathways: sewage (industrial and domestic wastewater), stormwater runoff, and potentially groundwater infiltration into combined sewer system. Sewage originates from

residential, commercial, and industrial uses in the basin. The stormwater runoff is collected from streets, parking lots, roofs, and other impervious surfaces. Groundwater can infiltrate into combined sewer pipes if the pipes are below the seasonally-fluctuating local groundwater elevation. This study was conducted to better understand the present-day chemical inputs to the combined sewer system attributable to these main pathways to assist in any needed source control efforts prior to CSO control.

The following questions guided the study design:

1. What are the chemical loadings within the Brandon combined sewer system during dry season baseflow conditions (which represents the sewage component)?
2. What are the chemical loadings within the Brandon combined sewer system during wet season baseflow conditions (which represents both sewage and infiltration components)?
3. What are the chemical loadings within the Brandon combined sewer system during stormflow conditions (which represents both the sewage and stormwater inflow components and low infiltration due to the hydrostatic pressure gradient)?
4. What are the chemical loadings within the Brandon combined sewer system from infiltration to the collection system pipes (which represents the wet season baseflow condition minus the sewage [dry season baseflow] component)?
5. What are the chemical loadings within the Brandon combined sewer system from stormwater inflow (which represents the stormflow condition minus the sewage [baseflow] component)?

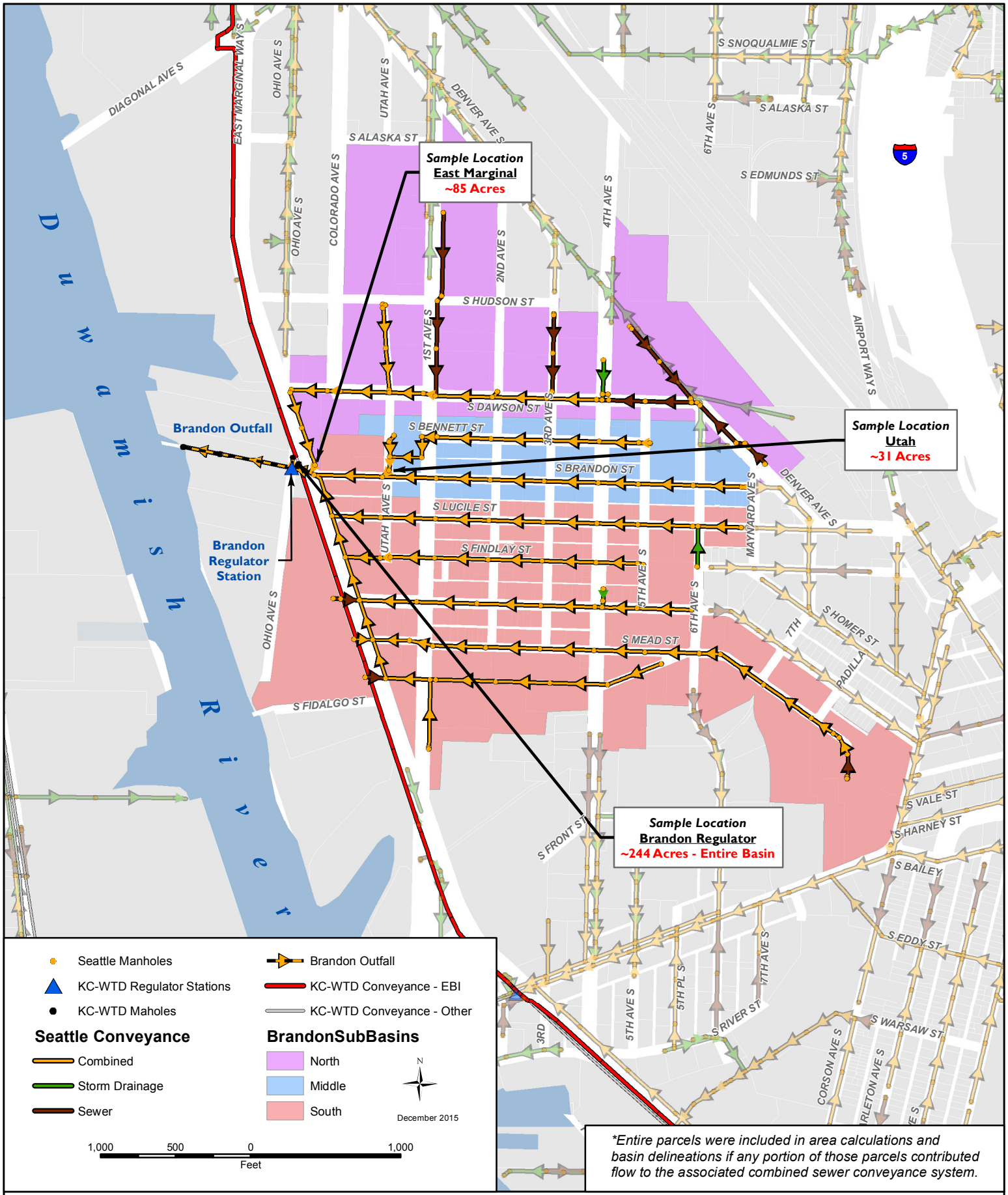
These study design questions are slightly modified from those originally presented in the Sampling and Analysis Plan (SAP; King County 2011c) to better capture the true scope of this project. These questions support the study objective of evaluating the relative magnitude of pathways (i.e., sewage versus stormwater) within the combined sewer system during storm events.

1.2 Study Area

The Brandon Basin was chosen for this study because it is a relatively small combined sewer basin comprised primarily of commercial and industrial facilities with a relatively small number of residential properties. The Brandon Basin has the smallest percentage of residential land use of any combined sewer basin with CSO discharges to the LDW. This basin also has many unpaved roads, increasing the potential for roadway solids wash off in stormwater. In addition, the Brandon Basin has a higher frequency of CSO discharges and represents the second largest CSO volume discharged to the LDW when compared with other CSOs in the LDW drainage basin (King County 2013c). By 2022, CSO discharges from the Brandon CSO outfall, in addition to the adjacent Michigan CSO outfall, will be controlled through the construction of a wet weather treatment plant (King County 2012b).

The Brandon Basin encompasses approximately 244 acres (0.987 km^2) and is located on the eastern side of the LDW; the outfall is located south of Slip 1 (Figure 1). The basin is bounded on the west by East Marginal Way, on the north by South Dawson Street, on the

south by South Fidalgo Street, and on the east by 6th Avenue South. All flow in the Brandon combined system is routed through Brandon Regulator and into the Elliott Bay Interceptor (EBI), which then flows to the West Point Treatment Plant. Under sufficient storm conditions, the regulator can divert flows that cannot be accommodated in the EBI to the CSO outfall, which discharges to the LDW. Over the last 20 years, on average, the Brandon CSO discharged 31 times annually; there were 7 discharge events in 2011 and 12 events in 2012 (King County 2012b and King County 2013c).



*Entire parcels were included in area calculations and basin delineations if any portion of those parcels contributed flow to the associated combined sewer conveyance system.

King County
Department of
Natural Resources and Parks
Wastewater Treatment Division

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Figure 1
Brandon CSO Basin Areas Contributing to Sampling Locations

2.0. FIELD SAMPLING METHODS

This section provides an overview of the field and sampling methods used in this study; greater detail is presented in the project SAP (King County 2011c). The sampling locations are described in Section 2.1. Section 2.2 summarizes the sample collection methods including sample processing and schedule. Section 2.3 describes the field sampling deviations from the SAP that were encountered. Copies of completed chain of custody forms used to track sample custody are included in Appendix A.

2.1 Sampling Locations

Wastewater samples from within the combined sewer basin were collected from three locations. One sampling site (Brandon Regulator) is located at the Brandon Regulator and allowed for collection of samples that represent flow from the entire basin. The remaining two sampling locations are located upstream of the Brandon Regulator at smaller branches of the combined system. These two stations were selected to provide a spatial evaluation of chemical loadings for two of the three main branches of the system. In this report, these sampling sites are called East Marginal, which is located on East Marginal Way; and Utah, which is located on Brandon Street South and Utah Avenue South. The third branch of the system was not sampled as part of this study, because there was no safe access to a sampling location. Table 1 summarizes the sampling location details; locations are presented in Figure 1.

Table 1. Brandon Basin Sampling Locations and Locator Names

KCEL Locator	Manhole Number	Report Name[a]	Location Description	Northing[b]	Easting[b]	km^2 (Acres)
BrandUtah	063-073	Utah	Utah Avenue South and Brandon Street South intersection	205766	1269520	0.125 (31)
A01007	063-059	East Marginal	E. Marginal Way South just north of Brandon Street South intersection	205843	1269072	0.344 (85)
BrandReg	063-050	Brandon Regulator	Brandon Regulator Wet Well	205897	1268924	0.987 (244)

[a] Nomenclature used for each sampling location in tables and figures in this report.
[b] State plane coordinates in North American Datum 1983 (NAD983) Washington State Plane North (4601)

2.2 Sample Collection

All samples were collected according to methods described in the SAP (King County 2011c). Autosamplers and flow measuring equipment were used to collect flow-weighted composite wastewater samples from the Brandon combined sewer basin. Samples were collected during both dry and wet season baseflow and stormflow conditions. Baseflow is defined as the period when flow in the combined sewer system returns to pre-storm conditions, approximately 48 hours after any significant rainfall event that generates

runoff. Baseflow represents the sewage and other inflow/infiltration that is constantly flowing in the pipe (i.e. does not include runoff from a storm event). For this project, the wet season was defined as November through March, while the dry season was July through September[7]. Deviations from these definitions are discussed in Section 2.3.

To survey baseflow conditions during the dry season, five to six sampling events were conducted depending on location. Wet season baseflow conditions were sampled between five and six times depending on location, while eight to 14 storm events were sampled depending on location. Each sample was analyzed for conventional parameters, total and dissolved metals including mercury, polycyclic aromatic hydrocarbons (PAHs) and phthalates, if sufficient volume was available. A subset of samples was analyzed for 209 PCB congeners and 17 dioxin/furan congeners. Conventional parameters included dissolved organic carbon (DOC), total organic carbon (TOC), and total suspended solids (TSS). Table 2 documents the number of samples collected at each location and measured analytes. There was insufficient space at the sampling locations to install a second autosampler to collect field replicate samples as designated by the SAP; therefore, none were collected.

Table 2. Number of Samples by Flow Condition, Location and Analysis

Flow Conditions	Location	Sample Number	
		Conventionals, Metals, SVOCs[a]	PCBs and Dioxin/furans
Dry Baseflow	Utah	6	3
	East Marginal	5	3
	Brandon Regulator	5	3
	TOTAL	16	9
Wet Baseflow	Utah	5	2
	East Marginal	5	2
	Brandon Regulator	6	3
	TOTAL	16	7
Stormflow	Utah	14	5
	East Marginal	8	4
	Brandon Regulator	14	5
	TOTAL	36	14
	GRAND TOTAL	**68**	**30**

[a] Semi-volatile organic compounds (SVOCs) analyzed included PAHs and phthalates.

[7] King County's Wastewater Treatment Division (WTD) calculates an average wet weather flow (AWWF) as part of a National Pollutant Discharge Elimination System (NPDES) permit. The AWWF is defined as the average flow from October to May, and is not comparable to the wet baseflow averages used in this report, which are based on individual sampling events.

2.2.1 Sample Collection

Composite wastewater samples were collected using ISCO® autosamplers equipped with 10-liter (L) glass carboys. Autosamplers were installed inside access ports below street level using appropriate mounting hardware and fitted with new or site-dedicated, pre-cleaned silicon peristaltic pump tubing for each sampling event. Teflon® tubing and stainless steel fittings were used throughout the remainder of the autosamplers. Field blanks were not collected (see Section 2.3), although previous projects have used comparable samplers and tubing as discussed in Section 2.1.1 of the project SAP (King County 2011c).

A flow meter was installed at each sampling location and continuous flow data were recorded for loading calculations and to trigger autosampler collection of sample aliquots. The flow meter at Brandon Regulator was a Flo-dar device while Utah and East Marginal locations used Hawk Sigma meters. These meters are area velocity sensors which also use Doppler acoustic technology in conjunction with either bubbler or ultrasonic level sensors to calculate flow. Flow meters are field tested in a round robin fashion every ten years by WTD. Each installation follows WTD Standard Operating Procedure (SOP) VII, which includes field verification of flow meter performance with manual depth and independent velocity instruments. Flow meters are verified at the time of installation and again approximately two to three weeks later. The flow meters allowed for the collection of flow-weighted composite samples.

Baseline flow information from the three sampling locations was collected for approximately 6 weeks to determine flow-weighted aliquot collection pacing and to establish the flow conditions that represent dry season baseflow conditions. Samples were collected after a pre-determined volume of water passed by the flow meter, a pulse trigger is sent to the autosampler to collect a predetermined sample volume ranging from 100mL to 500mL. The aliquot volume is based on anticipated flow conditions in the particular combined sewer pipeline.

Autosamplers collected flow-weighted composite samples, with a goal of 24 hour (hr) sample periods as specified in the SAP. However, in some cases this goal could not be met; deviations are described in Section 2.3. Start and end times for the autosamplers were recorded to the nearest minute by King County Environmental Laboratory (KCEL). The goal was to collect 10 L per sampling event (both baseflow and storm events). If 10 L were collected during a sampling event, 4 L were used for the PCB congener and dioxin/furan analyses. However, given the uncertainty and high peak flow factors associated with the stormwater component of the combined sewers being sampled, a range of sample volumes were encountered and not every sample collected sufficient volume for PCB or dioxin/furan analysis.

A minimum of 4.5 L per sampling event were collected for TOC, DOC, TSS, PAH/phthalates, metals, and mercury analyses. Any additional volume, with a minimum of 1 L, was used to create composite samples for PCB and dioxin/furan congener analyses. Analyses were prioritized when the minimum sample volume was not met. The order of priority was: total metals, total mercury, TOC, DOC, TSS, PAHs/ phthalates, dissolved metals and dissolved mercury.

2.2.2 Sample Processing

As soon as possible after an event ended KCEL Field Science Unit (FSU) staff retrieved the carboys. Once on site, staff reviewed flow data to confirm that sample aliquots were collected over the 24-hr target sampling period (or the period of the storm). The composite samples were stored on ice and transported back to KCEL where samples were split into individual laboratory containers. This was done by continuously agitating the sample in the carboy while transferring sample aliquots to the appropriate laboratory containers using a Teflon® siphon tube. This procedure ensured a representative aliquot from the carboy was decanted into each laboratory sample container. Once the sample had been split, the dissolved metals sample was filtered. Dissolved metals samples were drawn through a cleaned Nalgene 500mL filtration apparatus with 0.45 micron filters using a peristaltic pump. Because the composite sample could not be split and filtered within 15 minutes of retrieving the sample from the autosampler, appropriate hold-time exceedance flags were added by KCEL to the dissolved metals and mercury data.

Containers for PCB and dioxin/furan congener analyses were held at 4°C and delivered to AXYS Analytical Services (AXYS) within 1 to 4 months of sample collection. Samples were either driven to AXYS or shipped via overnight express delivery service.

2.2.3 Sampling Schedule

Dry baseflow sampling was conducted in September, October, and November 2011[8]. Wet baseflow sampling began in February 2012 and was completed by May 2012. Storm event sampling began in January 2011 and was completed in June 2012 (see Section 2.3 for deviations from the SAP). The sampling dates and times, lab sample identification (ID), and sample analyses for each event type are presented in Table 3. All samples in this report were analyzed for total metals, total mercury, and conventional parameters. One sample did not contain enough volume for PAHs, phthalates, and dissolved metals. Dissolved metals and mercury were not analyzed in four additional samples (Table 3). Due to both budgetary and sample volume constraints, only a subset of collected samples was analyzed for PCBs and dioxin/furans (Table 3).

[8] Section 2.3 discusses the deviation from the dry baseflow sampling SAP timing.

Table 3. Summary of Samples Collected

Location	Flow Category	Sample Start Date/Time	Sample End Date/Time	Lab Sample ID	Metals, Mercury and SVOCs Analysis	PCB, Dioxin/ Furan Analysis
Utah	Dry base	9/13/11 8:51	9/14/11 9:16	L54126-3	X	
		9/14/11 9:25	9/15/11 5:05	L54154-3	X	X
		9/28/11 14:33	9/29/11 14:27	L54307-3	X	X
		10/17/11 10:47	10/18/11 10:35	L54454-3	X	X
		10/18/11 10:47	10/19/11 1:12	L54455-3	X	
		10/19/11 10:55	10/20/11 8:15	L54488-3	X	
	Wet base	4/9/12 10:31	4/10/12 9:32	L55183-3	X	X
		4/10/12 9:53	4/11/12 8:12	L55184-3	X	X
		4/23/12 9:11	4/23/12 22:02	L55511-3	X	
		5/7/12 9:00	5/8/12 9:00	L55572-3	X	
		5/8/12 9:40	5/9/12 9:40	L55686-3	X	
	Storm	1/25/12 14:45	1/25/12 22:57	L54687-3	X	X
		2/28/12 10:10	2/28/12 18:08	L55011-3	X	X
		2/29/12 10:39	2/29/12 11:51	L55186-3	X	X
		3/27/12 10:45	3/27/12 17:56	L55185-3	X	X
		3/28/12 9:54	3/29/12 3:23	L55285-3	X	X
		4/11/12 10:09	4/11/12 16:02	L55433-3	X	
		4/24/12 9:16	4/25/12 0:32	L55512-3	X	
		4/25/12 9:14	4/25/12 19:02	L55584-3	X	
		5/21/12 9:00	5/22/12 9:00	L55638-3	X	
		5/22/12 9:14	5/22/12 17:57	L55763-3	X	
		6/4/12 8:40	6/5/12 3:50	L55764-3	X	
		6/5/12 9:31	6/5/12 12:42	L55859-3	X	
		6/6/12 9:53	6/7/12 6:33	L55875-3	X	
		6/7/12 10:43	6/7/12 14:14	L55876-3	X	
East Marginal	Dry base	9/13/11 10:36	9/14/11 12:14	L54126-1	A	
		9/28/11 15:02	9/29/11 14:53	L54307-1	X	X
		10/17/11 11:05	10/18/11 10:51	L54454-1	X	X
		10/25/11 10:53	10/26/11 10:53	L54531-1	X	X
		11/1/11 8:48	11/2/11 9:00	L54591-1	X	
	Wet base	4/9/12 11:01	4/10/12 10:00	L55183-1	X	
		4/10/12 10:04	4/11/12 10:15	L55184-1	B	
		4/23/12 9:25	4/24/12 3:40	L55511-1	X	X
		5/7/12 9:15	5/7/12 20:06	L55572-1	X	X
		5/8/12 10:10	5/9/12 8:16	L55686-1	X	
	Storm	1/25/12 15:08	1/25/12 23:06	L54687-1	X	X
		2/28/12 10:30	2/28/12 19:50	L55011-1	X	X
		2/29/12 10:50	3/1/12 8:40	L55186-1	X	X
		3/27/12 11:00	3/27/12 19:16	L55185-1	X	X
		4/11/12 10:24	4/11/12 18:24	L55433-1	X	
		4/25/12 9:28	4/25/12 22:56	L55584-1	X	
		6/4/12 8:55	6/5/12 4:17	L55764-1	X	
		6/7/12 10:52	6/8/12 10:34	L55876-1	A	

Table 3, Continued

Location	Flow Category	Sample Start Date/Time	Sample End Date/Time	Lab Sample ID	Metals, Mercury and SVOCs Analysis	PCB, Dioxin/ Furan Analysis
Brandon Regulator	Dry base	9/14/11 9:31	9/15/11 10:01	L54154-2	A	
		9/21/11 14:15	9/22/11 13:52	L54174-2	X	X
		10/17/11 10:45	10/18/11 10:15	L54454-2	X	X
		10/18/11 10:35	10/19/11 10:15	L54455-2	X	X
		10/19/11 10:45	10/20/11 10:15	L54488-2	X	
	Wet base	3/26/12 10:24	3/26/12 18:46	L55154-2	X	X
		4/9/12 9:38	4/10/12 9:30	L55183-2	X	
		4/10/12 9:40	4/11/12 9:40	L55184-2	X	X
		4/23/12 8:52	4/24/12 6:26	L55511-2	X	X
		5/8/12 14:28	5/9/12 14:28	L55686-2	X	
		6/20/12 14:33	6/21/12 14:11	L55698-1	X	
	Storm	1/25/12 14:15	1/25/12 23:17	L54687-2	X	X
		2/28/12 9:50	2/28/12 22:05	L55011-2	X	X
		2/29/12 10:12	2/29/12 12:26	L55186-2	X	X
		3/27/12 10:29	3/28/12 1:35	L55185-2	X	X
		3/28/12 9:35	3/29/12 7:00	L55285-2	X	X
		4/11/12 9:54	4/12/12 5:00	L55433-2	X	
		4/24/12 9:02	4/25/12 2:10	L55512-2	X	
		4/25/12 8:59	4/26/12 0:00	L55584-2	X	
		5/21/12 8:41	5/21/12 17:52	L55638-2	X	
		6/4/12 8:05	6/5/12 5:12	L55764-2	X	
		6/5/12 9:05	6/5/12 16:17	L55859-2	X	
		6/6/12 9:34	6/7/12 9:34	L55875-2	X	
		6/7/12 11:02	6/8/12 10:00	L55876-2	A	
		6/18/12 8:23	6/18/12 13:03	L55936-2	X	

X = sample analyzed for all parameters; A = sample analyzed for all parameters except dissolved metals and mercury; B = sample analyzed only for total metals, total mercury and conventionals.

2.3 Field Sampling Deviations from the SAP

All field sampling methods were conducted according to the SAP (King County 2011c) except where noted below:

- The SAP specified the use of ADS Flowshark flow meters, but Flow-Dar and Hawk Sigma meters were used for this study instead because they facilitated communication with the ISCO® autosamplers to collect flow-weighted composite samples. These meters are both comparable to the Flowshark meters specified in the SAP.
- Ten dry baseflow samples were collected in October (9) and November (1) which were outside the SAP defined dry season period of July-September. Samples were collected during this period because the dry 2011 autumn resulted in summer

baseflow characteristics that were deemed appropriate for sample collection and logistical delays to beginning the project. Post-hoc analysis of flow data indicated flow conditions were similar to dry season baseflow collected from July through September.

- Collection of the wet season baseflow samples was delayed due to logistical reasons. Fourteen wet season baseflow samples were collected in April and May 2012, in addition to a sample collected in June 2012. This sampling period was outside the "wet season" defined in the SAP. These samples were retained in the analysis because the precipitation patterns during these months approximated wet season conditions.
- The SAP specified that one field equipment blank sample would be collected at each sampling location; however, none were collected. Equipment blank results from a previous Duwamish CSO study (King County 2011a), which used similar sampling equipment, were used as a surrogate for this study. These results were presented in Section 2.2.1 of the SAP (King County 2011c). This deviation is not expected to result in significant impacts to this study because this study is evaluating relative differences in chemical loads from different flow conditions and any bias associated with equipment contamination is expected to be similar across the sampling locations. The previous CSO sampling study field equipment blanks found low (2.2 µg/L or less) levels of cadmium, chromium, and copper in field blanks (King County 2011a). Field blanks also contained less than 0.2 µg/L benzyl butyl, bis(2-ethylhexyl), diethyl, dimethyl, and di-n-butyl phthalates and less than 0.03 µg/L naphthalene. Total PCB congeners in field blanks ranged from 0.012 to 1.13 ng/L. This is more than ten times lower than the total PCB congeners detected in the Brandon base and stormflow samples for this project. Except for cadmium, the metal concentrations detected in the Brandon Basin samples were greater than five times those detected in the field blanks. Therefore with the exception of cadmium, no bias was expected in the Brandon Basin samples based on field blank metal results. There was a possible high bias for benzyl butyl phthalate in the East Marginal samples which was typically detected in the samples at concentrations within five times the concentrations detected in the field blanks. This was also the case for diethyl, dimethyl, and di-n-butyl phthalates at all locations where high bias is expected based on prior field blank results. Lastly, naphthalene detections in prior blanks indicate that all but the highest naphthalene concentrations (greater than 0.3 µg/L) could be subject to high bias from field or laboratory contamination.
- Section 3.7 of the SAP specifies that the autosampler tubing and carboys would be decontaminated by rinsing with (1) Detergent 8 or other suitable laboratory detergent; (2) a H_2SO_4 rinse; (3) a deionized water (ASTM I or II) rinse, and (4) acetone prior to each use. However, based on data associated with equipment blanks for a concurrent study (King County 2013d), as well as laboratory evaluation of equipment decontamination procedures (Elliott 2013), KCEL determined that residual acetone in the tubing resulted in high biased TOC and DOC concentrations. Based on this finding, the acetone rinse for both the autosampler tubing and the carboy was eliminated for all remaining sampling events (i.e., dry baseflow samples

collected after September 2011, and all wet baseflow and storm event samples). The acetone rinse was intended to reduce the probability of PCB contamination between sampling events at a site. However, given the observed organic carbon bias due to residual acetone, AXYS Analytical agreed to this change. The other decontamination procedures for tubing and carboys were continued; therefore, this change was not expected to result in cross-contamination issues for the remaining samples.

- The SAP specified an antecedent dry period of 48 hours for all baseflow sample collection; however, this specification was not met for some samples. Five baseflow samples were collected after a rain event occurred within 48 hours before collection (two dry at Utah, one dry at East Marginal and one dry and one wet at Brandon Regulator). A comparison of rainfall data to the hydrographs at each site indicated flows in this system returned to baseflow conditions prior to the 48 hours sampling trigger (See Appendix B for hydrographs from each sample collection). Few samples were collected when more than 0.02 inches of rain fell in the preceding 48 hours, and only one sample was collected within 12 hours of a rainfall event (0.01 inches, See Table 6 in Section 5.1). In addition, during one dry baseflow collection at Brandon Regulator, there was 0.01 inches of rain. These occurrences of slight rainfall did not compromise the baseflow conditions in this system, based on the quick recovery to baseflow conditions observed in the hydrographs and a lack of stormflow peaks in the hydrograph (Appendix B, Figure B-39).
- Flows in this system are fairly dynamic, even during baseflow conditions (See Appendix B). While the goal was to collect 24 hr flow-weighted samples, if flows were greater than expected, the sample container filled more quickly than planned. Baseflow sample periods ranged from 8.37 to 25.6 hours, with a mean of 21.8 hours and storm event sampling periods ranged from 1.22 to 24.0 hours, with a mean of 12.9 hours (See Table 3). During dry weather conditions, there is a strong daily signal of increased flow in the basin during business hours Monday through Friday. Baseflow samples collected over less than 24 hours may not fully represent daily mean baseflow conditions. Weekend conditions were not captured in these sampling events. It is unknown what effect this sampling regime may have had on study conclusions.

3.0. LABORATORY METHODS

A summary of analytical methods are presented in this section. The KCEL reports both the reporting detection limit (RDL) and the method detection limit (MDL) for each sample and parameter, where applicable. PCB and dioxin/furan congeners were analyzed using high resolution isotopic dilution based methods, therefore MDL and RDL terms are less applicable because limits of quantitation are derived from calibration capabilities and ubiquitous, but typically low level equipment and laboratory blank contamination. As a result, PCB and dioxin/furan congener data are reported to lowest method calibration limits (LMCLs) and flagged as estimated down to the sample specific detection limit (SDL). In most cases the SDL is below the LMCL. The following sections provide a summary of the laboratory methods; greater detail can be found in the project SAP (King County 2011c).

3.1 Metals and Mercury

Total and dissolved metal samples were analyzed and reported by EPA Method 200.8 (Inductively Coupled Plasma-Mass Spectrometry [ICP-MS]), KCEL SOP 624. The specific metals analyzed included: arsenic, cadmium, chromium, copper, lead, nickel, silver, vanadium and zinc. Total and dissolved mercury samples were analyzed by EPA Method 245.1 (Cold Vapor Atomic Absorbance [CVAA]), KCEL SOP 604.

3.2 PAHs and Phthalates

PAHs and phthalates samples were prepared by liquid-liquid extraction as detailed in EPA method 3520C, KCEL SOP 701. This extraction was modified by breaking down the liquid-liquid extractors without decanting the remaining solvent from the extractor bodies into round bottomed flasks. Leaving this step out avoided the need to use sodium sulfate as a drying agent. Sodium sulfate may contribute significant PAH and phthalate contamination at levels typically found in these samples.

Samples were analyzed by a modified EPA Method 625 Gas Chromatography/Mass Spectrometry – Selected Ion Monitoring Large Volume Injection method (GC/MS-SIM LVI), developed for this project (KCEL SOP 772D). The specific PAHs analyzed included: 2-methylnaphthalene, acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo (g,h,i)perylene, benzo(a)pyrene, benzo(b,j,k)fluoranthene, chrysene, dibenzo(a,h)anthracene, fluorene, fluoranthene, indeno(1,2,3-cd)perylene, naphthalene, phenanthrene, and pyrene. The phthalates analyzed included: benzyl butyl phthalate, bis(2-ethylhexyl)phthalate, diethyl phthalate, dimethyl phthalate, di-n-butyl phthalate, and di-n-octyl phthalate.

3.3 PCB Congeners

PCBs are found in up to 209 different forms, called congeners, and were measured using high resolution PCB congener analysis. Analysis followed EPA Method 1668 Revision C (EPA 2010a), which is a high-resolution gas chromatography/high-resolution mass spectroscopy (HRGC/HRMS) method using an isotope dilution internal standard

quantification. This method provides reliable analyte identification and very low detection limits. An extensive suite of labeled surrogate standards are added before samples are extracted. Data are "recovery-corrected" for losses in extraction and cleanup, and analytes are quantified against their most similar labeled analogues. The analysis included all 209 PCB congeners. AXYS performed the PCB congener analysis according to their SOP MLA-010 Analytical Method for the Determination of 209 PCB Congeners by EPA Method 1668.

The SAP indicated PCB congeners would be analyzed by Revision A of Method 1668. However, on September 15, 2011, AXYS switched from using Revision A of EPA Method 1668 to Revision C of this method. Method 1668C provides similarly reliable analyte identification and very low detection limits. The principle difference between Method 1668A and 1668C is the replacement of individual laboratory acceptance criteria with inter-laboratory developed acceptance criteria.

3.4 Dioxin/Furan Congeners

Dioxin/furan congener analysis was performed according to EPA Method 1613B (EPA 1994), which is a HRGC/HRMS method using an isotope dilution internal standard quantification similar to Method 1668C for PCBs. The analysis included 7 dioxin and 10 furan congeners. This method provides reliable analyte identification and very low detection limits. Labeled native and surrogate standards are added before samples are extracted. Data are "recovery-corrected" for losses in extraction and cleanup, and analytes are quantified against their labeled analogues or a related labeled compound. AXYS performed this analysis according to their Standard Operating Procedure MLA-017, which is based on EPA Method 1613b.

3.5 Conventional Parameters

Conventional analyses followed Standard Methods (SM) protocols (American Public Health Association [APHA] 1998). TOC and DOC were analyzed following Standard Methods 5310-B (KCEL SOP 336) and TSS following Standard Methods 2540-D (KCEL SOP 309).

3.6 Deviations from the SAP

There were no laboratory deviations from the planned methods.

4.0. DATA AND LOADING ANALYSIS METHODS

The analytical data were prepared for data analysis by applying rules for: (1) non-detect results; (2) determining PAH, PCB and dioxin/furan sums; (3) use of laboratory replicate data; and (4) calculation of dioxin Toxicity Equivalents or TEQs. Further data analysis methods, such as converting concentration data to mass loadings, are also presented. The details of these calculations, as well as a summary of data analysis methods, are described below.

4.1 Use of Non-detect Result Values

Depending on the sample, one or more chemicals may have been reported as not detected. These non-detects may have been reported with highly elevated detection limits due to the multiple dilutions required for the sewage/stormwater matrix. Thus, in several cases the sample-specific MDLs, exceeded reported detected concentrations in other samples. Including the MDLs as a surrogate value when calculating means within each flow type would, for some samples, increase the resulting mean concentration and for other samples the inclusion of MDLs would decrease the mean concentration. Since the influence of the surrogate values would be either high or low depending on the matrix/sample, the decision was made to report the means of detected concentrations along with the number of samples and frequency of detection (FOD).

Non-detect results (at the MDL value) were included in the calculation of median concentrations for parameters at each location with at least 50% FOD. This summary statistic was included to provide context for the possible distribution of concentrations. Any medians that included non-detect results are more uncertain for the reasons described above.

Because the use of surrogate values for non-detect chemicals in this study would not add reliable information to calculated loads, only detected results were included in loadings analysis. For each sampling location, analytes with FODs below 75% were not included in statistical analysis or in primary pathway estimates because of the particularly high uncertainty associated with these few detections.

4.2 Summation for PAH Compounds, PCB Congeners and Dioxin/Furan Congeners

Total high molecular weight PAH (HPAH) concentrations are the sum of detected concentrations of benzo(a)anthracene, benzo(a)pyrene, benzo(b,j,k)fluoranthene, benzo(g,h,i)perylene, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-Cd)pyrene, and pyrene. If no HPAH compounds were detected in a given sample, the highest MDL value was used as the non-detect value. These HPAH non-detects were only included in the median calculation in Section 5.6. Figures and loadings calculations include

only detected concentrations of total HPAH. Total low molecular weight PAHs (LPAHs) were not evaluated due to lower FOD.

For summing total PCBs and total dioxins/furans, only detected concentrations of PCB congeners, or dioxin/furan congeners were included in their respective mass totals. Non-detect estimated maximum concentrations (K flagged data) were only included in the sum of dioxin TEQs.

4.3 Laboratory Replicates

Laboratory replicates were considered laboratory quality control values and were not used in data analysis, but rather as part of the data validation process. As per the project SAP, no field replicates were collected.

4.4 Dioxin TEQs

Dioxin and furan congener data are summarized on both a total dioxin/furan (Section 4.2) and TEQ basis. The dioxin TEQs are included because the cleanup targets for the LDW are based on dioxin TEQs. TEQs provide a toxicity-based approach to interpreting the dioxin and furan congener data. Dioxin and furan congener concentrations were converted to TEQs based on 2,3,7,8-Tetrachlorodibenzodioxin (2,3,7,8-TCDD) toxicity by multiplying the concentration of an individual congener by its toxicity equivalent factor (TEF) for mammals from Van den Berg et al. (2006) (Table 4) to result in a TEQ concentration. The total dioxin TEQ concentration was based on summing the 17 TEQ values. Non-detected dioxins and furans were not included in the TEQ calculation[9].

Table 4. TEFs Applied for Dioxin TEQ Calculation.

Dioxins	TEF
2,3,7,8-TCDD	1
OCDD	0.0003
1,2,3,4,6,7,8-HPCDD	0.01
1,2,3,4,7,8-HXCDD	0.1
1,2,3,6,7,8-HXCDD	0.1
1,2,3,7,8,9-HXCDD	0.1
1,2,3,7,8-PECDD	1

Furans	TEF
2,3,7,8-TCDF	0.1
1,2,3,4,6,7,8-HPCDF	0.01
1,2,3,4,7,8,9-HPCDF	0.01
1,2,3,4,7,8-HXCDF	0.1
1,2,3,6,7,8-HXCDF	0.1
1,2,3,7,8,9-HXCDF	0.1
1,2,3,7,8-PECDF	0.03
2,3,4,6,7,8-HXCDF	0.1
2,3,4,7,8-PECDF	0.3
OCDF	0.0003

[9] For laboratory results qualified as "K" by AXYS, which were re-qualified as U by data validation, the dioxin and furan congener based on the result value was multiplied by the respective TEF and included in the TEQ calculation.

4.5 Data Analysis Methods

This section presents the methods used to ensure samples represented the intended flow condition. Also described are the methods used to calculate chemical and conventional parameter loadings. Finally, a summary of the statistical methods used for data analysis are presented.

4.5.1 Sample Categorization

After all samples were collected, composite sample start and end times were compared to measured rainfall based on local rain gauge data. Sample collection periods and flow triggered sample volumes were also compared with recorded flow measurements. These comparisons were made to ensure the samples were representative of their respective condition (i.e., dry or wet baseflow or stormflow). Table 5 provides a summary of the samples that did not meet the required specifications and the rationale to remove them from further analysis.

Table 5. Samples Not Included in Data Analysis Due to Flow Meter Failures, Rainfall, or Flow Conditions.

Planned Flow Condition	Location	Sample Start Date/Time	Sample End Date/Time	Lab Sample ID	Rationale
Dry Baseflow	East Marginal	10/26/11 11:10	10/27/11 11:17	L54532-1	0.04" rainfall during sample collection; conditions insufficient to categorize as dry baseflow or a storm
	Brandon Regulator	9/28/11 14:30	9/29/12 14:16	L54307-2	Flow meter failure
Wet Baseflow	East Marginal	2/15/12 12:32	2/16/12 12:25	L55012-1	Excess elevated flows and 0.04" rainfall over the sample period; conditions insufficient to categorize as wet baseflow or a storm
	East Marginal	3/26/12 10:59	3/27/12 10:55	L55154-1	0.03" rainfall during sample collection; conditions insufficient to categorize as wet baseflow or a storm
	Utah	2/15/12 12:14	2/16/12 10:17	L55012-3	Excess elevated flows and 0.04" rainfall over the sample period; conditions insufficient to categorize as wet baseflow or a storm
	Utah	3/26/12 10:45	3/27/12 10:38	L55154-3	Excess elevated flows and 0.04" rainfall during the sample period; conditions insufficient to categorize as wet baseflow or a storm
Storm	East Marginal	4/24/12 9:30	4/24/12 23:07	L55512-1	Insufficient sample volume derived from elevated flows (<50%)
	East Marginal	5/21/12 9:12	5/21/12 17:17	L55638-1	Flow meter failure
	East Marginal	5/22/12 9:25	5/23/12 9:25	L55763-1	Insufficient sample volume derived from elevated flows (<50%)
	Brandon Regulator	5/22/12 9:32	5/23/12 9:08	L55763-2	Insufficient sample volume derived from elevated flows (<50%)

4.5.1.1 Dry Baseflow

Dry baseflow conditions during each sampling period were confirmed by comparing to flow data collected during July-August and by reviewing rain gauge data to confirm no rainfall occurred during the collection period or within 12 hours preceding the collection period.

During collection of three dry baseflow samples (not listed in Table 5, See Table 6 in Section 5.1), 0.01 inches of rain was recorded either during the sampling period or within 12 hours preceding the collection period. Rainfall data presented in this report is based on the East Marginal rain gauge. Although the East Marginal gauge is closest to the sampling basin, rainfall is expected to be variable across the basin, and one rain gauge does not directly represent total rainfall in the basin. Therefore, data from three nearby rain gauges were also consulted to help inform these categorization decisions. For all three of these dry baseflow samples with some measurable rainfall based on one rain gauge, other nearby gauges did not record any rainfall and there was no evidence of increased flows recorded. Therefore, all three of these samples were retained as dry baseflow samples in the data analysis.

One dry baseflow sample (East Marginal – 10/26/2011) was not representative of dry baseflow conditions because it was collected during a rain event (0.04 in as recorded by the East Marginal rain gauge). While there was no evidence of increased flows due to the measured rainfall, at least 0.01 inches of rain was recorded at the three other nearby rain gauges suggesting the potential for stormwater to enter the combined system. This sample was removed from further analysis (Table 5). Additionally, another dry baseflow sample (Brandon Regulator – 9/28/2011) met the dry baseflow requirements; however, the flow meter failed to record any data to estimate flow which is necessary for loading analyses (Table 5). Although the concentration results are representative of baseflow conditions, the data from this sample could not be included in loadings analysis. Tables and figures in Section 5 do not include concentration results for this sample; however, the text reports the influence this sample would have had on the mean baseflow concentration in Section 5.10. All other samples targeted as dry baseflow were determined to be representative of dry baseflow conditions.

4.5.1.2 Wet Baseflow

Wet baseflow conditions were confirmed by reviewing rain gauge data to ensure no rainfall occurred during the collection period or within 12 hours preceding the collection period. Four wet baseflow samples did not meet these requirements and were deemed non-representative and removed from further data analysis (Table 5). Because they were collected during a rainfall event, these samples were evaluated to determine if they could meet stormflow conditions. However, the corresponding rainfall and flows were insufficient to consider these four samples to be representative of stormflow conditions (as defined in Section 4.5.1.3). Therefore, loadings for these samples have not been calculated and the samples were removed from further analysis.

4.5.1.3 Storm Events

For storm event samples, the percent of sample volume collected during “elevated flows” was evaluated to confirm the appropriate classification of these samples. Flow was recorded every five minutes. Elevated flow was defined as 0.05 million gallons per day (MGD) at the Utah sampling location, 0.2 MGD at the East Marginal sampling location and 0.5 MGD at Brandon Regulator. These thresholds were determined based on normal baseflow variability and levels that are consistently associated with rainfall at each site. This threshold is not related to conditions resulting in a CSO discharge.

For three samples collected during storm events, less than 50% of the volume was collected during an elevated flow period (Table 5). As such, these samples did not represent stormflow conditions and were removed from further analysis. In addition, one sample (East Marginal -5/21/2012) met storm requirements, but the flow meter failed to record any data to estimate mean flow (Table 5). This sample could not be included in the loadings analysis, although the concentration results are still representative of stormflow conditions. Therefore, while Section 5.0 tables and figures do not include concentration results for this sample, the text reports the influence this sample would have had on the mean stormflow concentration at this site in Section 5.10. The tables and figures do not use these concentrations to allow the reported concentrations in the tables to match the tables and loadings figures presented later in the report (Section 6).

4.5.1.4 Summary

Ten of the 78 samples collected did not meet their designated sample conditions or category. Appendix B includes the hydrograph and rainfall conditions during each sampling event with further description of samples that did and did not meet their designated sample conditions. Chemical and conventional parameter concentration data for these ten samples are provided in Appendix C.

4.5.2 Mass Loading Calculations

Estimates of mass loading of chemical and conventional parameters into the combined sewer system under different system flow conditions (e.g., baseflow) were developed. These sample specific loading rates represent loads within the Brandon Basin that would be going to the West Point Treatment Plant via the EBI. A loading rate is a mass per unit time, e.g. mg/hr. Because storm duration varies (hours to days), it is not possible to calculate a “per storm” loading. Such a loading would also be dissimilar to a calculated wet or dry baseflow loading rate. Therefore to provide consistency and comparability, loading rates were calculated in mass per (one) hr units and all statistical analyses were based on mass/hr loading rates.

To calculate loadings per hr for a given event and flow condition, the arithmetic mean flow was calculated from the 5 minute flow measurements recorded by the flow meters. When the flow meter was unable to record or report a value for any given five-minute interval, no substitution or interpolation occurred; i.e., the flow data gap was ignored. This method was reasonable, because sample aliquots were not collected when flow meters were unable to record or report a value. Thus, only reported flow data were used to derive an arithmetic mean flow over the course of each sampling event.

Mean flow values in MGD were multiplied by the fraction of the day the sampler collected. For example, if the autosampler collected the flow-weight composite for eight hours (33.3 percent of a day), then the mean flow in MGD was multiplied by 0.333 to derive a flow volume for the sampled event. The volume per event in million gallons was then converted to L and divided by the duration of the sampling event, which varied from 1.22 hours to a maximum of 25.63 hours, to derive a flow rate in L/hr for each event. Because loadings are mass per unit time values, multiplying measured water concentrations in mg/L or µg/L by the flow rate in L/hr provides results in mass/hr by flow type (dry baseflow, wet baseflow,

or stormflow as applicable). Different parameters have been reported in kg, mg, or µg per hr loading rates to avoid excessive zeroes in the reported loads and because different chemical loading rates were up to 6 orders of magnitude different depending on the chemical.

If a parameter was not detected, mass loading rates were not calculated, nor included in further analysis. While there are common methods to substitute concentrations for non-detects (e.g., using the MDL or half the MDL value or resampling techniques like boot-strapping), the uncertainty in this value would be further propagated by a loadings calculation. This also had the potential to result in biased loading rates for parameters with fewer detections. For this reason, parameters with low FODs (<75%) were only included in summary statistics, not other statistical analyses.

4.5.3 Significant Figures

The reporting precision of sample concentrations, flow volumes, and sampling durations varied across data types. In the interest of consistency, all digits were used in the loading calculations and final values were rounded to three significant figures in the results tables (Section 6.0). All input data to allow development of sample-specific significant figures are presented in Appendix C should it be required.

4.5.4 Statistical Data Analysis and Data Presentations

For normally distributed data, t-tests ($p<0.05$) were conducted using Sigma Plot 12.0 software to compare concentrations and loading rates between baseflow (combination of both dry and wet) and stormflow samples, as well as flow and loading rates between dry and wet baseflow samples. If the data did not pass the Shapiro-Wilk Normality test ($p<0.05$) or the Equal Variance test ($p<0.05$), then the non-parametric Mann-Whitney Rank Sum Test ($p<0.05$) was performed instead. Parametric t-tests can identify statistical differences in means between two groups, while the Rank Sum tests identify differences in medians. Only parameters with greater than 75% FOD across flow conditions at a given site were included in statistical analyses.

Summary statistics for concentration data for analyzed parameters are presented in Section 5.0. When FOD was greater than 50%, medians are presented in summary tables. In these cases, the non-detect values were included in the median calculation using the MDL as a surrogate value; the inclusion of non-detects may bias the median higher when there were an even number of samples and a non-detect and detected value were averaged to derive a median. Means were included when there were two or more detections. Dilution of study samples was common to allow for analysis within the calibrated range of the GC/MS instruments. This resulted in variability in the magnitude of sample-specific MDLs within a sample group, especially for organic chemicals. This means an organic chemical could be detected in one sample at a concentration below the MDL of another sample. Substituting the MDL value for the non-detect is commonly practiced, with the understanding that this results in a high bias for the dataset. Since the MDL values were variable, the potential influence of using the MDLs for non-detects would have an unpredictable bias on calculated mean values. This is another reason why only detected concentrations were used to calculate loadings. The values potentially substituted for non-detects affect the arithmetic

mean more than the median, therefore, non-detects were not included in mean calculations but were included in median calculations by substituting for the MDL value. By using only detected values, the bias to mean loading rates, although reduced by only used chemicals with FOD > 75%, is unknown. In addition, box plots were used to represent distribution of the flow, concentration, and loadings data. Only detected concentrations were used in the box plots. Figure 2 illustrates the components of a box plot.

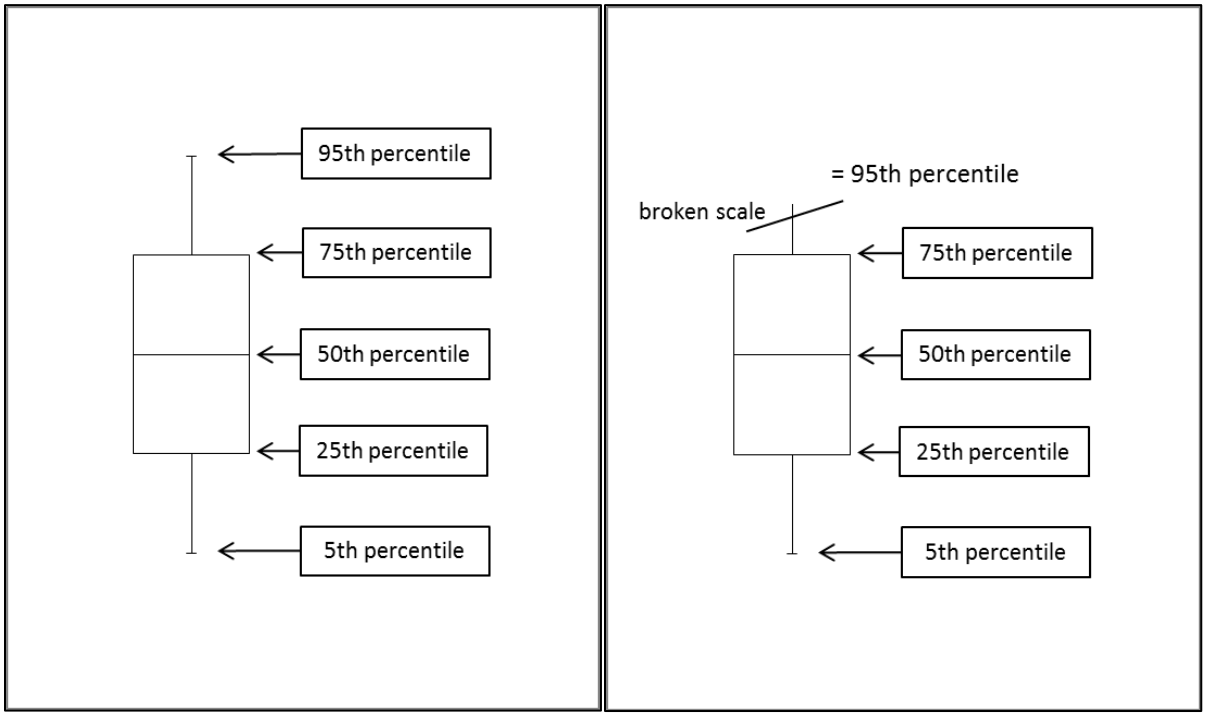

Figure 2. Box Plot Schematics Uncluding Box Plots with Y-axis Gaps.

5.0. RESULTS: RAINFALL, FLOW, AND CONCENTRATION

This section provides a summary of the rainfall and flow data for each sampling event (Sections 5.1 and 5.2, respectively) with graphical representation of the rainfall and flow data presented in Appendix B. Sections 5.3 through 5.9 present summaries of the analytical data results for the study samples as well as box plots to illustrate data distributions between flow conditions and by sampling location. These figures include only detected concentrations. More detailed evaluations of differences between sampling locations and flow conditions are presented in Sections 6.0 and 7.0 based on the mass load of each parameter. All analytical data as reported by the laboratories are presented in Appendix C. A summary of data validation findings for all chemistry analyses is included in Section 5.10; complete data validation reports are included in Appendix D.

5.1 Rainfall Data

Rainfall data for the 12 hours leading up to and during each sampling event are summarized in Table 6 below. Rainfall data are presented based on the East Marginal Way rain gauge maintained by King County WTD. The rain gauge is located at East Marginal Way South, southeast of Ellis Avenue South and at the eastern edge of the King County International Airport at 7343 East Marginal Way South. While the East Marginal rain gauge was the primary data source, these data were compared with the WTD King, Chelan, and Henderson gauges to better characterize conditions during sampling events. These latter data are not presented in this report.

Many rainfall events initiated changes in flow within one or two hours; however, 12 hr antecedent rainfall is also reported to provide additional data to describe event conditions. As shown in Table 6, storm events of varying intensity were captured by this sampling effort; combined total rainfall 12 hours before and during storm samples ranged from 0.04 inches (Utah sample 4/24/12) to 0.56 inches (East Marginal and Brandon Regulator samples 6/7 to 6/8/12). The Utah sample associated with only 0.04 inches of rainfall was retained in the analysis as a storm sample due to the elevated flows and because the nearby Henderson rain gauge recorded 0.14 inches of rainfall during this sampling event. These data illustrate how the rainfall and flow data were synthesized with best professional judgment to ensure samples were categorized appropriately. Annotated flow graphics for all sampling events are shown in Appendix B.

All storm events had less than 0.4 inches of rainfall during the sampling period. This indicates only relatively small storms were captured in this study effort. This is important to consider when interpreting the stormflow and stormwater data, because the loading rates would likely differ under higher stormflow conditions. Lower intensity storms are also much less likely to trigger CSO discharge events, meaning the stormflow samples in this study are not representative of typical CSO discharge conditions.

Table 6. Rainfall During Sampling Event and 12 Hours Prior.

Location	Flow Category	Sample Start Date/Time	Sample End Date/Time	Timespan (hours)	Total Rainfall (inches)	
					12 Hours Prior to Sampling	During Sampling
Utah	Dry base	9/13/11 8:51	9/14/11 9:16	24.4	0.00	0.00
		9/14/11 9:25	9/15/11 5:05	19.7	0.00	0.00
		9/28/11 14:33	9/29/11 14:27	23.9	0.00	0.00
		10/17/11 10:47	10/18/11 10:35	23.8	0.00	0.00
		10/18/11 10:47	10/19/11 1:12	14.4	0.00	0.00
		10/19/11 10:55	10/20/11 8:15	21.3	0.01	0.00
	Wet base	4/9/12 10:31	4/10/12 9:32	23.0	0.00	0.00
		4/10/12 9:53	4/11/12 8:12	22.3	0.00	0.00
		4/23/12 9:11	4/23/12 22:02	12.8	0.00	0.00
		5/7/12 9:00	5/8/12 9:00	24.0	0.00	0.00
		5/8/12 9:40	5/9/12 9:40	24.0	0.00	0.00
	Storm	1/25/12 14:45	1/25/12 22:57	8.2	0.22	0.10
		2/28/12 10:10	2/28/12 18:08	8.0	0.00	0.10
		2/29/12 10:39	2/29/12 11:51	1.2	0.08	0.02
		3/27/12 10:45	3/27/12 17:56	7.2	0.03	0.10
		3/28/12 9:54	3/29/12 3:23	17.5	0.09	0.14
		4/11/12 10:09	4/11/12 16:02	5.9	0.00	0.05
		4/24/12 9:16	4/25/12 0:32	15.3	0.00	0.04
		4/25/12 9:14	4/25/12 19:02	9.8	0.15	0.09
		5/21/12 9:00	5/22/12 9:00	24.0	0.11	0.31
		5/22/12 9:14	5/22/12 17:57	8.7	0.00	0.10
		6/4/12 8:40	6/5/12 3:50	19.2	0.02	0.13
		6/5/12 9:31	6/5/12 12:42	3.2	0.35	0.07
		6/6/12 9:53	6/7/12 6:33	20.7	0.00	0.14
		6/7/12 10:43	6/7/12 14:14	3.5	0.39	0.11

Table 6, Continued

Location	Flow Category	Sample Start Date/Time	Sample End Date/Time	Timespan (hours)	Total Rainfall (inches)	
					12 Hours Prior to Sampling	During Sampling
East Marginal	Dry base	9/13/11 10:36	9/14/11 12:14	25.6	0.00	0.00
		9/28/11 15:02	9/29/11 14:53	23.9	0.00	0.00
		10/17/11 11:05	10/18/11 10:51	23.8	0.00	0.00
		10/25/11 10:53	10/26/11 10:53	24.0	0.00	0.00
		11/1/11 8:48	11/2/11 9:00	24.2	0.00	0.00
	Wet base	4/9/12 11:01	4/10/12 10:00	23.0	0.00	0.00
		4/10/12 10:04	4/11/12 10:15	24.2	0.00	0.00
		4/23/12 9:25	4/24/12 3:40	18.3	0.00	0.00
		5/7/12 9:15	5/7/12 20:06	10.9	0.00	0.00
		5/8/12 10:10	5/9/12 8:16	22.1	0.00	0.00
	Storm	1/25/12 15:08	1/25/12 23:06	8.0	0.22	0.11
		2/28/12 10:30	2/28/12 19:50	9.3	0.11	0.03
		2/29/12 10:50	3/1/12 8:40	21.8	0.08	0.03
		3/27/12 11:00	3/27/12 19:16	8.3	0.03	0.15
		4/11/12 10:24	4/11/12 18:24	8.0	0.00	0.06
		4/25/12 9:28	4/25/12 22:56	13.5	0.15	0.22
		6/4/12 8:55	6/5/12 4:17	19.4	0.02	0.17
		6/7/12 10:52	6/8/12 10:34	23.7	0.39	0.17

Table 6, Continued

Location	Flow Category	Sample Start Date/Time	Sample End Date/Time	Timespan (hours)	Total Rainfall (inches)	
					12 Hours Prior to Sampling	During Sampling
Brandon Regulator	Dry base	9/14/11 9:31	9/15/11 10:01	24.5	0.00	0.00
		9/21/11 14:15	9/22/11 13:52	23.6	0.00	0.00
		10/17/11 10:45	10/18/11 10:15	23.5	0.00	0.00
		10/18/11 10:35	10/19/11 10:15	23.7	0.00	0.01
		10/19/11 10:45	10/20/11 10:15	23.5	0.01	0.00
	Wet base	3/26/12 10:24	3/26/12 18:46	8.4	0.00	0.00
		4/9/12 9:38	4/10/12 9:30	23.9	0.00	0.00
		4/10/12 9:40	4/11/12 9:40	24.0	0.00	0.00
		4/23/12 8:52	4/24/12 6:26	21.6	0.00	0.00
		5/8/12 14:28	5/9/12 14:28	24.0	0.00	0.00
		6/20/12 14:33	6/21/12 14:11	23.6	0.00	0.00
	Storm	1/25/12 14:15	1/25/12 23:17	9.0	0.22	0.12
		2/28/12 9:50	2/28/12 22:05	12.3	0.00	0.13
		2/29/12 10:12	2/29/12 12:26	2.2	0.10	0.04
		3/27/12 10:29	3/28/12 1:35	15.1	0.03	0.24
		3/28/12 9:35	3/29/12 7:00	21.4	0.10	0.32
		4/11/12 9:54	4/12/12 5:00	19.1	0.00	0.06
		4/24/12 9:02	4/25/12 2:10	17.1	0.00	0.10
		4/25/12 8:59	4/26/12 0:00	15.0	0.15	0.26
		5/21/12 8:41	5/21/12 17:52	9.2	0.11	0.32
		6/4/12 8:05	6/5/12 5:12	21.1	0.02	0.24
		6/5/12 9:05	6/5/12 16:17	7.2	0.35	0.10
		6/6/12 9:34	6/7/12 9:34	24.0	0.00	0.34
		6/7/12 11:02	6/8/12 10:00	23.0	0.40	0.16
		6/18/12 8:23	6/18/12 13:03	4.7	0.10	0.03

*This table does not include samples that were removed from further analysis for not meeting baseflow or storm criteria (See Section 4.5.1).

5.2 Flow Data

Flow was monitored continuously at five-minute intervals throughout the study period (July 2011 to July 2012) at each sampling location. However, the flow meters did not always perform as intended resulting in occasional periods of missing flow data. Flow for these periods were neither interpolated nor assumed to be zero; they were omitted from all analyses.

For each sampling event, flow data are summarized as total volume and minimum, maximum, mean and median flow (Table 7). This table also includes a column reporting the percentage of the sampling duration for which flows were recorded. Flow in the pipe before the first or after the last sample aliquot was collected by the autosampler are not included in the flow volumes. Aliquots were only collected according to measured (or

recorded) flow, not during periods missing flow data, so the flow data presented below is representative of the condition under which the flow-paced sampling actually occurred. Flow was measured in MGD but was converted to L/hr.

Table 7. Summary of Flow Conditions for Each Sampling Event.

Location	Flow	Sample Start Date/Time	Sample End Date/Time	Total Volume Estimate (L)	Timespan (days)	% of Flows Recorded during Sampling Period	Flow (L/hr)			
							Min	Max	Mean	Median
Utah	Dry Base	9/13/11 8:51	9/14/11 9:16	9,377	1.02	92%	158[b]	4,889	384	315
		9/14/11 9:25	9/15/11 5:05	17,138	0.82	85%	158[b]	6,309	871	473
		9/28/11 14:33	9/29/11 14:27	13,303	1.00	54%	158[b]	2,681	557	315
		10/17/11 10:47	10/18/11 10:35	20,491	0.99	47%	158[b]	2,839	861	789
		10/18/11 10:47	10/19/11 1:12	16,369	0.60	82%	158[b]	5,520	1,135	946
		10/19/11 10:55	10/20/11 8:15	16,809	0.89	88%	[b]	4,101	788	473
		Utah - Dry base - Overall[a]		15,581	0.89	73%	158[b]	6,309	726	473
	Wet Base	4/9/12 10:31	4/10/12 9:32	37,265	0.96	97%	158[b]	7,571	1,619	1,420
		4/10/12 9:53	4/11/12 8:12	36,952	0.93	98%	158[b]	7,571	1,656	1,420
		4/23/12 9:11	4/23/12 22:02	27,080	0.54	100%	315	5,205	2,107	2,050
		5/7/12 9:00	5/8/12 9:00	19,601	1.00	86%	158[b]	8,675	817	473
		5/8/12 9:40	5/9/12 9:40	22,632	1.00	98%	158[b]	5,363	943	631
		Utah - Wet base - Overall[a]		28,706	0.88	95%	158[b]	8,675	1,369	946
	Storm	1/25/12 14:45	1/25/12 22:57	178,469	0.34	100%	473	163,877	21,765	2,366
		2/28/12 10:10	2/28/12 18:08	65,081	0.33	100%	315	161,038	8,169	1,735
		2/29/12 10:39	2/29/12 11:51	85,008	0.05	100%	54,888	90,692	70,840	69,399
		3/27/12 10:45	3/27/12 17:56	62,197	0.30	100%	315	154,098	8,659	3,785
		3/28/12 9:54	3/29/12 3:23	129,540	0.73	100%	631	106,938	7,409	3,470
		4/11/12 10:09	4/11/12 16:02	62,290	0.25	100%	631	55,046	10,588	2,997
		4/24/12 9:16	4/25/12 0:32	57,722	0.64	96%	158[b]	35,804	3,781	1,735
		4/25/12 9:14	4/25/12 19:02	209,706	0.41	100%	315	238,954	21,399	4,968
		5/21/12 9:00	5/22/12 9:00	136,214	1.00	87%	315	95,739	5,676	2,524
		5/22/12 9:14	5/22/12 17:57	102,917	0.36	100%	1,104	69,557	11,807	5,836
		6/4/12 8:40	6/5/12 3:50	109,964	0.80	94%	158[b]	215,611	5,737	946
		6/5/12 9:31	6/5/12 12:42	132,334	0.13	100%	4,889	198,892	41,571	18,769
		6/6/12 9:53	6/7/12 6:33	181,287	0.86	89%	158[b]	156,779	8,772	789
		6/7/12 10:43	6/7/12 14:14	163,408	0.15	100%	2,839	222,235	46,467	25,078
		Utah - Storm - Overall[a]		119,724	0.45	96%	158[b]	238,954	112,88	2,681

Table 7, Continued

Location	Flow	Sample Start Date/Time	Sample End Date/Time	Total Volume Estimate (L)	Timespan (days)	% of Flows Recorded during Sampling Period	Flow (L/hr)			
							Min	Max	Mean	Median
East Marginal	Dry Base	9/13/11 10:36	9/14/11 12:14	135,160	1.07	100%	473[b]	26,498	5,273	4,101
		9/28/11 15:02	9/29/11 14:53	129,989	0.99	100%	631	20,347	5,450	4,732
		10/17/11 11:05	10/18/11 10:51	145,999	0.99	100%	631	42,113	6,143	3,943
		10/25/11 10:53	10/26/11 10:53	111,096	1.00	99%	473[b]	26,971	4,629	2,997
		11/1/11 8:48	11/2/11 9:00	92,250	1.01	100%	473[b]	23,028	3,812	1,735
		East Marginal - Dry base - Overall[a]		124,305	1.01	100%	473[b]	42,113	5,062	3,628
	Wet Base	4/9/12 11:01	4/10/12 10:00	139,444	0.96	98%	473[b]	27,286	6,067	4,022
		4/10/12 10:04	4/11/12 10:15	135,422	1.01	100%	631	26,498	5,600	3,864
		4/23/12 9:25	4/24/12 3:40	102,932	0.76	100%	631	23,343	5,640	3,943
		5/7/12 9:15	5/7/12 20:06	81,085	0.45	100%	1,420	24,132	7,473	6,782
		5/8/12 10:10	5/9/12 8:16	124,425	0.92	100%	631	29,021	5,630	3,470
		East Marginal - Wet base - Overall[a]		116,662	0.82	100%	473[b]	29,021	5,930	4,101
	Storm	1/25/12 15:08	1/25/12 23:06	288,071	0.33	86%	1,420	137,537	36,160	19,085
		2/28/12 10:30	2/28/12 19:50	279,869	0.39	100%	1,104	174,760	29,986	11,041
		2/29/12 10:50	3/1/12 8:40	302,990	0.91	99%	631	93,058	13,877	3,470
		3/27/12 11:00	3/27/12 19:16	297,346	0.34	100%	946	197,157	35,969	7,571
		4/11/12 10:24	4/11/12 18:24	203,541	0.33	100%	789	88,169	25,443	19,085
		4/25/12 9:28	4/25/12 22:56	759,382	0.56	100%	946	370,970	56,390	30,520
		6/4/12 8:55	6/5/12 4:17	388,421	0.81	98%	473[b]	383,904	20,056	4,416
		6/7/12 10:52	6/8/12 10:34	595,546	0.99	85%	631	292,896	25,129	10,173
		East Marginal - Storm - Overall[a]		389,396	0.58	95%	473[b]	383,904	27,911	8,438

Table 7, Continued

Location	Flow	Sample Start Date/Time	Sample End Date/Time	Total Volume Estimate (L)	Timespan (days)	% of Flows Recorded during Sampling Period	Flow (L/hr)			
							Min	Max	Mean	Median
Brandon Regulator	Dry Base	9/14/11 9:31	9/15/11 10:01	152,213	1.02	100%	1,577[b]	96,213	6,213	3,155
		9/21/11 14:15	9/22/11 13:52	44,432	0.98	79%	1,577[b]	6,309	1,881	1,577
		10/17/11 10:45	10/18/11 10:15	570,389	0.98	100%	11,041	53,627	24,272	22,082
		10/18/11 10:35	10/19/11 10:15	560,451	0.99	100%	9,464	52,049	23,681	17,350
		10/19/11 10:45	10/20/11 10:15	576,021	0.98	100%	7,886	61,513	24,512	22,082
		Brandon Reg. - Dry base - Overall[a]		380,701	0.99	96%	1,577[b]	96,213	16,655	12,618
	Wet Base	3/26/12 10:24	3/26/12 18:46	577,580	0.35	69%	23,659	93,058	69,033	72,554
		4/9/12 9:38	4/10/12 9:30	293,413	0.99	63%	3,155	39,431	12,294	11,041
		4/10/12 9:40	4/11/12 9:40	299,321	1.00	67%	4,732	29,968	12,472	9,464
		4/23/12 8:52	4/24/12 6:26	239,483	0.90	58%	1,577[b]	23,659	11,104	11,041
		5/8/12 14:28	5/9/12 14:28	234,007	1.00	57%	1,577[b]	26,813	9,750	7,886
		6/20/12 14:33	6/21/12 14:11	324,985	0.98	61%	4,732	26,813	13,751	11,041
		Brandon Reg. - Wet base - Overall[a]		328,131	0.87	62%	1,577[b]	93,058	16,167	11,041
	Storm	1/25/12 14:15	1/25/12 23:17	707,778	0.38	65%	11,041	441,631	78,352	34,700
		2/28/12 9:50	2/28/12 22:05	599,913	0.51	41%	14,195	171,921	48,972	23,659
		2/29/12 10:12	2/29/12 12:26	564,584	0.09	67%	178,230	283,906	252,799	257,092
		3/27/12 10:29	3/28/12 1:35	2,368,317	0.63	55%	50,472	531,535	156,842	82,017
		3/28/12 9:35	3/29/12 7:00	2,648,471	0.89	67%	25,236	749,196	123,664	50,472
		4/11/12 9:54	4/12/12 5:00	602,300	0.80	62%	3,155	187,693	31,534	15,773
		4/24/12 9:02	4/25/12 2:10	637,801	0.71	60%	4,732	298,101	37,226	18,927
		4/25/12 8:59	4/26/12 0:00	2,489,441	0.63	58%	11,041	973,166	165,779	88,326
		5/21/12 8:41	5/21/12 17:52	2,988,801	0.38	50%	52,049	613,552	325,459	318,605
		6/4/12 8:05	6/5/12 5:12	1,358,137	0.88	66%	1,577[b]	940,043	64,316	9,464
		6/5/12 9:05	6/5/12 16:17	1,627,095	0.30	42%	74,131	416,395	225,985	214,507
		6/6/12 9:34	6/7/12 9:34	1,682,847	1.00	59%	1,577[b]	1.04×10^6	70,119	14,195
		6/7/12 11:02	6/8/12 10:00	1,507,870	0.96	48%	1,577[b]	520,494	65,655	15,773
		6/18/12 8:23	6/18/12 13:03	974,349	0.19	43%	88,326	454,249	208,789	201,100
		Brandon Reg. - Storm - Overall[a]		1,482,693	0.60	57%	1,577[b]	1.04×10^6	100,888	26,025

[a] Overall summaries include mean total volume, mean timespan, and minimum, maximum, mean and median flow across all sampling periods.
[b] These flow values represent the lowest measurement possible due to the precision of the flow meters at each location.
* Flow was reported to 1/1000th of an MGD at Utah and East Marginal and to 1/10,000th of an MGD at Brandon Regulator because of the specific flow meters and pipe sizes at each location. Flows and volumes presented in this table have been converted to L and L/hr from MGD without regard to significant figures, because this is an intermediary step to calculating loading rates.
L= liters

Figures 3 through 5 show the distribution of flow during each sampling event at the three locations, illustrating the variety of storms sampled. Figure 6 shows the distribution of the average flow for each sampling event by location and flow condition. This illustrates the extent to which flows during dry and wet baseflow conditions were lower than stormflow events. In addition, stormflow was much lower in the two lateral lines, Utah and East Marginal, when compared to Brandon Regulator, which includes flow from the entire Brandon Basin. Dry and wet baseflows were less variable than stormflow and flow was least variable at Utah and most variable at Brandon Regulator. Differences between dry and wet baseflow and their influence on loadings are further discussed in Section 7.1.

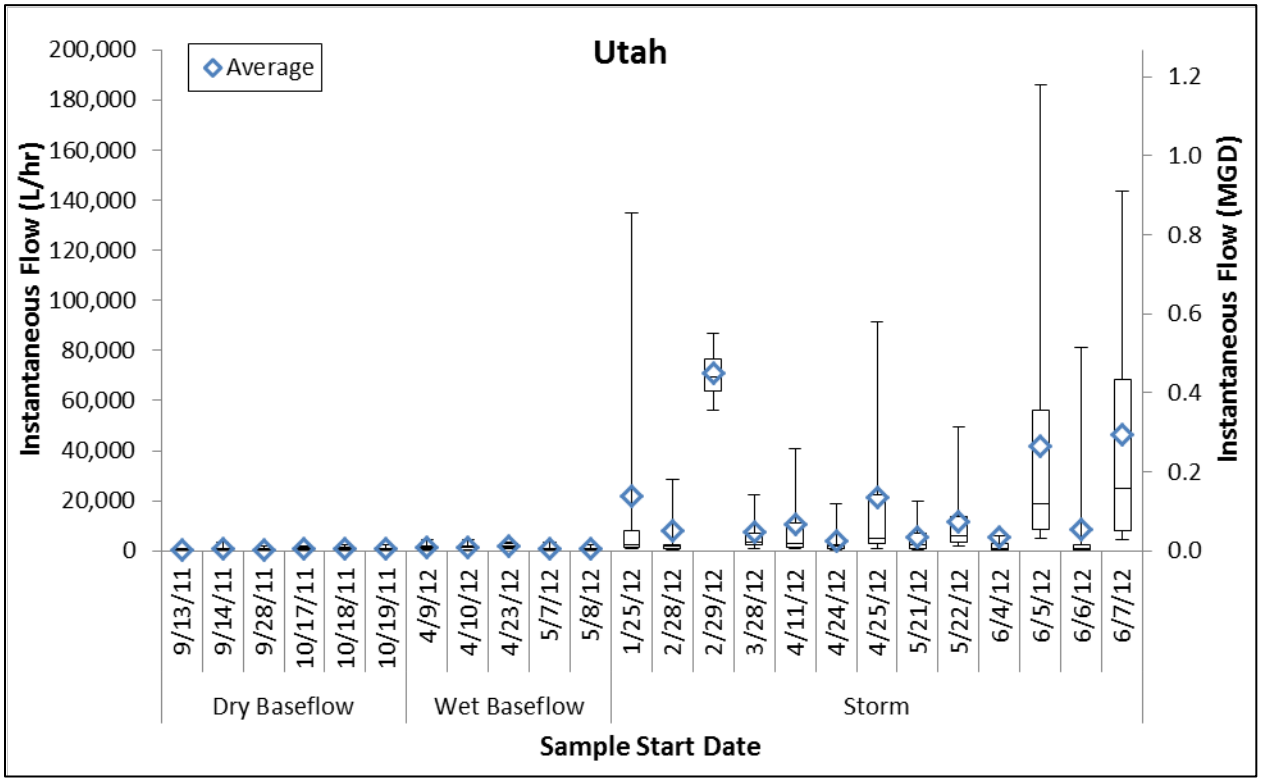

Figure 3. Flow Distribution during Each Sampling Event at Utah.

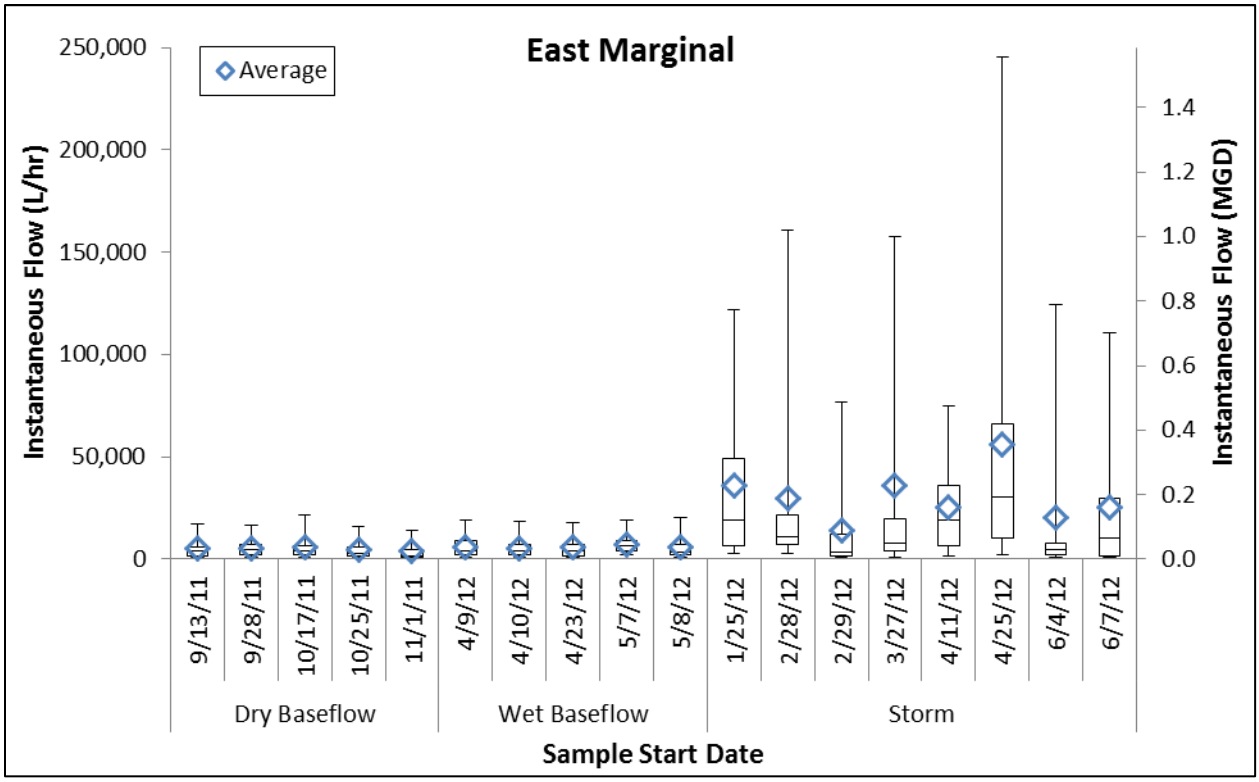

Figure 4. Flow Distribution during Each Sampling Event at East Marginal.

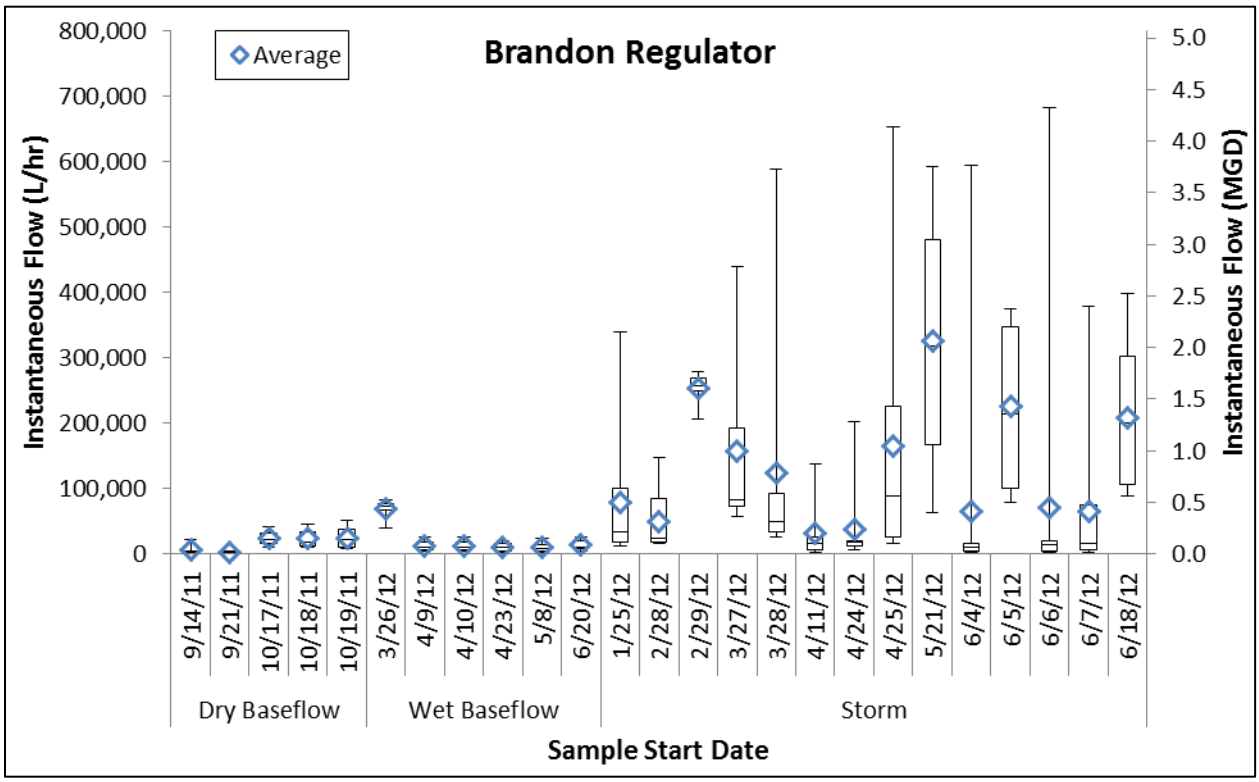

Figure 5. Flow Distribution during Each Sampling Event at Brandon Regulator.

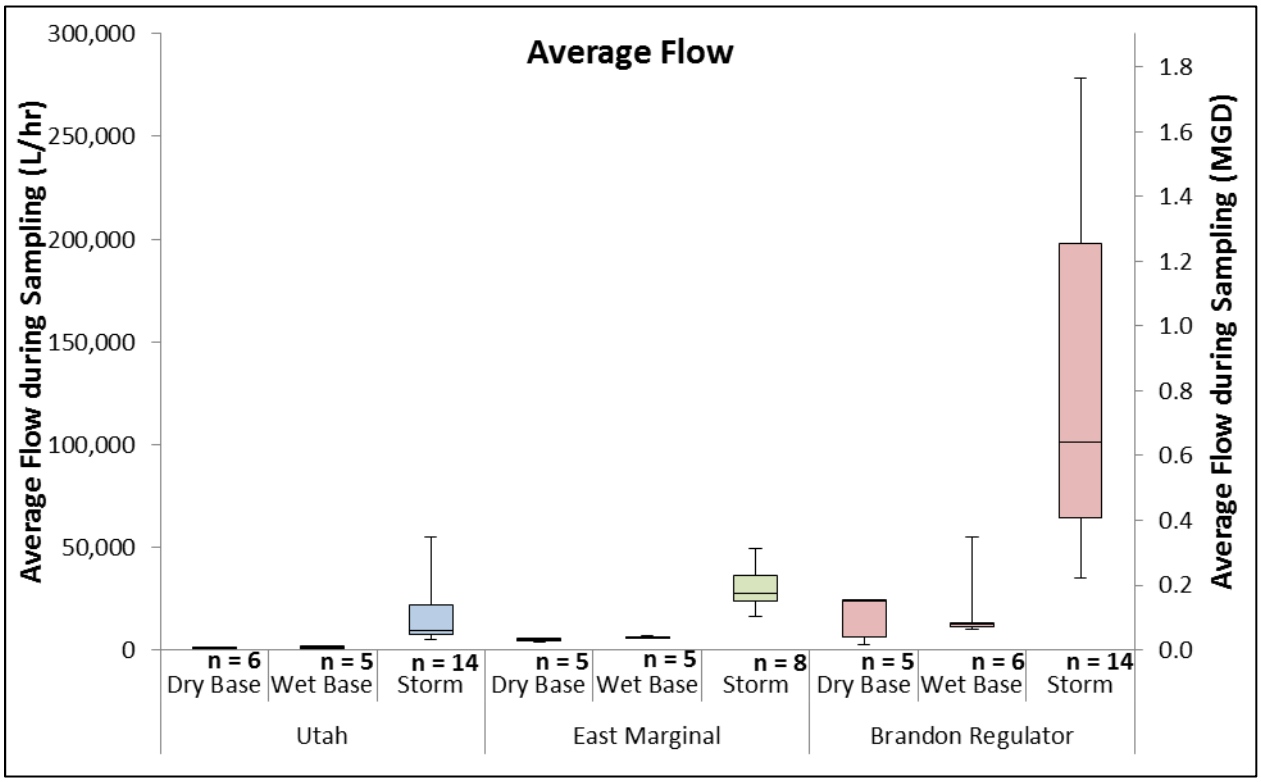

Figure 6. Brandon Basin Flows for Sampled Events

In addition to rainfall, flows throughout the combined system are influenced by permitted dischargers. Business activity and maintenance can measurably increase flow in the sanitary system. For example, during the March 26, 2012 wet baseflow sampling event at Brandon Regulator, mean flows were over five times higher than the next highest wet baseflow sample mean and higher than the mean flow during 40% of stormflow samples at this site (no measurable rainfall occurred during this time period). While the specific source of elevated flow during this particular sampling event was not identified, flow rates were not outside those measured during baseflow conditions that have been attributed to business and industrial activity[10]. A similar event occurred three days prior to this sampling event, and was associated with a permitted discharge. Resulting elevated flows can be seen in Appendix B (Figure B-40).

5.3 Conventionals

Flow condition and conventional parameter data for each sampling location are summarized in Table 8 and in Figures 7 through 9. For all conventional parameters

[10] Flow rates during this sampling event were within the range of flow conditions observed on days with no rainfall at any rainfall gauge and when the WTD Industrial Waste Section has notifications of additional inputs from permitted contributors.

analyzed (TOC, DOC and TSS), the minimum and lowest median concentrations occurred at Utah, mostly during stormflow events. The maximum and highest median concentrations for all conventional parameters occurred at East Marginal during dry or wet baseflow sampling. TOC and DOC had similar concentration ranges across all sample types; 17.0 mg/L to 1,230 mg/L for TOC and 7.05 mg/L to 1,130 mg/L for DOC. TSS concentrations ranged from 72.0 mg/L to 1,350 mg/L across all sample types. Concentrations for all three conventional parameters at East Marginal were most variable and of highest magnitude.

Table 8. Summary Statistics for Conventional Parameters by Location and Flow Condition.

Analyte	Location	Flow Condition	FOD	Concentration (mg/L)									
				Min Detected		Max Detected		Mean		Median	
Total Organic Carbon	Utah	Dry Base	6/6	69.1		159	J	130	J	140	J
		Wet Base	5/5	108		154		136		142	
		Storm	14/14	17.0		171		73		52.9	
	East Marginal	Dry Base	5/5	513	J	1,070		834	J	938	J
		Wet Base	5/5	239		1,230		695		819	
		Storm	8/8	68.2		759		424		419	
	Brandon Regulator	Dry Base	5/5	192		463	J	294	J	278	
		Wet Base	6/6	172		436		323		324	
		Storm	14/14	47.9		310		137		104	
Dissolved Organic Carbon	Utah	Dry Base	6/6	64.0		102	J	86.1	J	89.6	J
		Wet Base	5/5	62.6		95.0		80.1		85.2	
		Storm	14/14	7.05		53.9		26.8		19.4	
	East Marginal	Dry Base	5/5	157	J	916		657	J	737	J
		Wet Base	5/5	180		1,130		510		343	
		Storm	8/8	10.3		625		289		257	
	Brandon Regulator	Dry Base	5/5	170		322	J	230	J	226	J
		Wet Base	6/6	73.0		283		219		237	
		Storm	14/14	16.3		211		75.5		59.3	
Total Suspended Solids	Utah	Dry Base	6/6	158		605		343		282	
		Wet Base	5/5	76.0		138		114		125	
		Storm	14/14	72.0		696		252		168	
	East Marginal	Dry Base	5/5	240		1,350		698		468	
		Wet Base	5/5	188		1,130		556		456	
		Storm	8/8	102		760		414		371	
	Brandon Regulator	Dry Base	5/5	152		544		300		292	
		Wet Base	6/6	212		422		304		295	
		Storm	14/14	110		808		320		251	

FOD = frequency of detection; J = estimated value

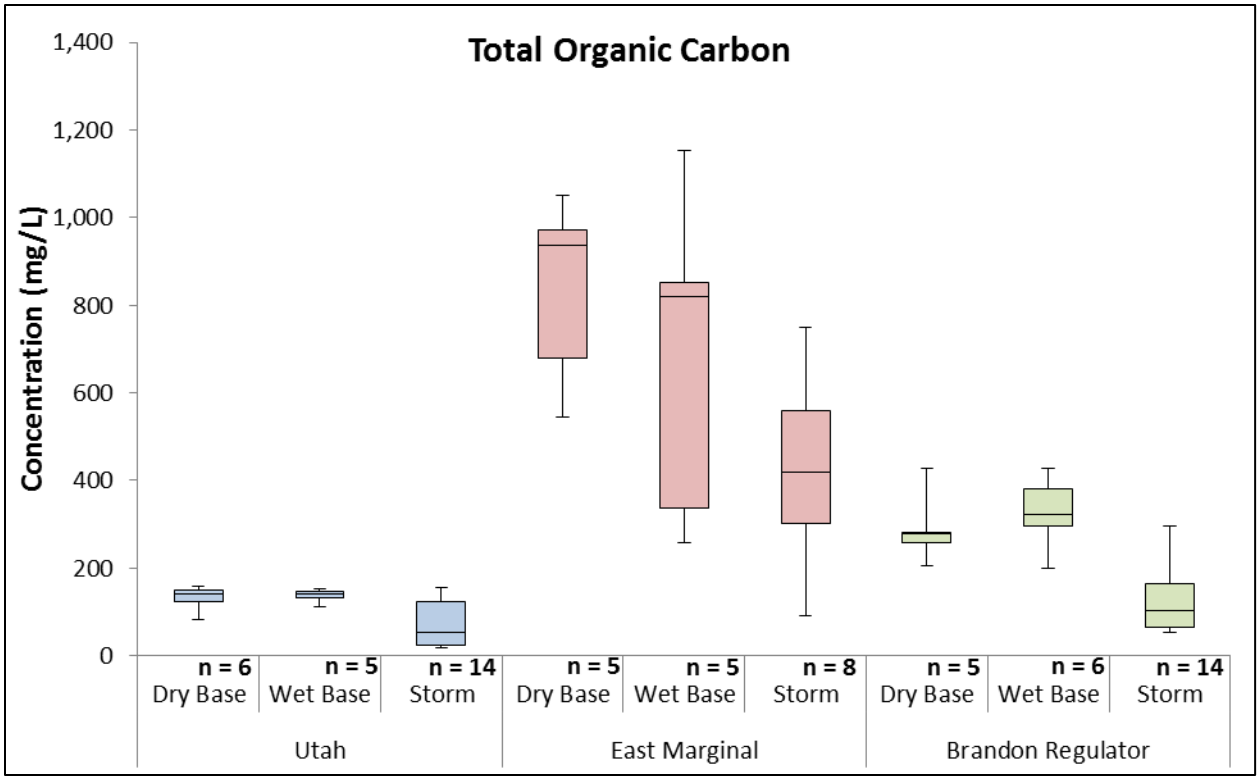

Figure 7. Boxplots of Total Organic Carbon Concentration by Location and Flow Condition.

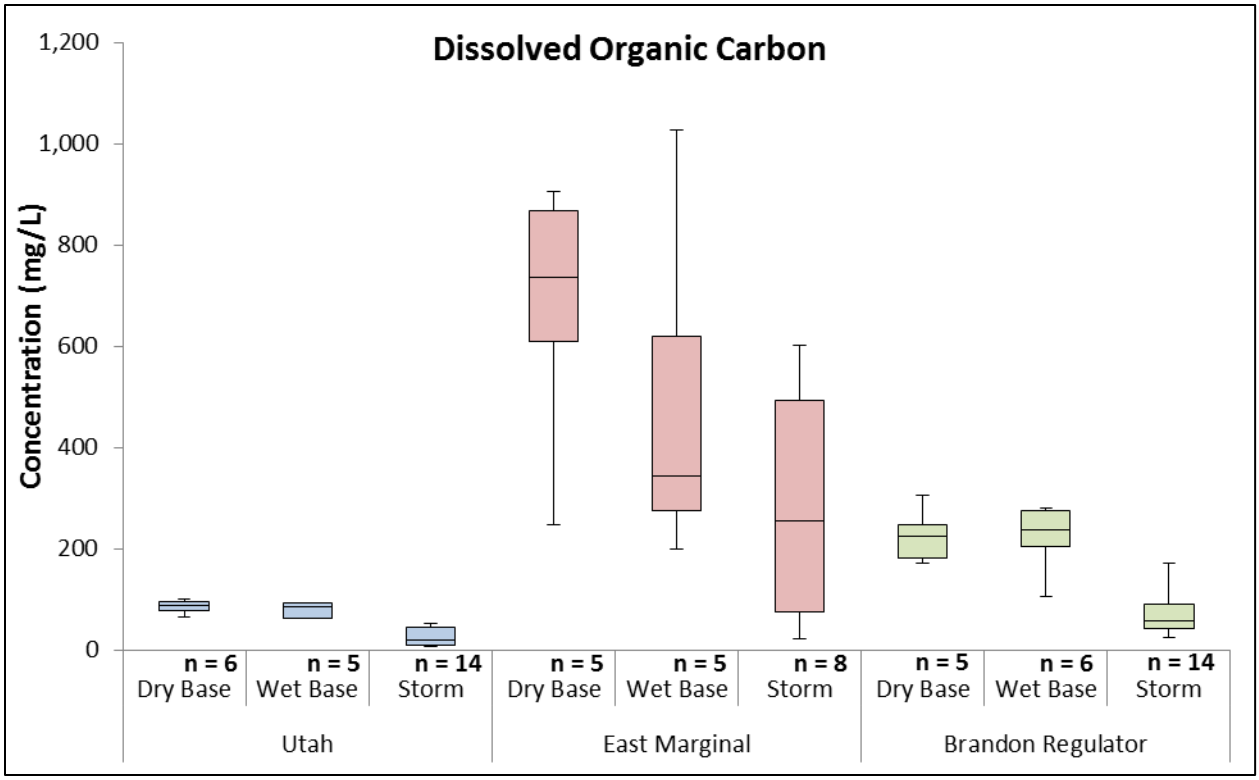

Figure 8. Boxplots of Dissolved Organic Carbon Concentration by Location and Flow Condition.

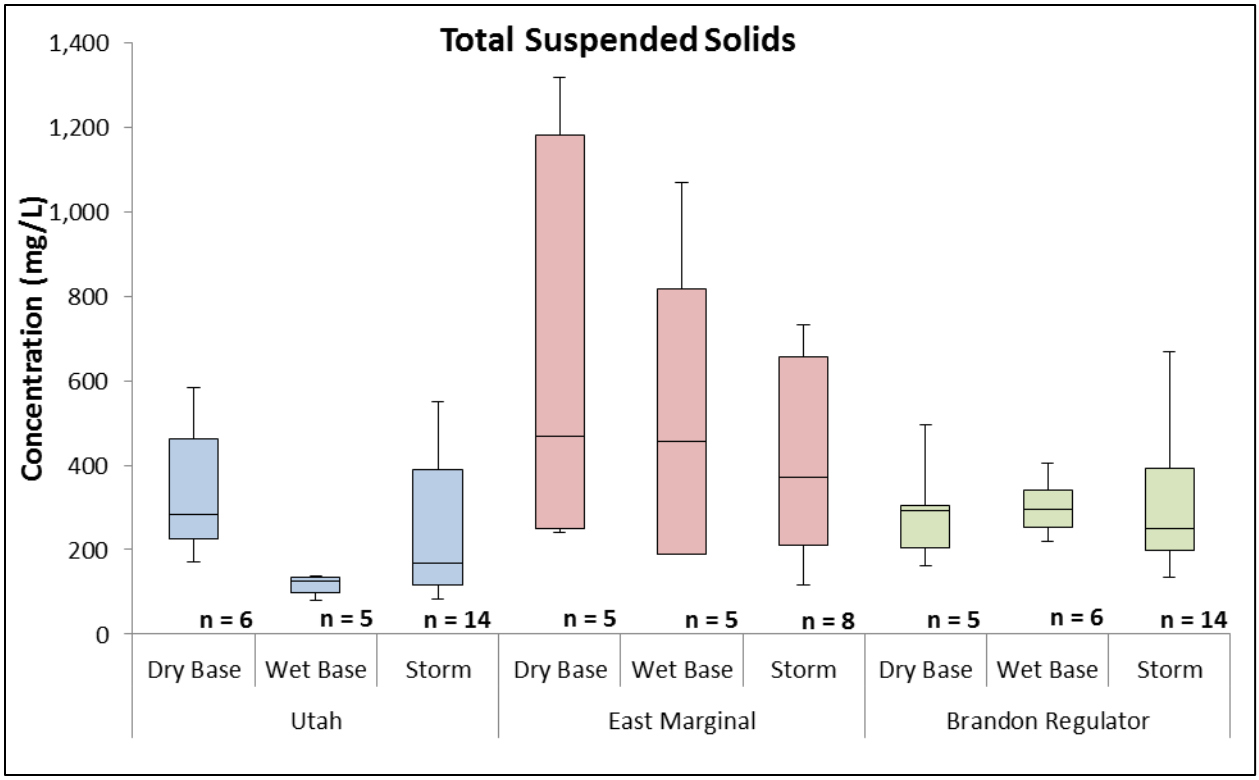

Figure 9. Boxplots of Total Suspended Solids Concentration by Location and Flow Condition.

5.4 Metals

Total and dissolved metals data for each sampling location and flow condition are summarized in Table 9. With the exception of dissolved cadmium and silver, all metals were detected at all locations for all sampling events. For five out of nine total metals, minimum concentrations were detected at Utah during wet baseflow sampling. For seven out of the nine dissolved metals, minimum concentrations were also detected at Utah, with most occurring during stormflow sampling. For five out of nine total metals, maximum concentrations were detected at Brandon Regulator during either wet baseflow or stormflow sampling. For eight of the nine dissolved metals maximum concentrations were also detected at Brandon Regulator with seven of these occurring during wet baseflow sampling.

Table 9. Summary Statistics for Metals Concentrations by Location and Flow Condition.

Analyte	Location	Flow Condition	FOD	Concentration (µg/L)										
				Min Detected		Max Detected		Mean		Median[a]		MDL
Total Arsenic	Utah	Dry Base	6/6	1.06		2.07		1.42		1.28		0.10
		Wet Base	5/5	0.806		1.41		1.01		0.883		0.10
		Storm	14/14	1.16		2.18		1.62		1.68		0.10
	East Marginal	Dry Base	5/5	1.51		3.52		2.59		2.88		0.10
		Wet Base	5/5	1.24		2.05		1.66		1.73		0.10
		Storm	8/8	1.29		9.92		2.88		1.90		0.10
	Brandon Regulator	Dry Base	5/5	1.13		2.41		1.93		2.02		0.10
		Wet Base	6/6	1.63		121		22.5		3.05		0.10
		Storm	14/14	1.60		6.02		2.78		2.22		0.10
Dissolved Arsenic	Utah	Dry Base	6/6	0.846	J	1.12	J	0.951	J	0.914	J	0.10
		Wet Base	5/5	0.800	J	1.00	J	0.892	J	0.896	J	0.10
		Storm	14/14	0.590	J	1.19	J	0.826	J	0.800	J	0.10
	East Marginal	Dry Base	4/4	1.04	J	1.38	J	1.21	J	1.21	J	0.10
		Wet Base	4/4	1.07	J	1.43	J	1.21	J	1.16	J	0.10
		Storm	7/7	0.659	J	8.62	J	2.12	J	1.13	J	0.10
	Brandon Regulator	Dry Base	4/4	0.951	J	1.58	J	1.35	J	1.43	J	0.10
		Wet Base	6/6	1.19	J	125	J	22.3	J	1.95	J	0.10
		Storm	13/13	0.879	J	3.35	J	1.44	J	1.06	J	0.10
Total Cadmium	Utah	Dry Base	6/6	0.18	J	0.700		0.401		0.300		0.050
		Wet Base	5/5	0.12	J	0.18	J	0.16	J	0.17	J	0.050
		Storm	14/14	0.23	J	0.722		0.404		0.379		0.050
	East Marginal	Dry Base	4/5	0.16	J	0.991		0.479		0.200		0.050
		Wet Base	5/5	0.20	J	0.562		0.346		0.325		0.050
		Storm	8/8	0.268		1.63		0.633		0.414		0.050
	Brandon Regulator	Dry Base	5/5	0.299		0.609		0.451		0.442		0.050
		Wet Base	6/6	0.325		1.90		0.726		0.531		0.050
		Storm	14/14	0.255		1.36		0.600		0.499		0.050
Dissolved Cadmium	Utah	Dry Base	3/6	0.058	J	0.080	J	0.069	J	NC		0.050
		Wet Base	4/5	0.053	J	0.080	J	0.068	J	0.065	J	0.050
		Storm	10/14	0.051	J	0.10	J	0.078	J	0.062	J	0.050
	East Marginal	Dry Base	0/4	NC		NC		NC		NC		0.050
		Wet Base	1/4	NC		0.067	J	NC		NC		0.050
		Storm	5/7	0.051	J	0.426	J	0.143	J	0.055	J	0.050
	Brandon Regulator	Dry Base	4/4	0.084	J	0.25	J	0.13	J	0.096	J	0.050
		Wet Base	6/6	0.069	J	0.743	J	0.22	J	0.14	J	0.050
		Storm	9/13	0.059	J	0.375	J	0.12	J	0.067	J	0.050

Table 9, Continued

Analyte	Location	Flow Condition	FOD	Concentration (µg/L)										
				Min Detected		Max Detected		Mean		Median[a]		MDL
Total Chromium	Utah	Dry Base	6/6	1.58		11.4		4.53		2.85		0.20
		Wet Base	5/5	0.94	J	6.14		2.25		1.30		0.20
		Storm	14/14	3.52		15.7		7.40		7.57		0.20
	East Marginal	Dry Base	5/5	1.71		10.0		5.21		2.78		0.20
		Wet Base	5/5	4.48		7.94		6.97		7.59		0.20
		Storm	8/8	3.64		8.76		6.46		6.33		0.20
	Brandon Regulator	Dry Base	5/5	6.17		21.1		11.1		9.95		0.20
		Wet Base	6/6	4.51		221		42.7		7.74		0.20
		Storm	14/14	6.04		24.6		11.8		9.91		0.20
Dissolved Chromium	Utah	Dry Base	6/6	0.39	J	0.57	J	0.47	J	0.47	J	0.20
		Wet Base	5/5	0.35	J	4.09	J	1.23	J	0.51	J	0.20
		Storm	14/14	0.42	J	1.25	J	0.68	J	0.64	J	0.20
	East Marginal	Dry Base	4/4	0.74	J	0.94	J	0.87	J	0.89	J	0.20
		Wet Base	4/4	2.01	J	4.70	J	2.96	J	2.56	J	0.20
		Storm	7/7	0.64	J	1.35	J	0.98	J	0.93	J	0.20
	Brandon Regulator	Dry Base	4/4	2.27	J	2.62	J	2.46	J	2.47	J	0.20
		Wet Base	6/6	1.63	J	177	J	31.0	J	1.76	J	0.20
		Storm	13/13	0.77	J	2.26	J	1.35	J	1.27	J	0.20
Total Copper	Utah	Dry Base	6/6	33.6		131		70.1		64.6		0.40
		Wet Base	5/5	24.0		37.0		29.9		30.2		0.40
		Storm	14/14	24.8		92.2		51.0		43.2		0.40
	East Marginal	Dry Base	5/5	4.06		162		70.3		39.9		0.40
		Wet Base	5/5	41.6		93.9		64.6		65.4		0.40
		Storm	8/8	27.5		79.0		50.6		47.8		0.40
	Brandon Regulator	Dry Base	5/5	44.0		122		71.9		63.4		0.40
		Wet Base	6/6	58.2		83.6		69.8		68.3		0.40
		Storm	14/14	37.2		223		77.1		65.7		0.40
Dissolved Copper	Utah	Dry Base	6/6	11.2	J	20.7	J	15.8	J	15.8	J	0.40
		Wet Base	5/5	7.87	J	17.5	J	14.4	J	15.3	J	0.40
		Storm	14/14	6.28	J	14.3	J	10.9	J	11.5	J	0.40
	East Marginal	Dry Base	4/4	10.7	J	12.7	J	11.4	J	11.1	J	0.40
		Wet Base	4/4	9.77	J	23.5	J	16.5	J	16.3	J	0.40
		Storm	7/7	8.61	J	18.7	J	13.9	J	14.9	J	0.40
	Brandon Regulator	Dry Base	4/4	18.0	J	23.3	J	21.1	J	21.5	J	0.40
		Wet Base	6/6	7.64	J	31.7	J	21.8	J	20.5	J	0.40
		Storm	13/13	8.85	J	29.1	J	16.2	J	15.9	J	0.40
Total Lead	Utah	Dry Base	6/6	3.84		42.5		16.4		11.9		0.10
		Wet Base	5/5	3.88		8.10		5.81		5.91		0.10
		Storm	14/14	11.7		38.9		23.2		22.9		0.10
	East Marginal	Dry Base	5/5	1.22		41.8		19.0		11.5		0.10
		Wet Base	5/5	6.15		18.3		11.2		8.2		0.10
		Storm	8/8	13.1		31.3		19.5		19.5		0.10
	Brandon Regulator	Dry Base	5/5	2.90		14.6		10.9		12.8		0.10
		Wet Base	6/6	5.74		27.7		16.5		17.1		0.10
		Storm	14/14	9.54		66.1		26.2		21.0		0.10

Table 9, Continued

Analyte	Location	Flow Condition	FOD	Concentration (µg/L)										
				Min Detected		Max Detected		Mean		Median[a]		MDL
Dissolved Lead	Utah	Dry Base	6/6	0.839	J	1.81	J	1.36	J	1.40	J	0.10
		Wet Base	5/5	1.01	J	2.03	J	1.54	J	1.57	J	0.10
		Storm	14/14	0.42	J	2.53	J	1.02	J	0.999	J	0.10
	East Marginal	Dry Base	4/4	0.734	J	1.42	J	1.04	J	1.01	J	0.10
		Wet Base	4/4	1.24	J	1.89	J	1.55	J	1.54	J	0.10
		Storm	7/7	1.22	J	2.81	J	1.66	J	1.34	J	0.10
	Brandon Regulator	Dry Base	4/4	0.616	J	2.85	J	1.75	J	1.78	J	0.10
		Wet Base	6/6	0.604	J	4.81	J	2.48	J	2.16	J	0.10
		Storm	13/13	0.614	J	3.48	J	1.46	J	1.16	J	0.10
Total Nickel	Utah	Dry Base	6/6	3.46		13.1		6.97		5.58		0.10
		Wet Base	5/5	2.45		3.47		2.93		2.92		0.10
		Storm	14/14	4.16		15.6		8.34		8.65		0.10
	East Marginal	Dry Base	5/5	3.84		13.0		7.99		5.65		0.10
		Wet Base	5/5	3.96		8.24		6.09		6.28		0.10
		Storm	8/8	4.30		9.15		6.65		6.19		0.10
	Brandon Regulator	Dry Base	5/5	19.7		72.0		36.4		31.7		0.10
		Wet Base	6/6	21.4		768		156		36.8		0.10
		Storm	14/14	17.0		668		156		36.8		0.10
Dissolved Nickel	Utah	Dry Base	6/6	2.02	J	3.30	J	2.90	J	3.00	J	0.10
		Wet Base	5/5	1.81	J	2.99	J	2.34	J	2.24	J	0.10
		Storm	14/14	1.25	J	3.49	J	2.33	J	2.64	J	0.10
	East Marginal	Dry Base	4/4	3.50	J	5.24	J	4.28	J	4.20	J	0.10
		Wet Base	4/4	3.17	J	4.81	J	3.96	J	3.93	J	0.10
		Storm	7/7	1.86	J	4.23	J	2.82	J	2.97	J	0.10
	Brandon Regulator	Dry Base	4/4	17.3	J	27.9	J	22.2	J	21.9	J	0.10
		Wet Base	6/6	11.4	J	748	J	146	J	28.6	J	0.10
		Storm	13/13	6.74	J	553	J	65.6	J	14.1	J	0.10
Total Silver	Utah	Dry Base	6/6	0.059	J	1.86		0.511	J	0.309		0.040
		Wet Base	5/5	0.054	J	1.24		0.321	J	0.10	J	0.040
		Storm	14/14	0.061	J	2.51		0.484	J	0.230		0.040
	East Marginal	Dry Base	4/5	0.054	J	0.290		0.16	J	0.059	J	0.040
		Wet Base	5/5	0.054	J	0.19	J	0.10	J	0.077	J	0.040
		Storm	8/8	0.050	J	0.19	J	0.11	J	0.10	J	0.040
	Brandon Regulator	Dry Base	5/5	0.230		0.681		0.434		0.464		0.040
		Wet Base	6/6	0.19	J	0.629		0.395	J	0.378		0.040
		Storm	14/14	0.11	J	1.49		0.504	J	0.412		0.040
Dissolved Silver	Utah	Dry Base	1/6	NC		0.398	J	NC		NC		0.040
		Wet Base	1/5	NC		0.908	J	NC		NC		0.040
		Storm	5/14	0.052	J	0.665	J	0.224	J	NC		0.040
	East Marginal	Dry Base	0/4	NC		NC		NC		NC		0.040
		Wet Base	0/4	NC		NC		NC		NC		0.040
		Storm	0/7	NC		NC		NC		NC		0.040
	Brandon Regulator	Dry Base	2/4	0.075	J	0.081	J	0.078	J	NC		0.040
		Wet Base	3/6	0.057	J	0.16	J	0.094	J	NC		0.040
		Storm	3/13	0.080	J	0.212	J	0.15	J	NC		0.040

Table 9, Continued

Analyte	Location	Flow Condition	FOD	Concentration (µg/L)										
				Min Detected		Max Detected		Mean		Median[a]		MDL
Total Vanadium	Utah	Dry Base	6/6	1.87		6.02		3.49		2.99		0.075
		Wet Base	5/5	1.13		17.9		4.72		1.49		0.075
		Storm	14/14	4.43		9.84		6.69		6.88		0.075
	East Marginal	Dry Base	5/5	2.90		11.9		6.87		5.34		0.075
		Wet Base	5/5	2.58		6.82		4.28		3.81		0.075
		Storm	8/8	3.42		8.23		5.90		5.50		0.075
	Brandon Regulator	Dry Base	5/5	2.04		6.60		4.54		5.19		0.075
		Wet Base	6/6	2.43		14.9		5.44		3.79		0.075
		Storm	14/14	3.24		13.2		7.32		6.29		0.075
Dissolved Vanadium	Utah	Dry Base	6/6	0.807	J	1.81	J	1.33	J	1.28	J	0.075
		Wet Base	5/5	0.800	J	1.04	J	0.911	J	0.890	J	0.075
		Storm	14/14	0.743	J	1.54	J	1.27	J	1.35	J	0.075
	East Marginal	Dry Base	4/4	0.980	J	2.22	J	1.68	J	1.76	J	0.075
		Wet Base	4/4	1.24	J	1.41	J	1.31	J	1.29	J	0.075
		Storm	7/7	0.771	J	1.31	J	1.14	J	1.24	J	0.075
	Brandon Regulator	Dry Base	4/4	0.645	J	3.08	J	2.36	J	2.85	J	0.075
		Wet Base	6/6	0.886	J	5.71	J	2.36	J	1.76	J	0.075
		Storm	13/13	0.737	J	1.58	J	1.16	J	1.13	J	0.075
Total Zinc	Utah	Dry Base	6/6	80.1		302		170		147		0.50
		Wet Base	5/5	55.2		88.7		71.9		73.5		0.50
		Storm	14/14	95.8		277		185		165		0.50
	East Marginal	Dry Base	5/5	13.8		555		236		115		0.50
		Wet Base	5/5	122		503		230		161		0.50
		Storm	8/8	164		379		240		220		0.50
	Brandon Regulator	Dry Base	5/5	87.4		236		148		148		0.50
		Wet Base	6/6	132		207		163		163		0.50
		Storm	14/14	136		451		228		203		0.50
Dissolved Zinc	Utah	Dry Base	6/6	11.7	J	38.1	J	25.5	J	25.7	J	0.50
		Wet Base	5/5	20.4	J	48.3	J	34.0	J	33.4	J	0.50
		Storm	14/14	22.5	J	84.5	J	53.1	J	55.1	J	0.50
	East Marginal	Dry Base	4/4	36.5	J	52.6	J	43.4	J	42.2	J	0.50
		Wet Base	4/4	52.4	J	85.4	J	62.8	J	56.6	J	0.50
		Storm	7/7	52.9	J	164	J	87.2	J	76.4	J	0.50
	Brandon Regulator	Dry Base	4/4	31.9	J	53.7	J	41.6	J	40.4	J	0.50
		Wet Base	6/6	60.0	J	98.0	J	76.8	J	78.9	J	0.50
		Storm	13/13	40.2	J	114	J	65.0	J	61.4	J	0.50

[a] Medians include nondetects, using the MDL for non-detect events. Medians are only calculated when frequency of detection is greater than 50%.
FOD = Frequency of detection; J = estimated value; MDL = method detection limit; NC = not calculated.

The highest concentrations of total and dissolved arsenic, dissolved cadmium, total and dissolved chromium, and dissolved vanadium were detected at Brandon Regulator in samples collected on March 26, 2012 during wet baseflow (Appendix C). Arsenic and chromium concentrations detected in this sample were two orders of magnitude higher than in any other sample. The mean flow during this sampling event was more than five

times higher than the mean wet baseflow measured during any other sampling event at this site (Section 5.2). However, these flow conditions were still within the range of dry and wet baseflows that have been attributed to business and industrial activity. Additional discussion summarizing the individual metal results is provided below.

5.4.1 Arsenic

Total and dissolved arsenic were detected in all samples analyzed; data are summarized in Table 9 and Figures 10 and 11. Concentrations of total arsenic ranged from 0.806 µg/L to 121 µg/L and dissolved arsenic ranged from 0.590 µg/L to 125 µg/L across all sample types. Total and dissolved arsenic concentrations in one wet baseflow sample at Brandon Regulator were almost 30 times greater than the next highest wet baseflow concentration at this site. The dissolved arsenic concentration in this sample was almost 50 times greater than the next highest wet baseflow concentration at this site. Storm event concentrations at East Marginal and Brandon Regulator were also quite variable. The scatter plots in Figure 12 highlights the difference between total and dissolved arsenic concentrations in the one wet baseflow sample at Brandon Regulator compared to all other wet baseflow samples.

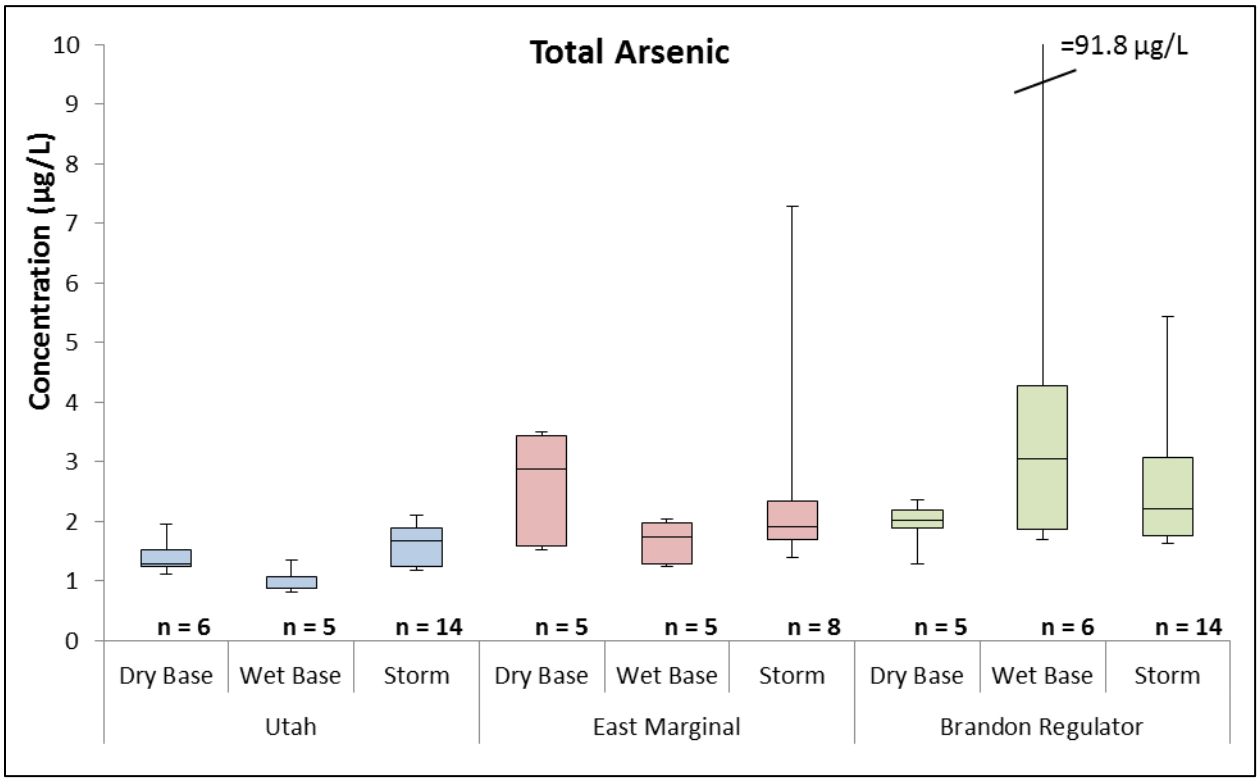

Figure 10. Boxplots of Total Arsenic Concentration by Location and Flow Condition.

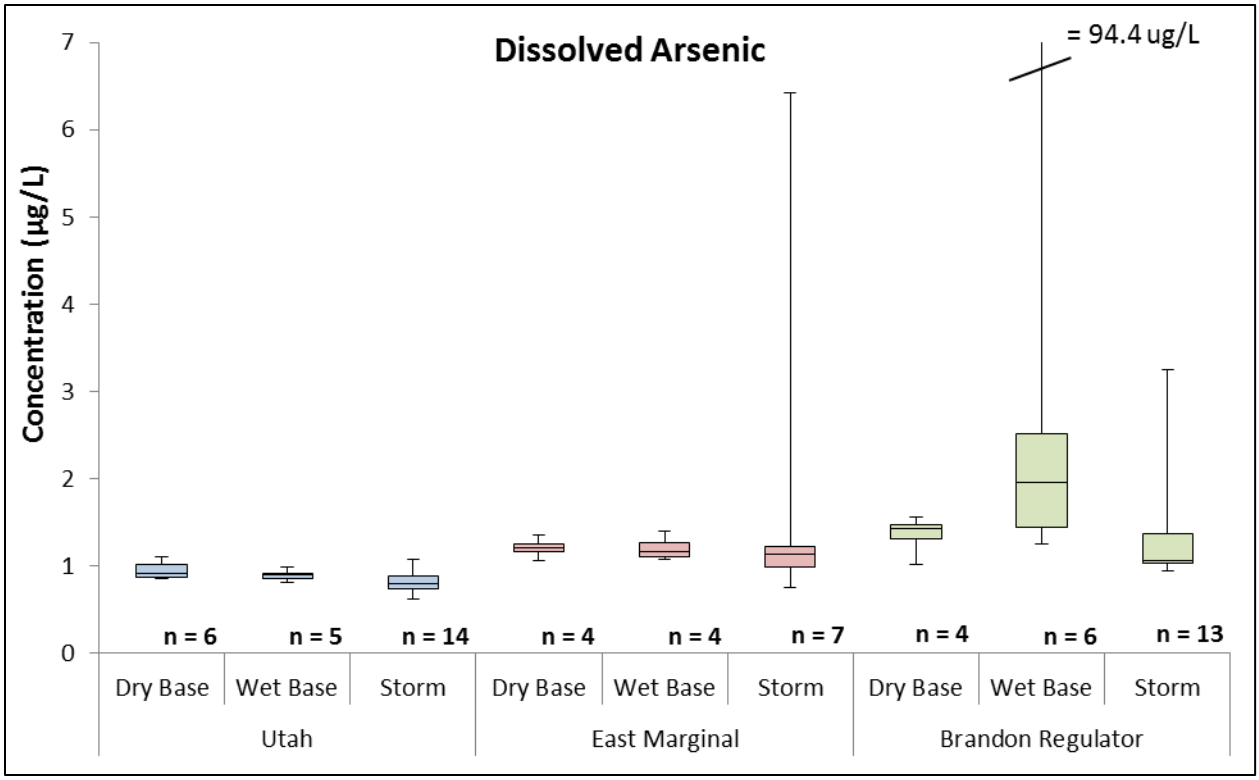

Figure 11. Boxplots of Dissolved Arsenic Concentration by Location and Flow Condition.

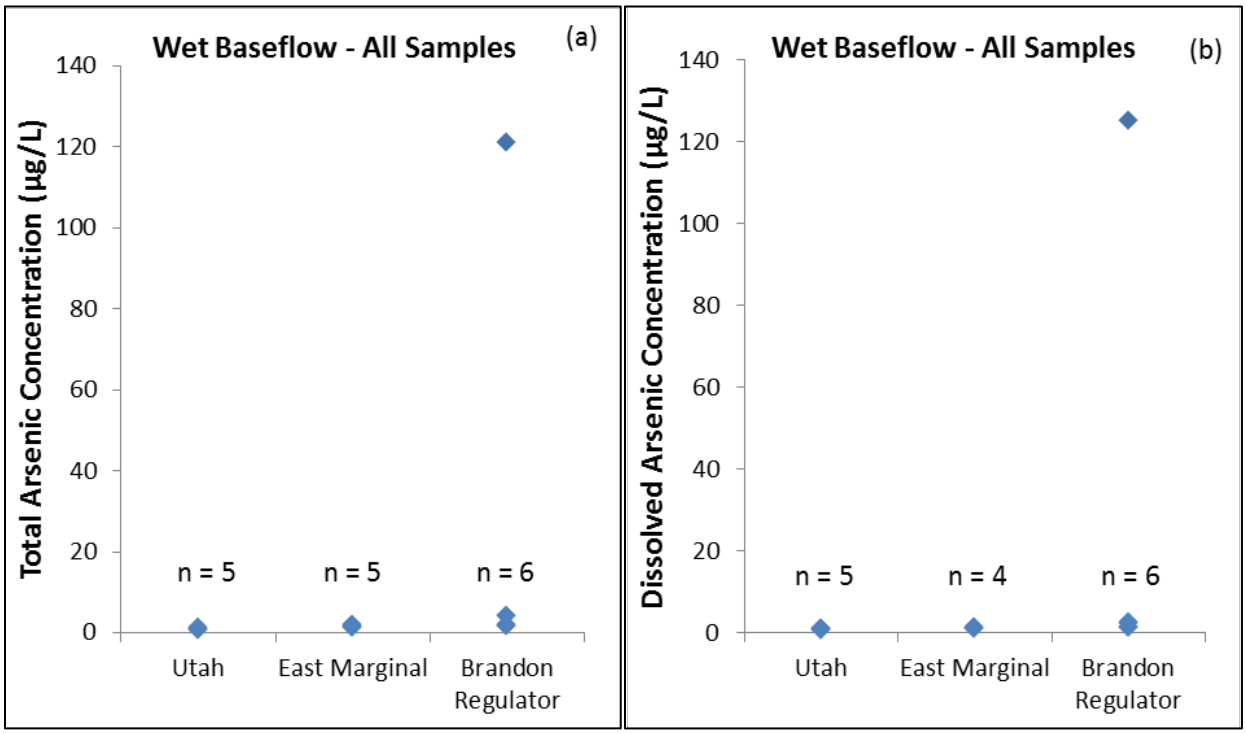

Figure 12. Scatter Plot of Wet Baseflow Arsenic Concentrations to Highlight Distribution of Results: (a) Total Arsenic; (b) Dissolved Arsenic.

5.4.2 Cadmium

Total cadmium was detected in all samples except one dry baseflow sample at East Marginal, although as mentioned in Section 2.3, these results may be biased high as indicated by field blank sample results from a previous study. All cadmium data are summarized in Table 9 and Figures 13 and 14. The FOD for dissolved cadmium was 68% across all samples. Detected concentrations of total and dissolved cadmium ranged from 0.12 µg/L to 1.90 µg/L and 0.051 µg/L to 0.743 µg/L, respectively, across all sample types. Where detected, the dissolved fraction comprised less than half the total cadmium. Total cadmium concentrations were similar across locations; wet baseflow concentrations at Utah were the least variable. Based on detected concentrations, dissolved cadmium at Utah was least variable across flow conditions.

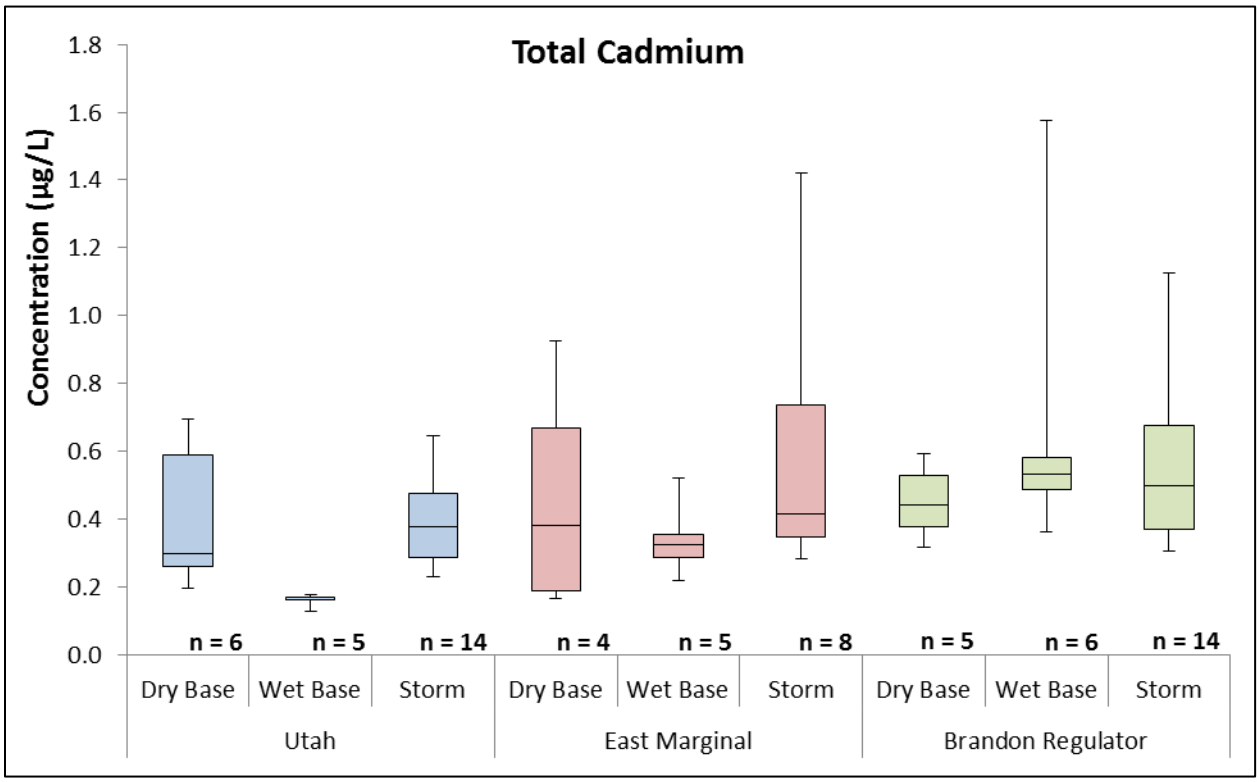

Figure 13. Boxplots of Total Cadmium Concentration by Location and Flow Condition.

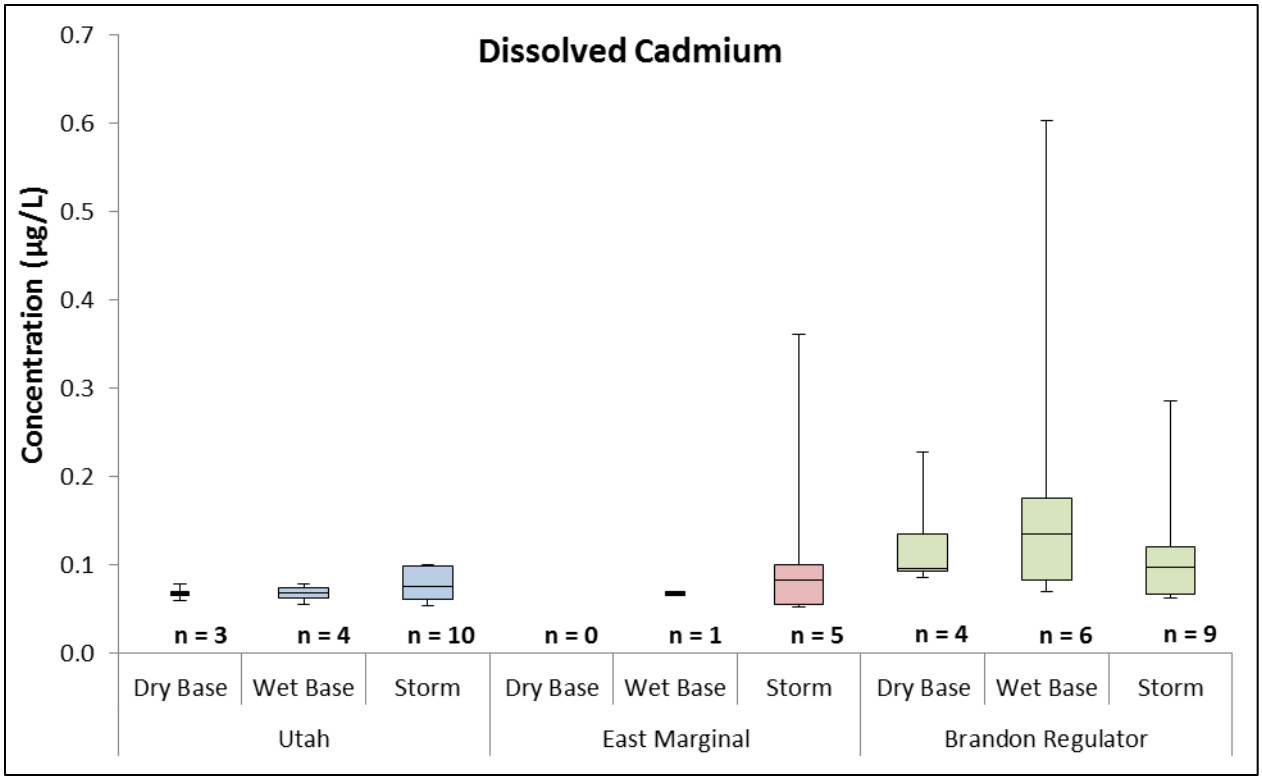

Figure 14. Boxplots of Dissolved Cadmium Concentration by Location and Flow Condition.

5.4.3 Chromium

Total and dissolved chromium were detected in all samples; data are summarized in Table 9 and Figures 15 and 16. Concentrations of total chromium ranged from 0.94 µg/L to 221 µg/L, while dissolved chromium ranged from 0.35 µg/L to 177 µg/L across all sample types. In general, the dissolved fraction comprised less than half the total chromium in all samples. The greatest variability in total chromium concentrations was observed at Brandon Regulator where one sample had concentrations more than 25% higher than any other wet baseflow sample at this site. The greatest variability in dissolved chromium concentrations were observed during wet baseflow conditions. Dissolved chromium concentrations in one Brandon Regulator wet baseflow sample were more than 85% higher than any other wet baseflow sample at this site. This sample also had the highest total and dissolved arsenic concentrations. Thus, it appears the unsampled branch of the basin (Figure 1) is potentially a substantial source of chromium to Brandon Regulator. The scatter plots in Figure 17 highlights the difference between total and dissolved chromium concentrations in the one wet baseflow sample at Brandon Regulator compared to all other wet baseflow samples.

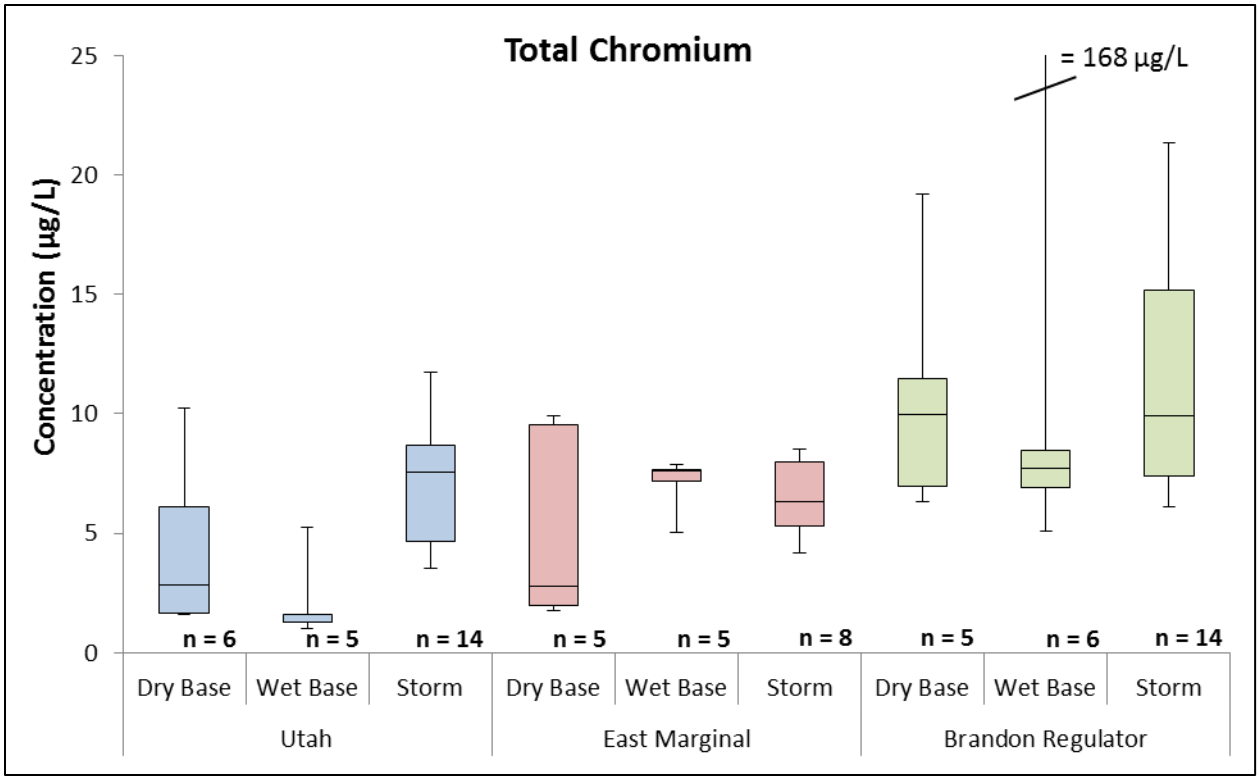

Figure 15. Boxplots of Total Chromium Concentration by Location and Flow Condition.

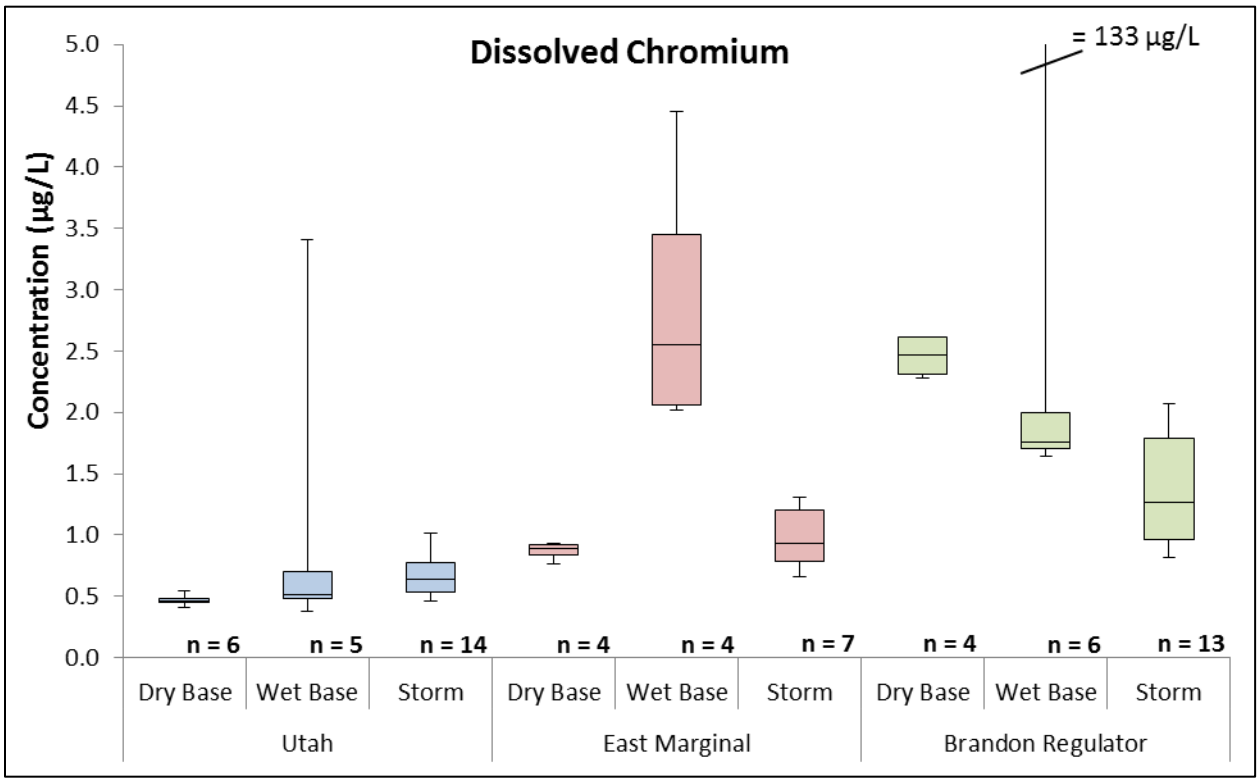

Figure 16. Boxplots of Dissolved Chromium Concentration by Location and Flow Condition.

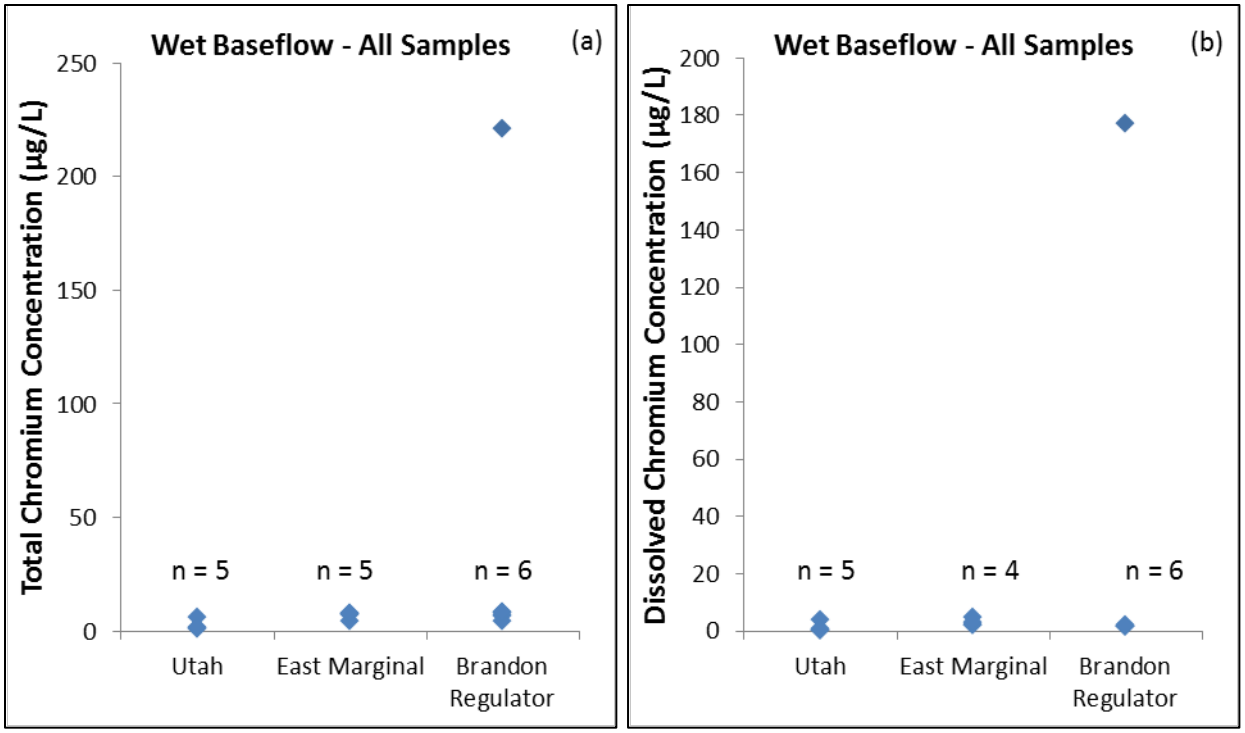

Figure 17. Scatter Plot of Wet Baseflow Chromium Concentrations to Highlight Distribution of Results: (a) Total Chromium; (b) Dissolved Chromium

5.4.4 Copper

Total and dissolved copper were detected in all samples; data are summarized in Table 9 and Figures 18 and 19. Total copper concentrations ranged from 24.0 µg/L to 223 µg/L and dissolved copper ranged from 6.28 µg/L to 31.7 µg/L across all sample types. In general, the dissolved fraction comprised less than half the total copper concentration. Concentrations of total copper during dry baseflow sampling at East Marginal were the most variable, while concentrations during wet baseflow sampling at Utah were the least variable. Concentrations of dissolved copper at Brandon Regulator during wet baseflow sampling had the widest range of concentrations, while concentrations during dry baseflow sampling at East Marginal exhibited the least variability.

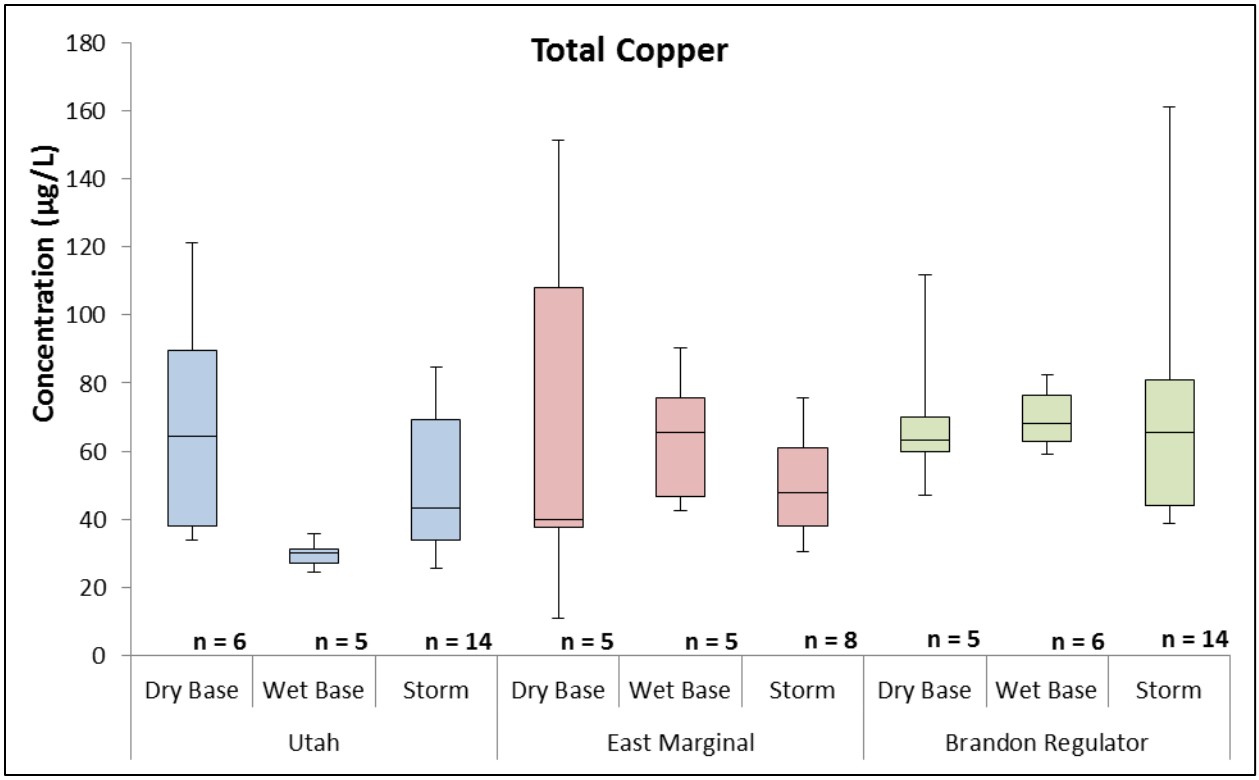

Figure 18. Boxplots of Total Copper Concentration by Location and Flow Condition.

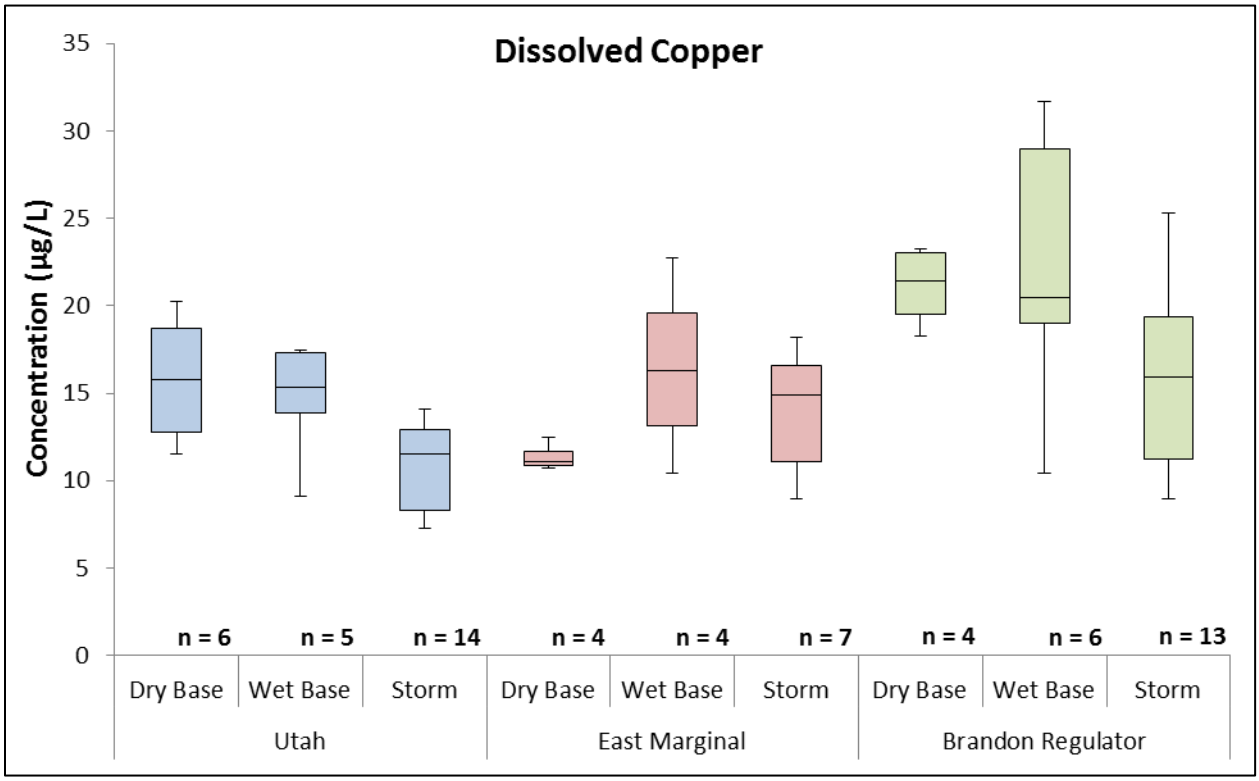

Figure 19. Boxplots of Dissolved Copper Concentration by Location and Flow Condition.

5.4.5 Lead

Total and dissolved lead were detected in all samples; concentrations ranged from 1.22 µg/L to 66.1 µg/L and 0.42 µg/L to 4.81 µg/L respectively across all sample types. Lead data are summarized in Table 9 and Figures 20 and 21. For all samples, the dissolved fraction comprised less than half the total lead concentration. Total lead concentrations were most variable at East Marginal during dry baseflow sampling and least variable at Utah during wet baseflow sampling. Dissolved lead concentrations were most variable at Brandon Regulator.

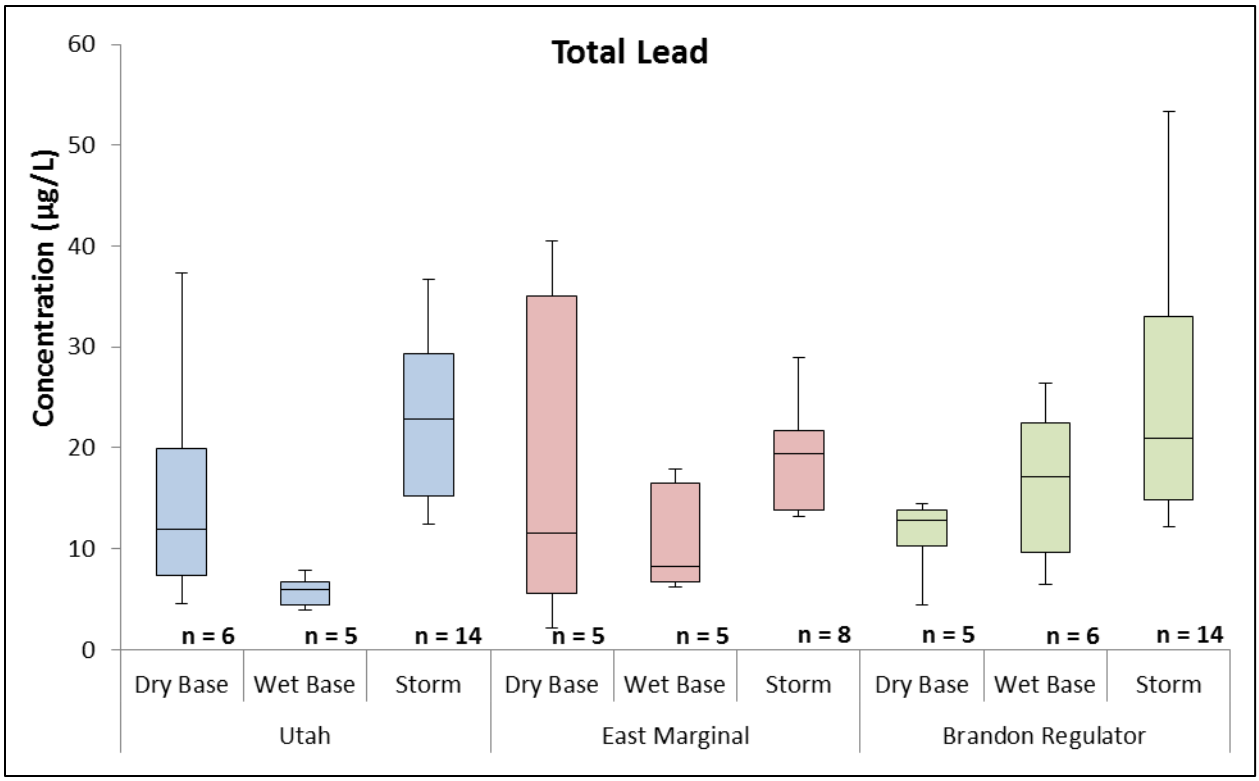

Figure 20. Boxplots of Total Lead Concentration by Location and Flow Condition.

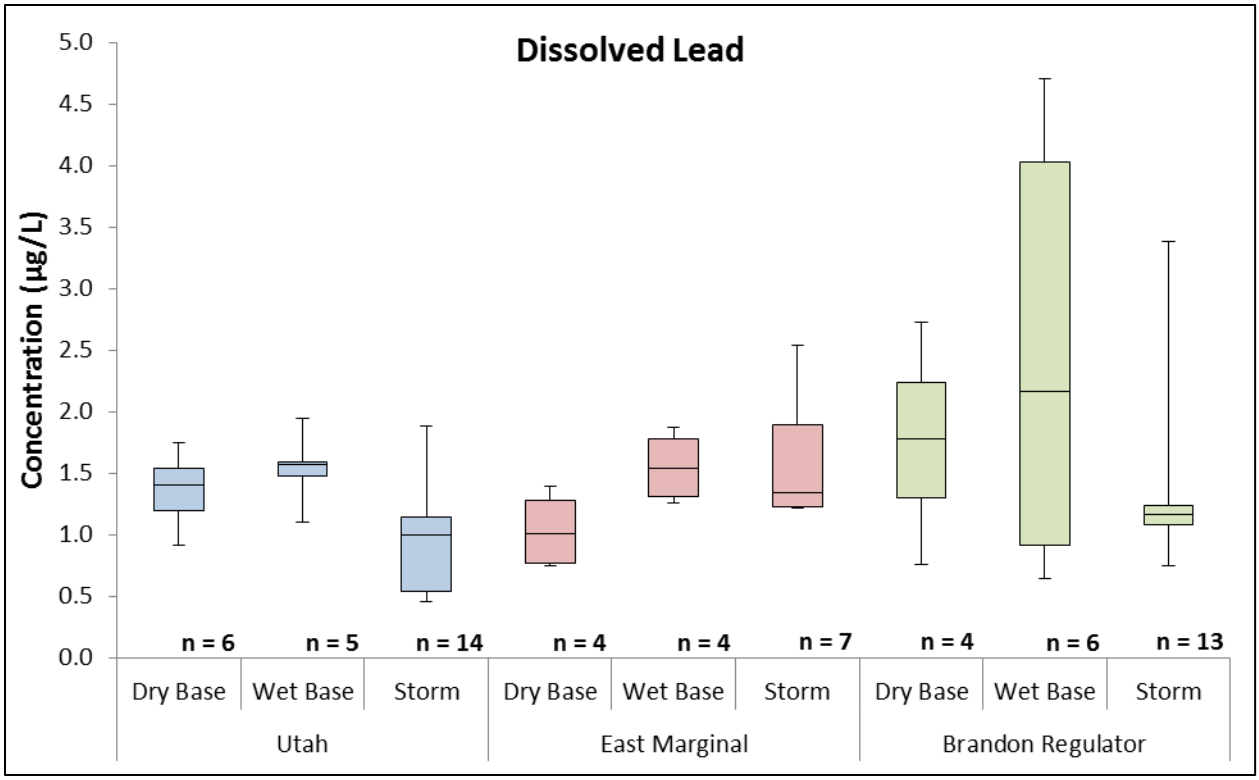

Figure 21. Boxplots of Dissolved Lead Concentration by Location and Flow Condition.

5.4.6 Nickel

Total and dissolved nickel were detected in all samples and ranged from 2.45 µg/L to 768 µg/L and 1.25 µg/L to 748 µg/L, respectively, across all sample types. Nickel data are summarized in Table 9 and Figures 22 and 23. Except during stormflow sampling at Utah and East Marginal, the dissolved fraction comprised the majority of the total nickel concentration. Total and dissolved nickel concentrations were highest and most variable at Brandon Regulator; one wet baseflow sample had concentrations more than 18 times higher than any other wet baseflow sample and one storm sample had concentrations over four times higher than any other storm sample. Thus, it appears the unsampled portion of the basin (Figure 1) is potentially a substantial source of nickel to Brandon Regulator.

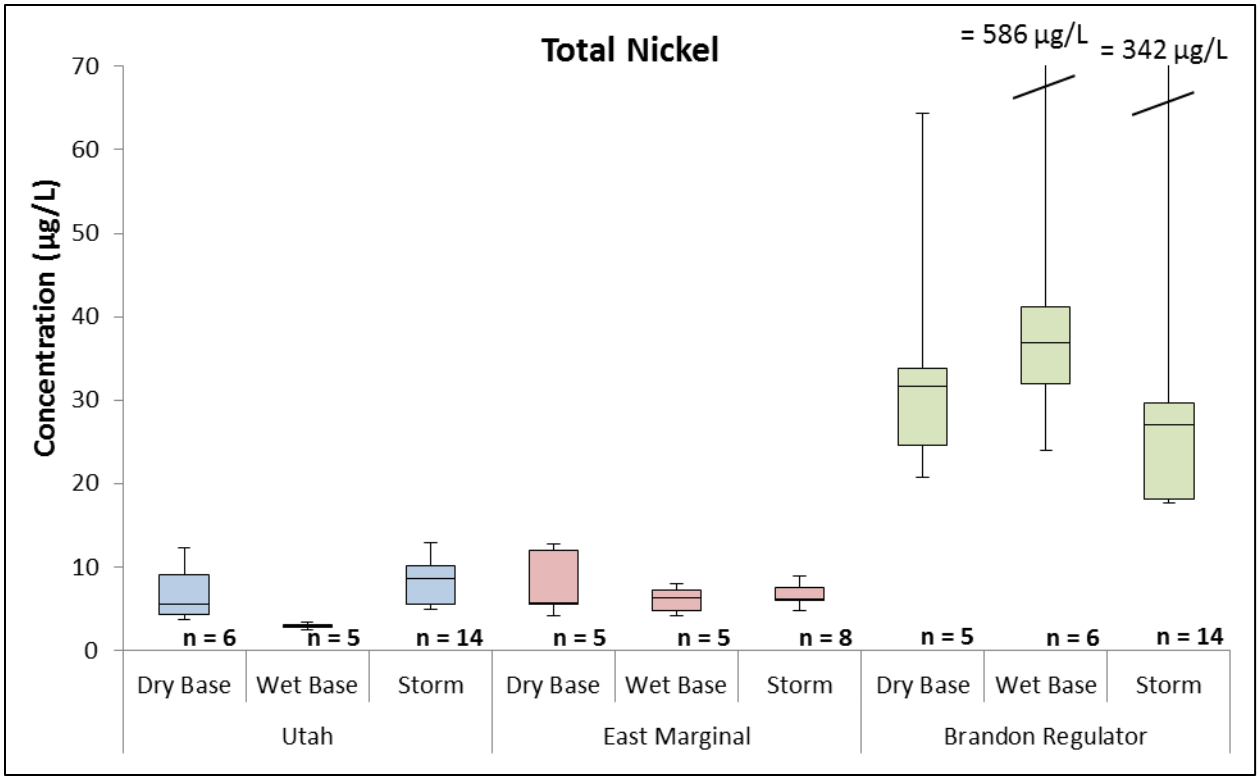

Figure 22. Boxplots of Total Nickel Concentration by Location and Flow Condition.

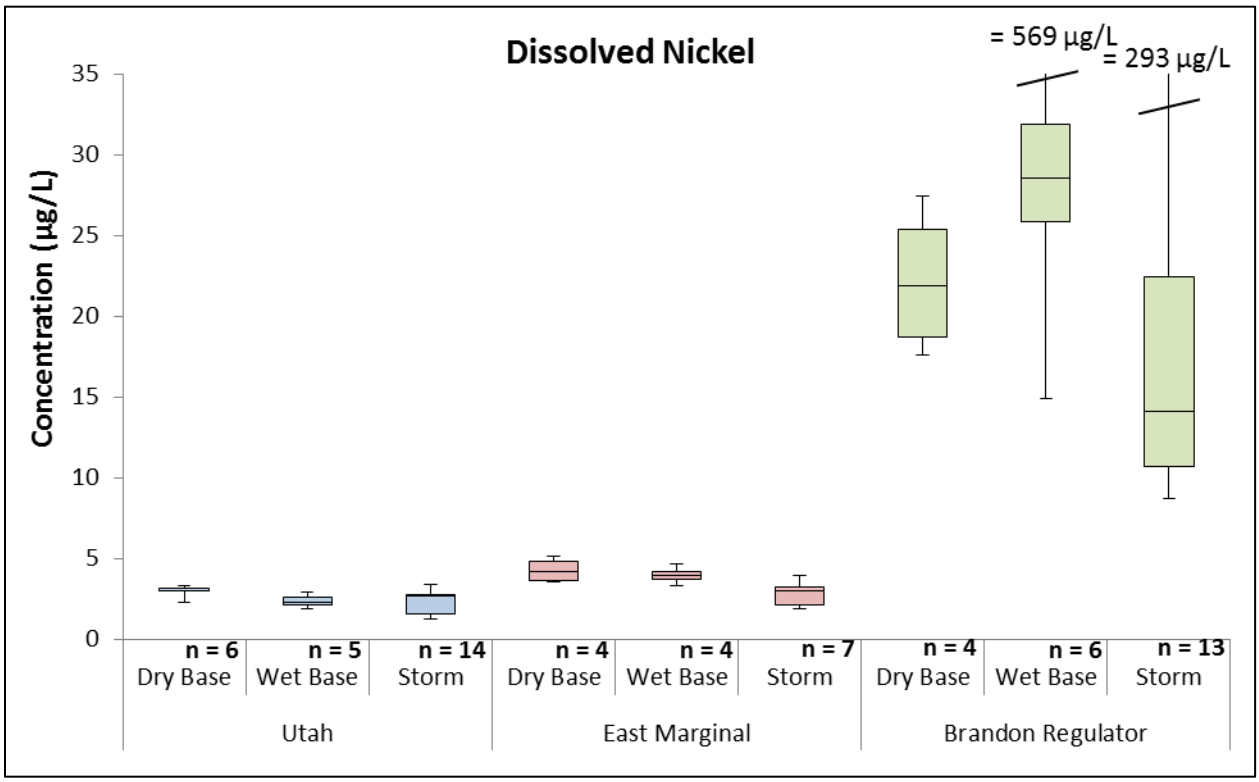

Figure 23. Boxplots of Dissolved Nickel Concentration by Location and Flow Condition.

5.4.7 Silver

Total silver was detected in all samples except one dry baseflow sample at East Marginal; data are summarized in Table 9 and Figures 24 and 25. However, dissolved silver was only detected in24% of the samples, with no detections at East Marginal under any flow condition. Detected concentrations of total and dissolved silver ranged from 0.050 µg/L to 2.51 µg/L and 0.052 µg/L to 0.908 µg/L, respectively, across all sample types. Where detected, less than half the total silver was comprised of the dissolved fraction in all but one sample. Concentrations of total silver were most variable at Utah.

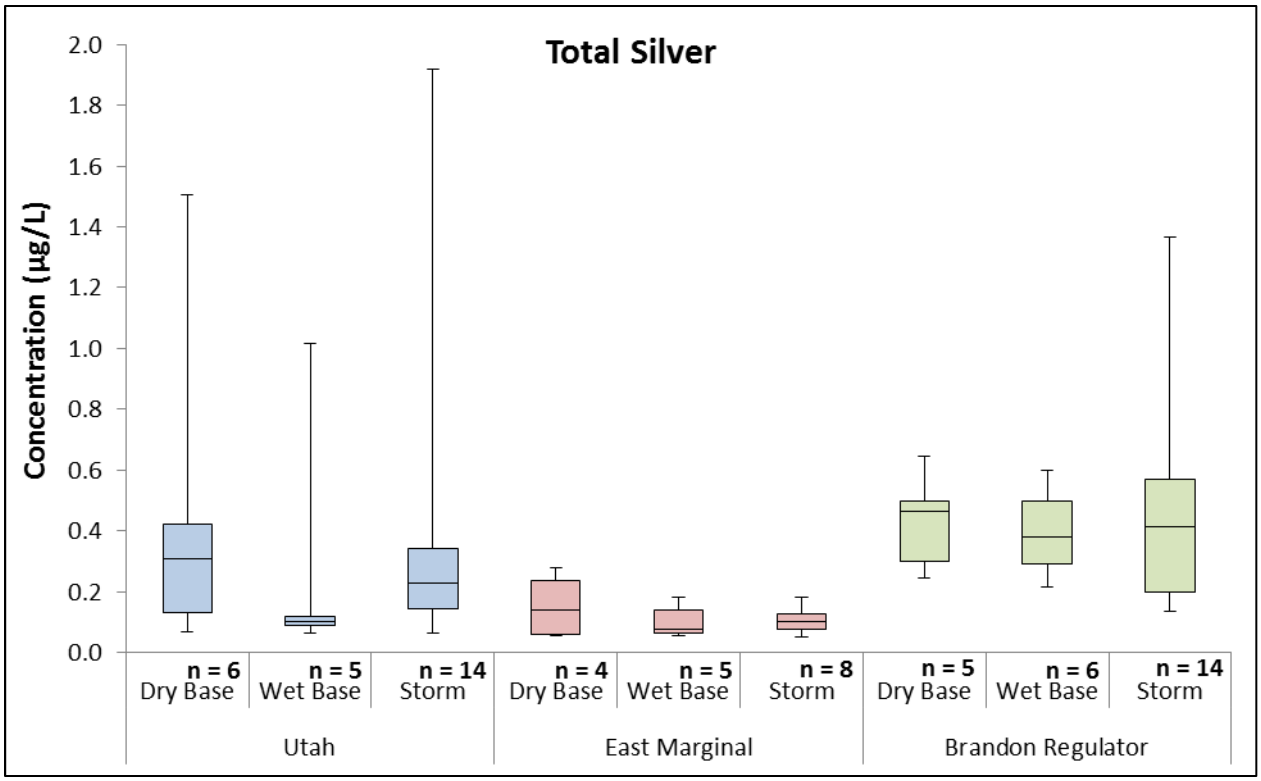

Figure 24. Boxplots of Total Silver Concentration by Location and Flow Condition.

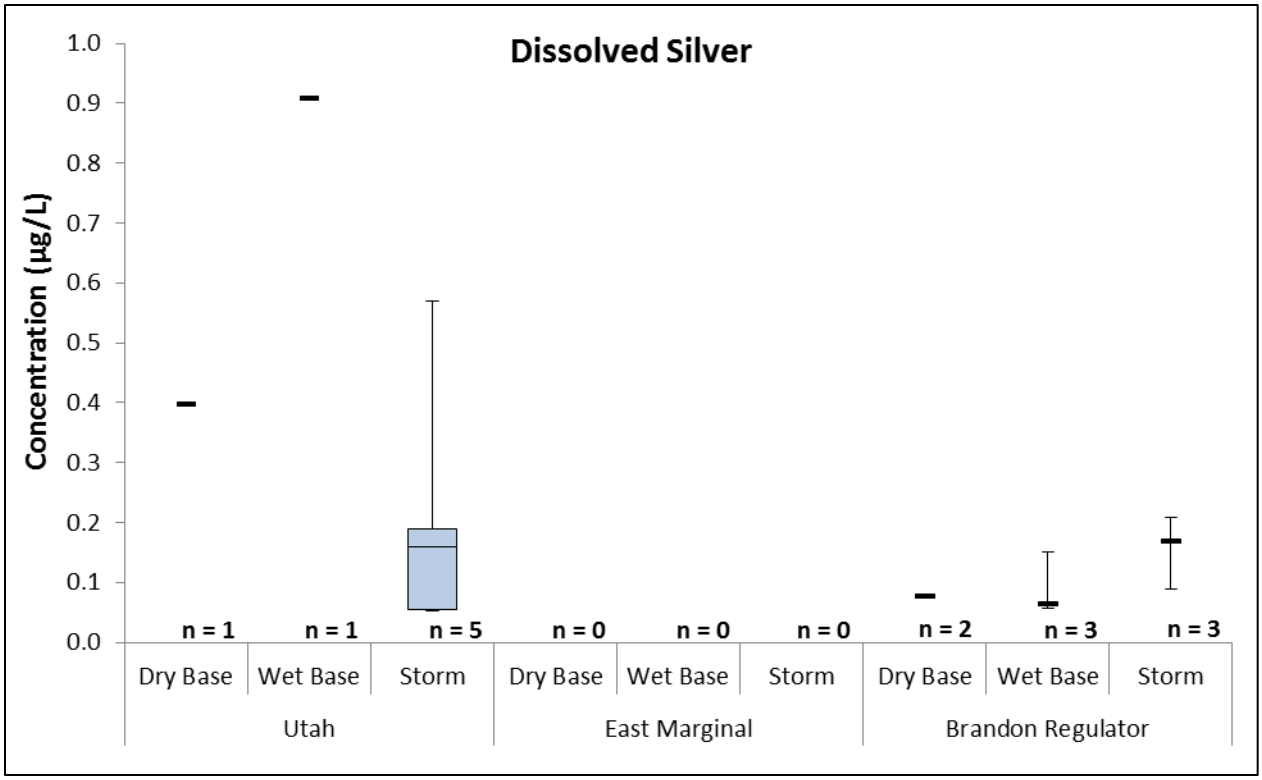

Figure 25. Boxplots of Dissolved Silver Concentration by Location and Flow Condition.

5.4.8 Vanadium

Total and dissolved vanadium were detected in all samples; data are summarized in Table 9 and Figures 26 and 27. Concentrations of total and dissolved vanadium ranged from 1.13 µg/L to 17.9 µg/L and 0.645 µg/L to 5.71 µg/L, respectively, across all sample types. The dissolved fraction was variable, but in all stormflow samples comprised less than 30% of the total vanadium concentration. At Utah during wet baseflow sampling, total vanadium concentrations were generally less variable than other sites, except one sample with a concentration more than ten times higher than other wet baseflow samples at this site. Concentrations of dissolved vanadium were most variable at Brandon Regulator during dry and wet baseflow sampling and least variable at Utah and East Marginal during wet baseflow sampling.

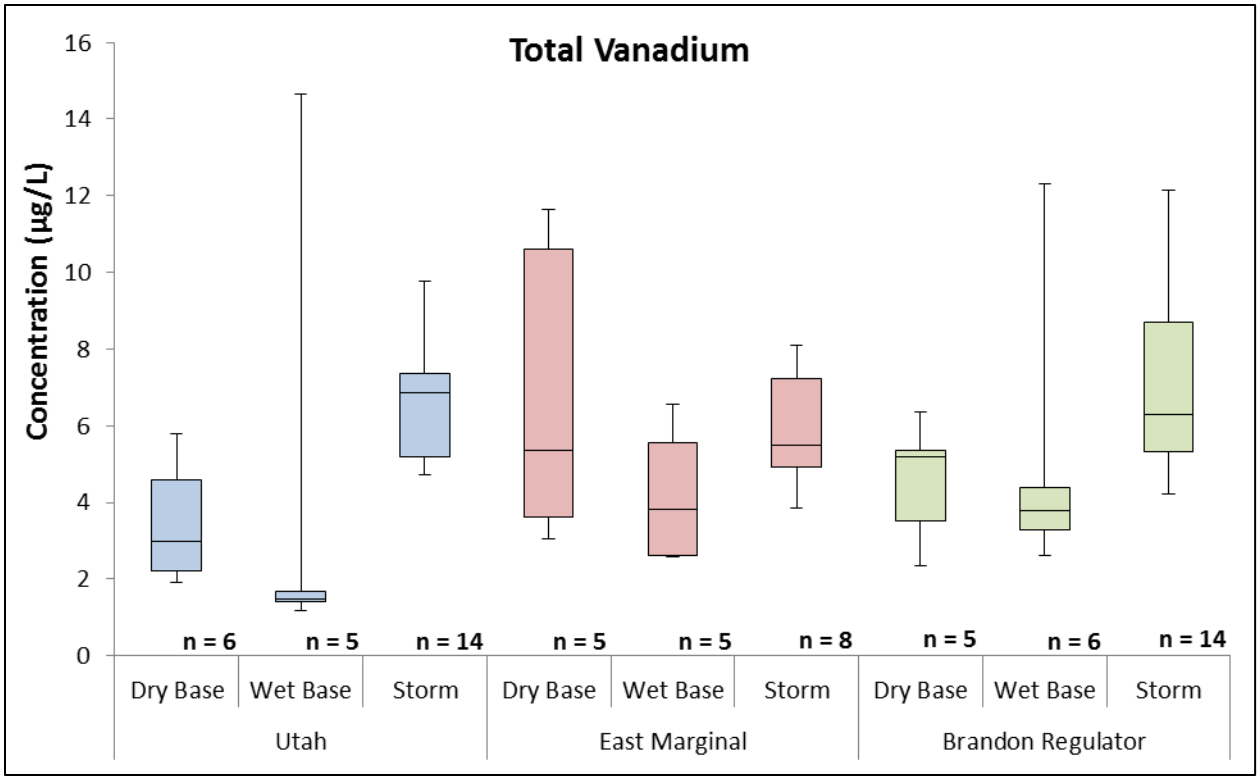

Figure 26. Boxplots of Total Vanadium Concentration by Location and Flow Condition.

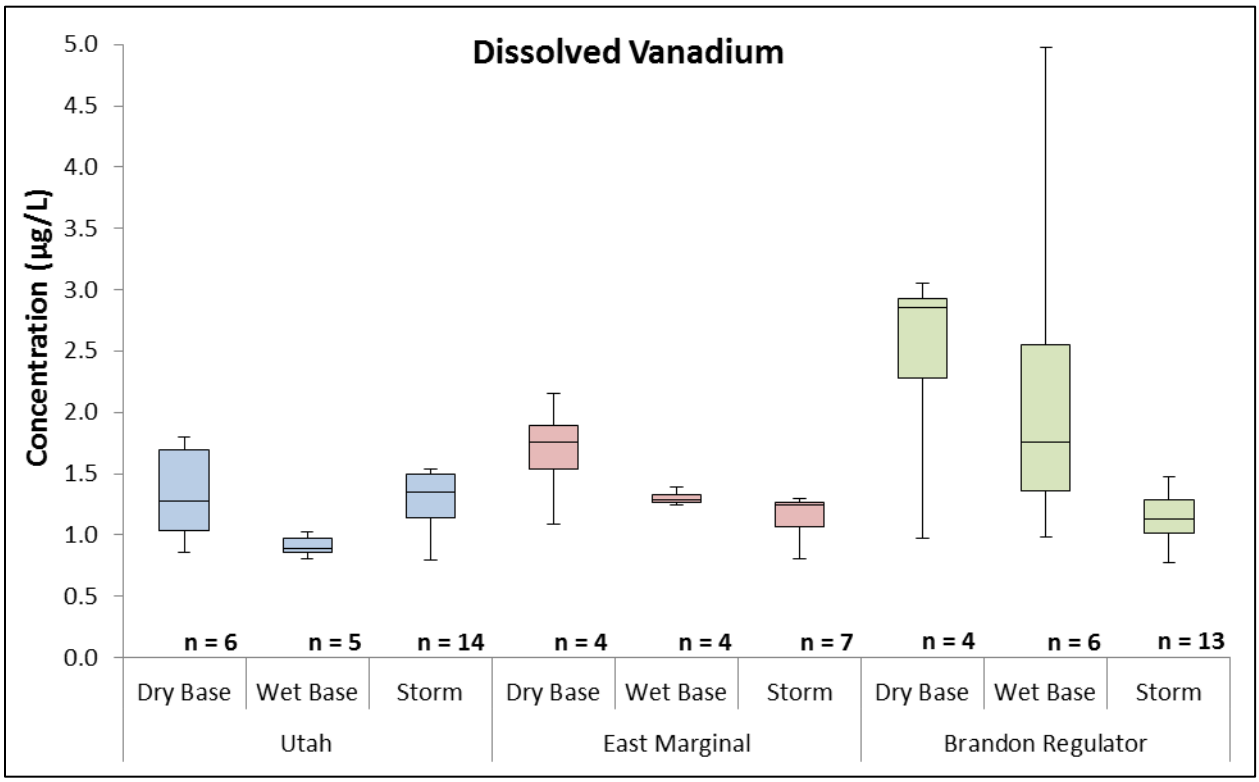

Figure 27. Boxplots of Dissolved Vanadium Concentration by Location and Flow Condition.

5.4.9 Zinc

Total and dissolved zinc were detected in all samples; data are summarized in Table 9 and Figures 28 and 29. Concentrations of total and dissolved zinc ranged from 13.8 µg/L to 555 µg/L and 11.7 µg/L to 164 µg/L, respectively, across all sample types. For most samples, the dissolved fraction made up less than half the total zinc concentration. Concentrations of total zinc were most variable at East Marginal during dry baseflow sampling and least variable at Utah during wet baseflow sampling. Variability in dissolved zinc levels was similar across locations and flow conditions.

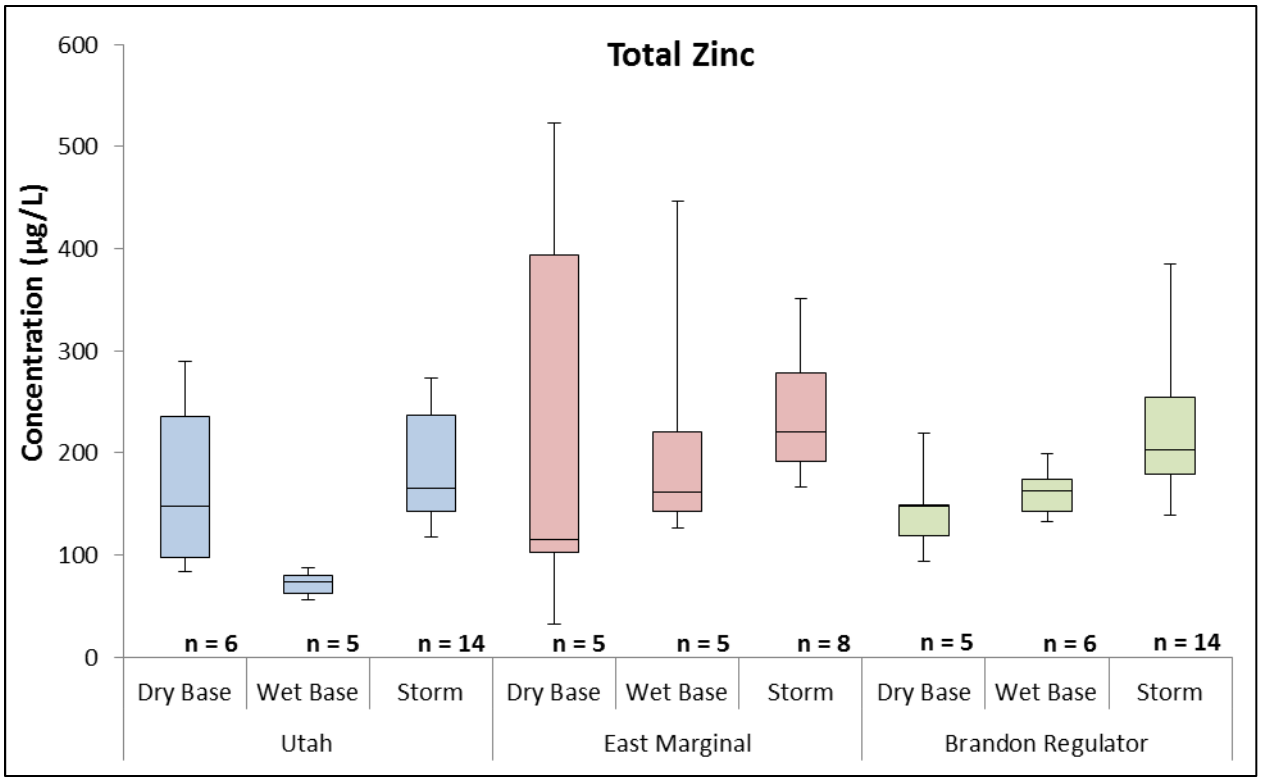

Figure 28. Boxplots of Total Zinc Concentration by Location and Flow Condition.

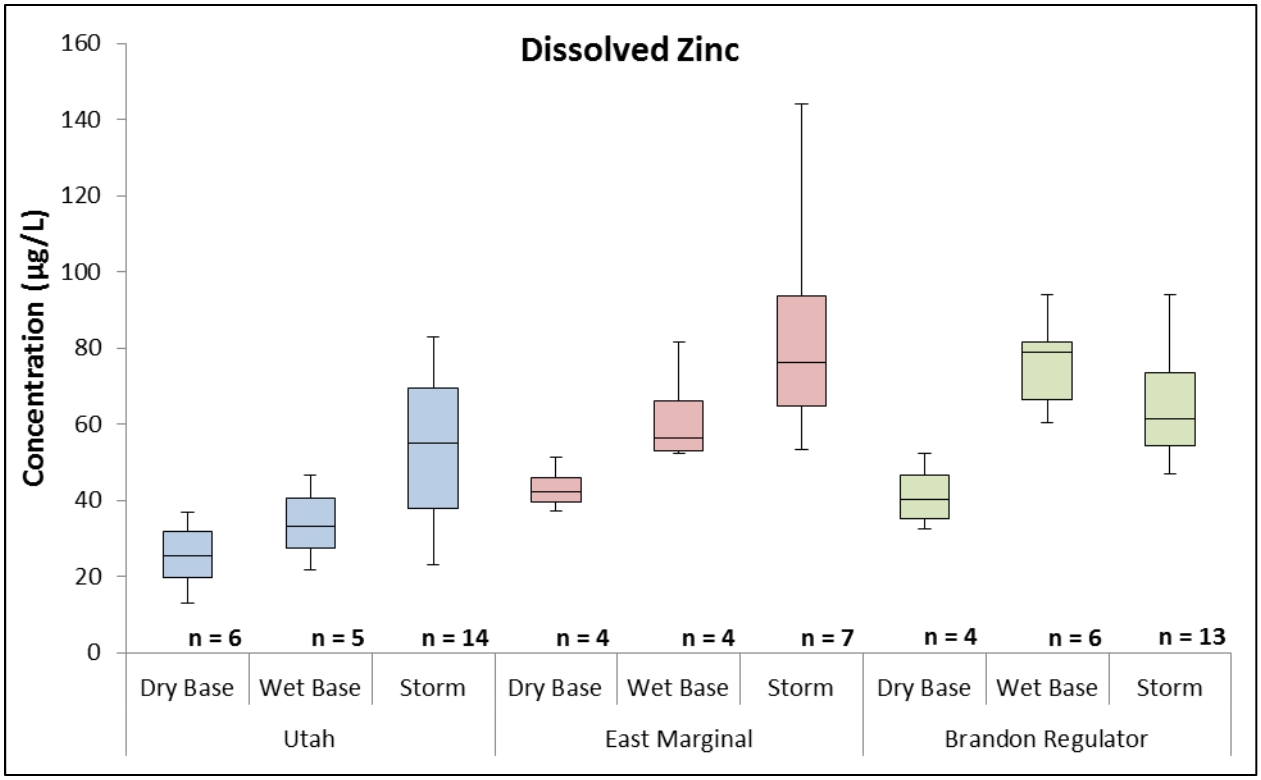

Figure 29. Boxplots of Dissolved Zinc Concentration by Location and Flow Condition.

5.5 Mercury

Mercury results are summarized in Table 10 and in Figures 30 and 31. Total mercury was detected in all samples, while dissolved mercury was detected in about 60% of the samples. Concentrations of total and dissolved mercury ranged from 0.0159 µg/L to 0.790 µg/L and 0.0051 µg/L to 0.0267 µg/L, respectively, across all sample types. Where detected, the dissolved fraction comprised less than half the total mercury concentration. The greatest variability in total mercury concentrations were observed at Brandon Regulator during stormflow sampling. When detected, dissolved mercury concentrations showed the greatest variability at East Marginal.

Table 10. Summary Statistics for Mercury Concentrations by Location and Flow Condition.

Analyte	Location	Flow Condition	FOD	Concentration (µg/L)					
				Min Detected	Max Detected	Mean	Median[a]	Min MDL	Max MDL
Total Mercury	Utah	Dry Base	6/6	0.0348	0.111	0.0666	0.0530	0.0050	0.0050
		Wet Base	5/5	0.0159	0.0287	0.0215	0.0216	0.0050	0.0050
		Storm	14/14	0.0216	0.0795	0.0481	0.0462	0.0050	0.0050
	East Marginal	Dry Base	5/5	0.0230	0.185	0.0794	0.0671	0.0050	0.0050
		Wet Base	5/5	0.0430	0.0930	0.0714	0.0714	0.0050	0.0050
		Storm	8/8	0.0211	0.153	0.0585	0.0449	0.0050	0.050
	Brandon Regulator	Dry Base	5/5	0.0224	0.102	0.0604	0.0625	0.0050	0.0050
		Wet Base	6/6	0.0243	0.0880	0.0543	0.0530	0.0050	0.0050
		Storm	14/14	0.0254	0.790	0.138	0.0838	0.0050	0.050
Dissolved Mercury	Utah	Dry Base	5/6	0.0077 J	0.012 J	0.0094 J	0.0081 J	0.0050	0.0050
		Wet Base	4/5	0.0051 J	0.0078 J	0.0067 J	0.0066 J	0.0050	0.0050
		Storm	6/14	0.0054 J	0.013 J	0.0078 J	NC	0.0050	0.0050
	East Marginal	Dry Base	1/4	0.0165 J	0.0165 J	NC	NC	0.0050	0.0050
		Wet Base	4/4	0.0098 J	0.0267 J	0.017 J	0.016 J	0.0050	0.0050
		Storm	3/7	0.0068 J	0.0260 J	0.0139 J	NC	0.0050	0.010
	Brandon Regulator	Dry Base	4/4	0.0051 J	0.010 J	0.0067 J	0.0059 J	0.0050	0.0050
		Wet Base	4/6	0.0065 J	0.014 J	0.0105 J	0.0070 J	0.0050	0.0050
		Storm	7/13	0.0054 J	0.0211 J	0.0093 J	0.0054 J	0.0050	0.0050

[a] Medians include nondetects, using the MDL for non-detect events. Medians are only calculated when frequency of detection is 50% or greater.
FOD = Frequency of detection; J = estimated value; MDL = method detection limit; NC = not calculated.

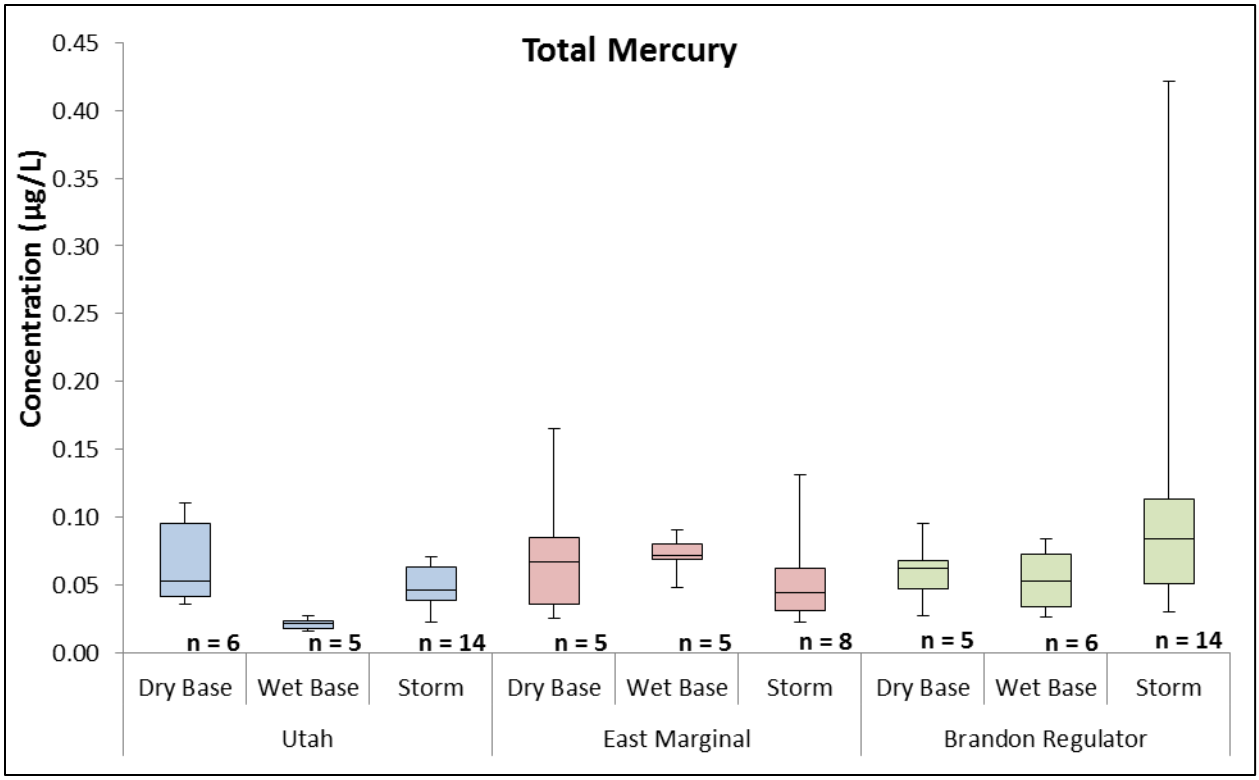

Figure 30. Boxplots of Total Mercury Concentration by Location and Flow Condition.

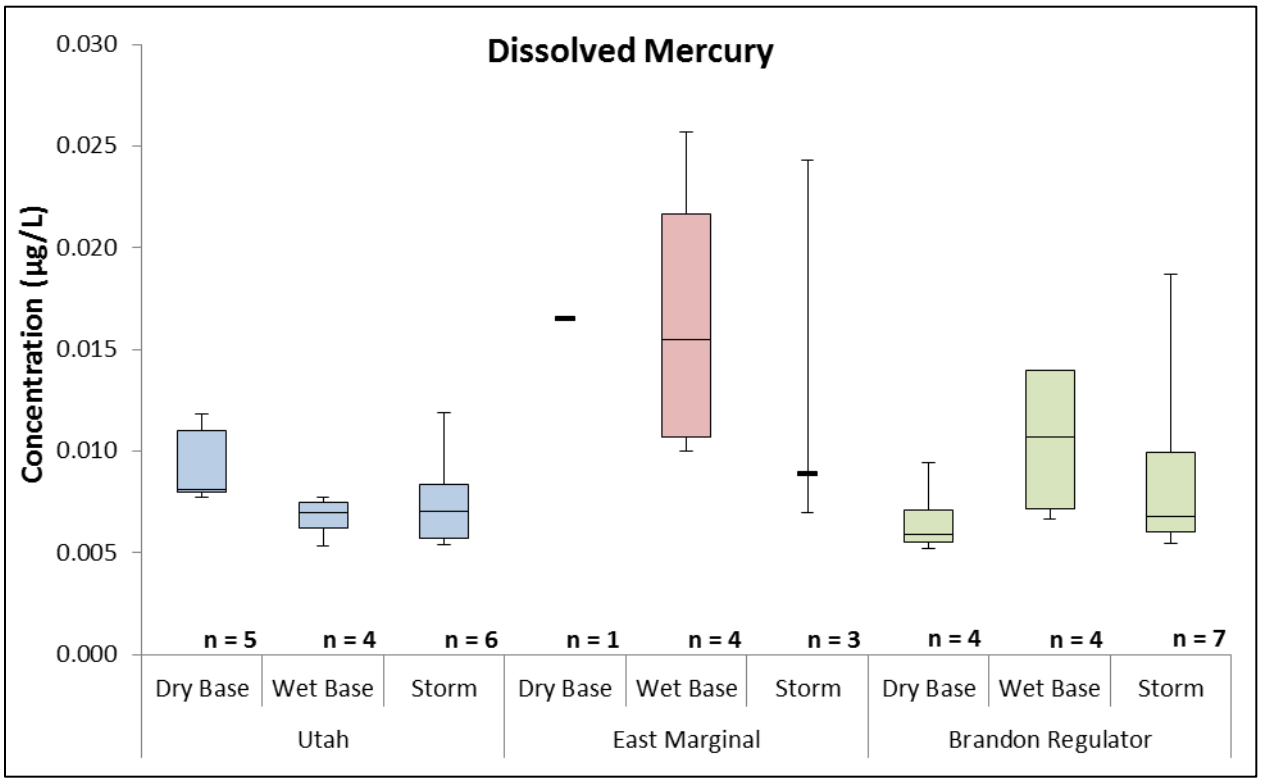

Figure 31. Boxplots of Dissolved Mercury Concentration by Location and Flow Condition.

5.6 PAHs

Data for individual PAH compounds, tabulated by LPAH or HPAH classification, are summarized in Tables 11 and 12. The LPAH and HPAH compound with the highest FOD across all samples were chosen to represent the PAHs; phenanthrene for LPAHs and fluoranthene for HPAHs (both 84% FOD). Several other HPAH compounds had greater than 50% FOD, but of the PAH results, only detected concentrations of phenanthrene, fluoranthene, and total HPAHs are presented graphically and included in later analysis.

In general, LPAH compounds were more frequently detected during stormflow sampling (Table 11). Frequency of detection was similar across sites for most LPAH compounds. Acenaphthene had the lowest FOD (18%) while phenanthrene had the highest FOD (84%). Phenanthrene concentrations ranged from 0.044 µg/L to 0.275 µg/L across all sample types, and were similar across all sites (Figure 32).

Table 11. Summary Statistics for LPAH Concentrations by Location and Flow Condition

Analyte	Location	Flow Condition	FOD	Concentration (µg/L)											
				Min Detected		Max Detected		Mean		Median[a]		Min MDL	Max MDL
2-Methylnaphthalene	Utah	Dry Base	0/6	NC		NC		NC		NC		0.019	0.040
		Wet Base	0/5	NC		NC		NC		NC		0.038	0.040
		Storm	5/14	0.0268		0.168		0.0786	J	NC		0.0080	0.080
	East Marginal	Dry Base	1/5	NC		0.0532		NC		NC		0.0080	0.040
		Wet Base	0/4	NC		NC		NC		NC		0.038	0.080
		Storm	6/8	0.0401		2.16		0.436	J	0.074	J	0.0080	0.080
	Brandon Regulator	Dry Base	2/5	0.0911		0.218	J	0.155	J	NC		0.019	0.032
		Wet Base	3/6	0.046	J	0.12	J	0.084	J	NC		0.038	0.080
		Storm	13/14	0.040	J	1.01		0.192	J	0.064	J	0.0080	0.040
Acenaphthene	Utah	Dry Base	0/6	NC		NC		NC		NC		0.019	0.040
		Wet Base	0/5	NC		NC		NC		NC		0.038	0.040
		Storm	4/14	0.012	J	0.0225		0.017	J	NC		0.0080	0.080
	East Marginal	Dry Base	0/5	NC		NC		NC		NC		0.0080	0.040
		Wet Base	0/4	NC		NC		NC		NC		0.038	0.080
		Storm	4/8	0.0095	J	0.046	J	0.022	J	0.039	U	0.0080	0.080
	Brandon Regulator	Dry Base	0/5	NC		NC		NC		NC		0.019	0.032
		Wet Base	0/6	NC		NC		NC		NC		0.038	0.080
		Storm	4/14	0.013	J	0.0270		0.021	J	NC		0.0080	0.080

Table 11, Continued

Analyte	Location	Flow Condition	FOD	Concentration (µg/L)											
				Min Detected		Max Detected		Mean		Median[a]		Min MDL	Max MDL
Acenaphthylene	Utah	Dry Base	0/6	NC		NC		NC		NC		0.0190	0.040
		Wet Base	3/5	0.040	J	0.419	J	0.262	J	0.040	J	0.038	0.040
		Storm	5/14	0.016	J	0.244		0.078	J	NC		0.0080	0.080
	East Marginal	Dry Base	0/5	NC		NC		NC		NC		0.0080	0.040
		Wet Base	2/4	0.331		0.697		0.514		0.206	J	0.038	0.080
		Storm	2/8	0.014	J	0.042	J	0.028	J	NC		0.0080	0.080
	Brandon Regulator	Dry Base	0/5	NC		NC		NC		NC		0.0190	0.032
		Wet Base	2/6	0.245		0.253		0.249		NC		0.038	0.080
		Storm	5/14	0.0083	J	0.205		0.061	J	NC		0.0080	0.080
Anthracene	Utah	Dry Base	0/6	NC		NC		NC		NC		0.019	0.040
		Wet Base	0/5	NC		NC		NC		NC		0.038	0.040
		Storm	5/14	0.0165		0.044	J	0.033	J	NC		0.0080	0.080
	East Marginal	Dry Base	1/5	NC		0.021	J	NC		NC		0.0080	0.040
		Wet Base	0/4	NC		NC		NC		NC		0.038	0.080
		Storm	3/8	0.0214		0.0252		0.0237		NC		0.0080	0.080
	Brandon Regulator	Dry Base	0/5	NC		NC		NC		NC		0.019	0.032
		Wet Base	0/6	NC		NC		NC		NC		0.038	0.080
		Storm	6/14	0.015	J	0.075	J	0.044	J	NC		0.0080	0.040
Fluorene	Utah	Dry Base	3/6	0.031	J	0.037	J	0.034	J	0.033	J	0.019	0.040
		Wet Base	1/5	NC		0.042	J	NC		NC		0.038	0.040
		Storm	5/14	0.0207		0.11	J	0.046	J	NC		0.0080	0.080
	East Marginal	Dry Base	0/5	NC		NC		NC		NC		0.0080	0.040
		Wet Base	1/4	NC		0.045	J	NC		NC		0.038	0.080
		Storm	4/8	0.0340		0.066	J	0.044	J	0.040	U	0.0080	0.080
	Brandon Regulator	Dry Base	2/5	0.024	J	0.025	J	0.025	J	NC		0.019	0.032
		Wet Base	0/6	NC		NC		NC		NC		0.038	0.080
		Storm	7/14	0.0191		0.10	J	0.051	J	0.040	U	0.0080	0.080
Naphthalene	Utah	Dry Base	1/6	NC		0.124		NC		NC		0.047	0.10
		Wet Base	2/5	0.11	J	0.18	J	0.15	J	NC		0.094	0.10
		Storm	6/14	0.0432		0.217		0.10	J	NC		0.020	0.20
	East Marginal	Dry Base	1/5	NC		0.143				NC		0.020	0.10
		Wet Base	0/4	NC		NC		NC		NC		0.094	0.20
		Storm	4/8	0.0493		0.953		0.293		0.097	U	0.020	0.20
	Brandon Regulator	Dry Base	2/5	0.164		0.239	J	0.202		NC		0.047	0.080
		Wet Base	0/6	NC		NC		NC		NC		0.094	0.20
		Storm	7/14	0.0633		0.695		0.224		0.10	U	0.020	0.10

Table 11, Continued

Analyte	Location	Flow Condition	FOD	Concentration (µg/L)											
				Min Detected		Max Detected		Mean		Median[a]		Min MDL	Max MDL
Phenanthrene	Utah	Dry Base	4/6	0.0710		0.131		0.0976		0.078	J	0.019	0.040
		Wet Base	4/5	0.044	J	0.0911	J	0.071	J	0.080	U	0.038	0.040
		Storm	14/14	0.071	J	0.239		0.129	J	0.119		0.0080	0.080
	East Marginal	Dry Base	2/5	0.0975		0.130	J	0.11	J	NC		0.0080	0.040
		Wet Base	2/4	0.0854		0.12	J	0.10	J	0.083	U	0.038	0.080
		Storm	7/8	0.111		0.183		0.144		0.141		0.0080	0.080
	Brandon Regulator	Dry Base	4/5	0.0499	J	0.103		0.0811		0.0800		0.019	0.032
		Wet Base	5/6	0.066	J	0.140		0.10	J	0.102		0.038	0.080
		Storm	14/14	0.0849		0.275		0.160		0.157		0.0080	0.040

[a] Medians include nondetects, using the MDL for non-detect events. Medians are only calculated when frequency of detection is 50% or greater.
FOD = Frequency of detection; U = nondetect, represented by MDL value; J = estimated value; MDL = method detection limit; NC = not calculated.

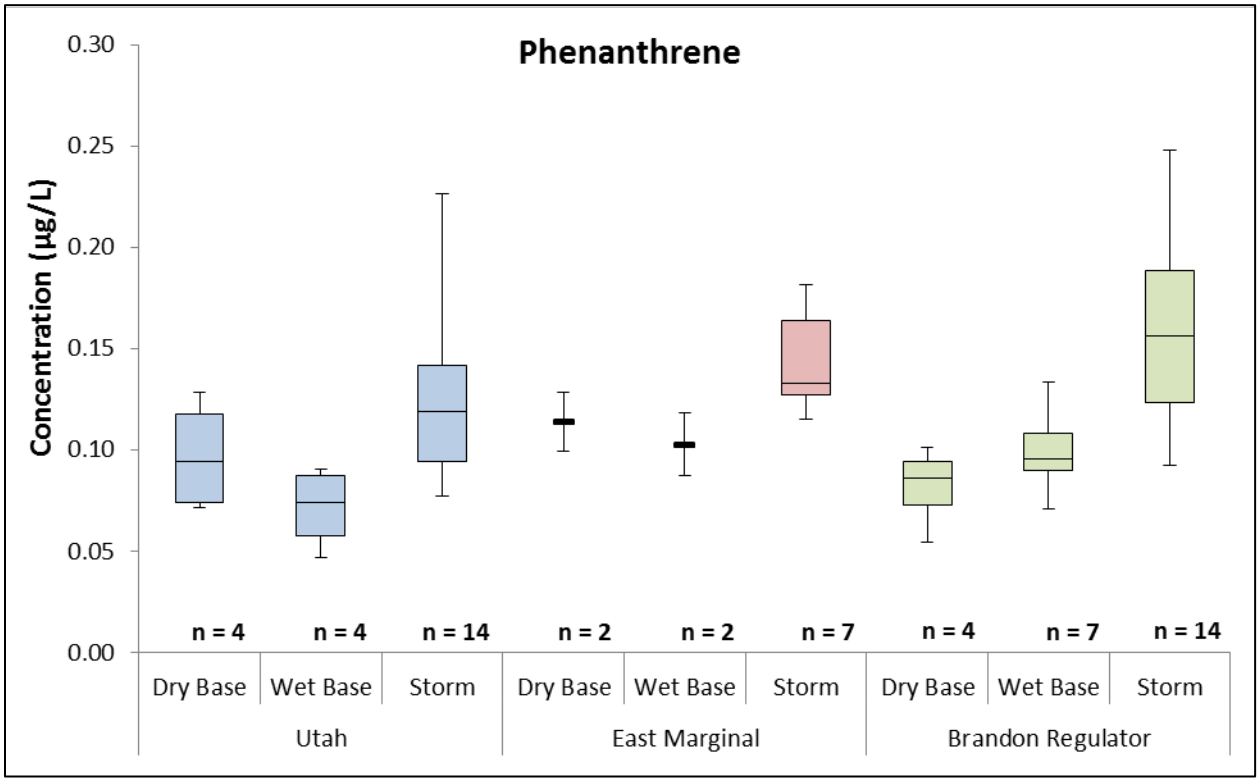

Figure 32. Boxplots of Phenanthrene Concentration by Location and Flow Condition.

HPAH data are summarized in Table 12 and Figures 33 and 34. As with LPAHs, HPAH compounds were more frequently detected during stormflow sampling (Table 12). The highest FOD for HPAHs was observed at Brandon Regulator. Dibenzo(a,h)anthracene had

the lowest FOD (13%), while fluoranthene had the highest FOD (84%); concentrations of fluoranthene ranged from 0.0266 µg/L to 0.416 µg/L across all sample types. The greatest variability and highest FODs were observed during stormflow sampling.

Table 12. Summary Statistics for HPAH Concentrations (µg/L) by Location and Flow.

Analyte	Location	Flow Condition	FOD	Concentration (µg/L)											
				Min Detected		Max Detected		Mean		Median[a]		Min MDL	Max MDL
Benzo(a)anthracene	Utah	Dry Base	1/5	NC		0.024	J	NC		NC		0.0190	0.040
		Wet Base	0/5	NC		NC		NC		NC		0.038	0.040
		Storm	10/14	0.040	J	0.113		0.0697	J	0.052	J	0.0080	0.080
	East Marginal	Dry Base	0/4	NC		NC		NC		NC		0.0080	0.040
		Wet Base	0/4	NC		NC		NC		NC		0.038	0.080
		Storm	6/8	0.0243		0.062	J	0.042	J	0.042	J	0.0080	0.080
	Brandon Regulator	Dry Base	0/4	NC		NC		NC		NC		0.0190	0.032
		Wet Base	1/6	NC		0.058	J	NC		NC		0.038	0.080
		Storm	11/14	0.015	J	0.195		0.0783	J	0.062	J	0.0080	0.040
Benzo(a)pyrene	Utah	Dry Base	3/6	0.0431		0.0522		0.049	J	NC		0.019	0.040
		Wet Base	1/5	NC		0.068	J	NC		NC		0.038	0.040
		Storm	13/14	0.040	J	0.120		0.0688	J	0.0555		0.0080	0.080
	East Marginal	Dry Base	2/5	0.0094	J	0.0473		0.028	J	NC		0.0080	0.040
		Wet Base	0/4	NC		NC		NC		NC		0.038	0.080
		Storm	4/8	0.0193		0.046	J	0.029	J	0.040	U	0.0080	0.080
	Brandon Regulator	Dry Base	1/5	NC		0.0492		NC		NC		0.019	0.032
		Wet Base	0/6	NC		NC		NC		NC		0.038	0.080
		Storm	12/14	0.013	J	0.178		0.0746	J	0.063	J	0.0080	0.040
Benzo(b,j,k)fluoranthene	Utah	Dry Base	3/6	0.0579		0.120		0.0871		0.049	J	0.019	0.040
		Wet Base	1/5	NC		0.050	J	NC		NC		0.038	0.040
		Storm	14/14	0.0784		0.295		0.184		0.180		0.0080	0.080
	East Marginal	Dry Base	3/5	0.0195		0.0446		0.035	J	0.040	U	0.0080	0.040
		Wet Base	0/4	NC		NC		NC		NC		0.038	0.080
		Storm	7/8	0.0580		0.0954		0.0757	J	0.0767	J	0.0080	0.080
	Brandon Regulator	Dry Base	2/5	0.037	J	0.0565		0.047	J	NC		0.019	0.032
		Wet Base	2/6	0.052	J	0.117		0.085	J	NC		0.038	0.080
		Storm	14/14	0.0413		0.363		0.160	J	0.156		0.0080	0.040
Benzo(g,h,i)perylene	Utah	Dry Base	3/6	0.029	J	0.044	J	0.036	J	0.034	J	0.019	0.040
		Wet Base	0/5	NC		NC		NC		NC		0.038	0.040
		Storm	13/14	0.051	J	0.138		0.0912	J	0.0912		0.0080	0.080
	East Marginal	Dry Base	2/5	0.012	J	0.034	J	0.023	J	NC		0.0080	0.040
		Wet Base	0/4	NC		NC		NC		NC		0.038	0.080
		Storm	5/8	0.0216		0.0492		0.039	J	0.042	J	0.0080	0.080
	Brandon Regulator	Dry Base	1/5	NC		0.0458		NC		NC		0.019	0.032
		Wet Base	1/6	NC		0.045	J	NC		NC		0.038	0.080
		Storm	11/14	0.0245		0.152		0.0863	J	0.0838		0.0080	0.040

Table 12, Continued

Analyte	Location	Flow Condition	FOD	Concentration (µg/L)											
				Min Detected		Max Detected		Mean		Median[a]		Min MDL	Max MDL
Chrysene	Utah	Dry Base	2/5	0.0384	J	0.0719	J	0.055	J	NC		0.019	0.040
		Wet Base	0/5	NC		NC		NC		NC		0.038	0.040
		Storm	14/14	0.055	J	0.218		0.146	J	0.153		0.0080	0.080
	East Marginal	Dry Base	3/5	0.015	J	0.037	J	0.030	J	0.037	J	0.0080	0.040
		Wet Base	0/4	NC		NC		NC		NC		0.038	0.080
		Storm	7/8	0.0596		0.0973		0.0786	J	0.0819	J	0.0080	0.080
	Brandon Regulator	Dry Base	1/5	NC		0.034	J	NC		NC		0.019	0.032
		Wet Base	2/6	0.045	J	0.075	J	0.060	J	NC		0.038	0.080
		Storm	14/14	0.0428		0.252		0.130	J	0.123		0.0080	0.040
Dibenzo(a,h)anthracene	Utah	Dry Base	0/6	NC		NC		NC		NC		0.019	0.040
		Wet Base	0/5	NC		NC		NC		NC		0.038	0.040
		Storm	4/14	0.015	J	0.0385		0.0279	J	NC		0.0080	0.080
	East Marginal	Dry Base	0/5	NC		NC		NC		NC		0.0080	0.040
		Wet Base	0/4	NC		NC		NC		NC		0.038	0.080
		Storm	1/8	NC		0.010	J	NC		NC		0.0080	0.080
	Brandon Regulator	Dry Base	0/5	NC		NC		NC		NC		0.019	0.032
		Wet Base	0/6	NC		NC		NC		NC		0.038	0.080
		Storm	3/14	0.013	J	0.042	J	0.025	J	NC		0.0080	0.040
Fluoranthene	Utah	Dry Base	6/6	0.038	J	0.148	J	0.0735	J	0.059	J	0.019	0.040
		Wet Base	2/5	0.049	J	0.066	J	0.058	J	NC		0.038	0.040
		Storm	14/14	0.0846		0.416		0.211	J	0.193		0.0080	0.080
	East Marginal	Dry Base	4/5	0.0266	J	0.0948	J	0.0599	J	0.040	U	0.0080	0.040
		Wet Base	1/4	NC		0.049	J	NC		NC		0.038	0.080
		Storm	7/8	0.0803		0.290		0.152		0.141		0.0080	0.080
	Brandon Regulator	Dry Base	5/5	0.028	J	0.0725		0.0585	J	0.0662	J	0.0190	0.032
		Wet Base	3/6	0.060	J	0.159		0.097	J	0.076	J	0.038	0.080
		Storm	14/14	0.075	J	0.457		0.207	J	0.194		0.0080	0.040
Indeno(1,2,3-Cd)pyrene	Utah	Dry Base	3/6	0.022	J	0.042	J	0.029	J	0.032	U	0.019	0.040
		Wet Base	0/5	NC		NC		NC		NC		0.038	0.040
		Storm	10/14	0.040	J	0.0983		0.066	J	0.060	J	0.0080	0.080
	East Marginal	Dry Base	2/5	0.011	J	0.023	J	0.017	J	NC		0.0080	0.040
		Wet Base	0/4	NC		NC		NC		NC		0.038	0.080
		Storm	3/8	0.010	J	0.0247		0.016	J	NC		0.0080	0.080
	Brandon Regulator	Dry Base	1/5	NC		0.025	J	NC		NC		0.019	0.032
		Wet Base	0/6	NC		NC		NC		NC		0.038	0.080
		Storm	10/14	0.014	J	0.131		0.060	J	0.054	J	0.0080	0.040

Table 12, Continued

Analyte	Location	Flow Condition	FOD	Concentration (µg/L)											
				Min Detected		Max Detected		Mean		Median[a]		Min MDL	Max MDL
Pyrene	Utah	Dry Base	2/6	0.038		0.056		0.0468		NC		0.019	0.040
		Wet Base	2/5	0.069	J	0.071	J	0.070	J	NC		0.038	0.040
		Storm	14/14	0.066	J	0.310		0.183	J	0.184		0.0080	0.080
	East Marginal	Dry Base	2/5	0.0473	J	0.053	J	0.050	J	NC		0.0080	0.040
		Wet Base	1/4	NC		0.084	J	NC		NC		0.038	0.080
		Storm	7/8	0.0804		0.198		0.136		0.119		0.008	0.080
	Brandon Regulator	Dry Base	4/5	0.034	J	0.060	J	0.047	J	0.040	J	0.019	0.032
		Wet Base	4/6	0.0827		0.135		0.11	J	0.0891		0.038	0.080
		Storm	14/14	0.0807		0.376		0.187		0.172		0.0080	0.040
Total HPAHs	Utah	Dry Base	6/6	0.038	J	0.477	J	0.212	J	0.185	J	0.019	0.040
		Wet Base	2/5	0.12	J	0.253	J	0.187	J	NC		0.038	0.040
		Storm	14/14	0.324	J	1.63		0.978	J	0.959	J	0.0080	0.080
	East Marginal	Dry Base	4/5	0.034	J	0.318	J	0.168	J	0.0935	J	0.0080	0.040
		Wet Base	2/4	0.049	J	0.084	J	0.067	J	NC		0.038	0.080
		Storm	7/8	0.345	J	0.667	J	0.531	J	0.545	J	0.0080	0.080
	Brandon Regulator	Dry Base	5/5	0.028	J	0.336	J	0.146	J	0.133	J	0.019	0.032
		Wet Base	4/6	0.11	J	0.589	J	0.276	J	0.13	J	0.038	0.080
		Storm	14/14	0.259	J	2.15	J	0.925	J	0.927	J	0.0080	0.040

[a] Medians include nondetects, using the MDL for non-detect events. Medians are only calculated when frequency of detection is 50% or greater.
FOD = Frequency of detection; U = nondetect represented by MDL value; J = estimated value;
MDL = method detection limit; NC = not calculated.

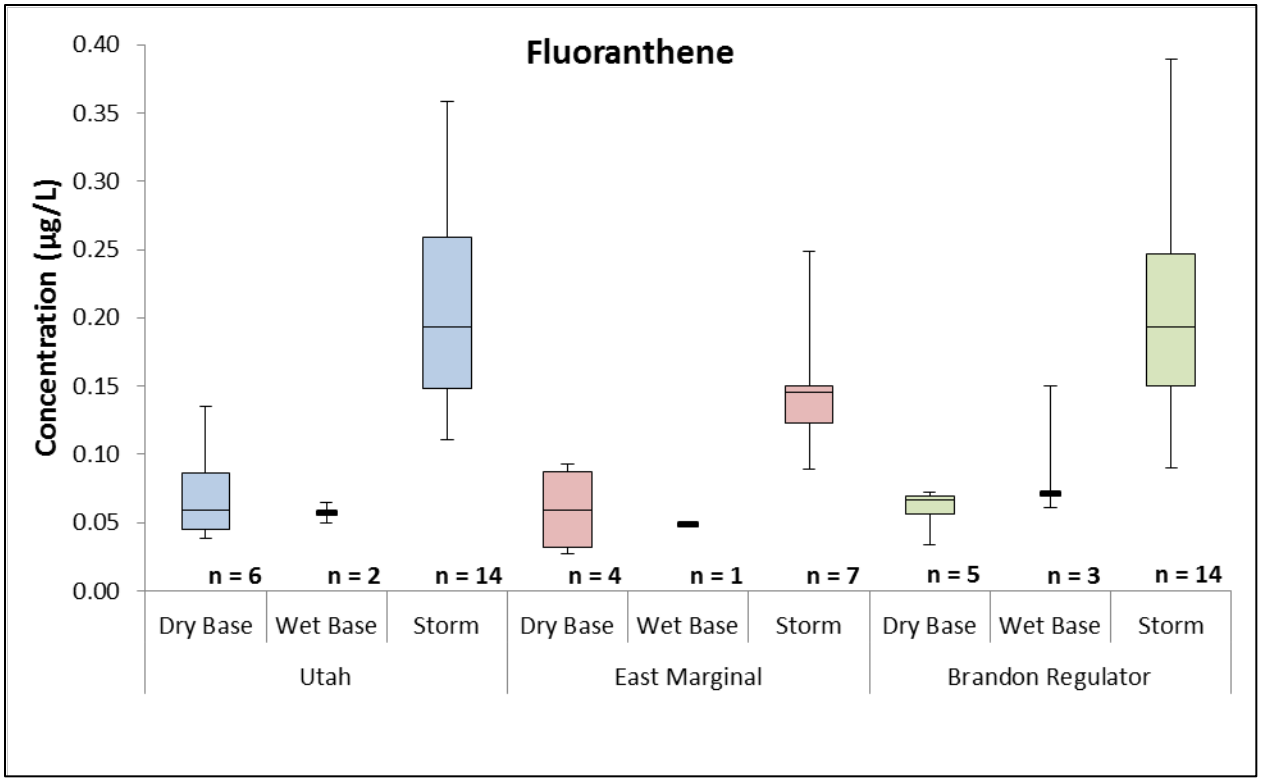

Figure 33. Boxplots of Fluoranthene Concentration by Location and Flow Condition.

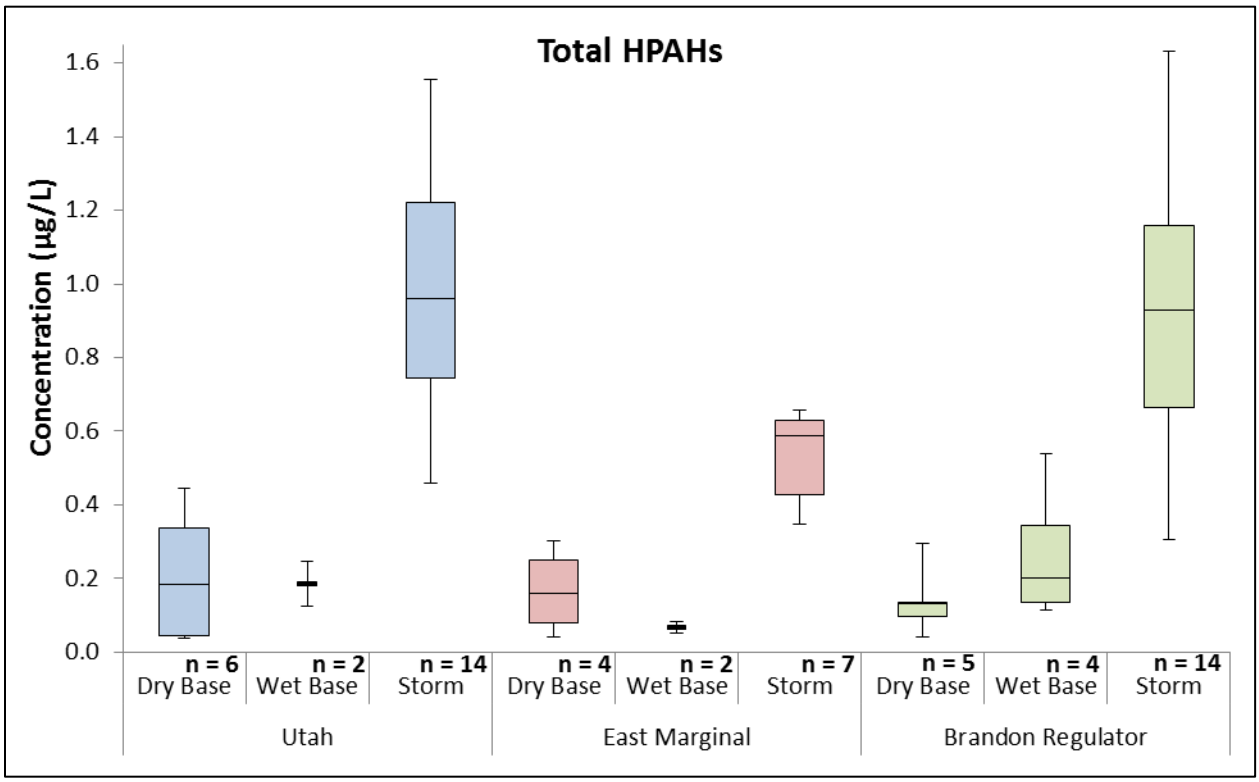

Figure 34. Boxplots of Total HPAH Concentration by Location and Flow Condition.

5.7 Phthalates

Phthalates were frequently detected (>80% FOD), except di-n-butyl phthalate, which had a 30% FOD (Table 13). Concentrations of the most frequently detected phthalates, benzyl butyl phthalate (99% FOD), bis(2-ethylhexyl)phthalate (87% FOD), and diethyl phthalate (100% FOD), are depicted in Figures 35 through 37.

Of the detected phthalates, benzyl butyl phthalate was found at the highest concentrations (0.210 µg/L to 186 µg/L), especially at Utah. The highest concentrations were detected at Utah during wet baseflow sampling (see Figures 35 through 37).

Table 13. Summary Statistics for Phthalate Concentrations by Location and Flow Condition.

Analyte	Location	Flow Condition	FOD	Concentration (µg/L)											
				Min Detected		Max Detected		Mean		Median[a]		Min MDL	Max MDL
Benzyl Butyl Phthalate	Utah	Dry Base	6/6	4.32	J	44.4	J	19.6	J	9.79	J	0.019	0.160
		Wet Base	5/5	38.8		186		90.3		76.1		0.160	0.80
		Storm	14/14	1.72	J	33.1		11.7	J	6.79		0.0080	0.20
	East Marginal	Dry Base	5/5	0.210	J	0.675	J	0.372	J	0.244	J	0.0080	0.040
		Wet Base	4/4	0.234		1.44		0.741	J	0.646	J	0.038	0.080
		Storm	7/8	0.445		154		22.8		0.617		0.0080	0.80
	Brandon Regulator	Dry Base	5/5	1.31	J	4.35		3.18	J	3.59	J	0.019	0.032
		Wet Base	6/6	5.02		13.2		7.84	J	5.78	J	0.038	0.080
		Storm	14/14	0.700		21.2		5.31	J	3.61		0.0080	0.040
Bis(2-Ethylhexyl)Phthalate	Utah	Dry Base	6/6	2.35	J	8.39	J	4.94	J	4.80	J	0.019	0.040
		Wet Base	5/5	9.18	J	33.9	J	17.8	J	13.9	J	0.038	0.400
		Storm	11/14	3.40	J	12.1	J	5.86	J	5.61	J	0.0080	0.080
	East Marginal	Dry Base	5/5	1.87	J	5.46	J	3.20	J	2.60	J	0.0080	0.040
		Wet Base	4/4	2.58	J	7.62	J	6.13	J	7.15	J	0.038	0.080
		Storm	7/8	2.71	J	16.8	J	6.80	J	5.79	J	0.0080	0.080
	Brandon Regulator	Dry Base	5/5	2.07	J	7.79	J	4.27	J	3.98	J	0.019	0.032
		Wet Base	6/6	3.08	J	11.1	J	6.66	J	6.34	J	0.038	0.080
		Storm	9/14	2.06	J	11.8	J	6.02	J	5.66	J	0.0080	0.040
Diethyl Phthalate	Utah	Dry Base	6/6	1.85		5.76		3.75		3.61		0.0190	0.040
		Wet Base	5/5	3.83		6.65		5.18	J	4.97		0.038	0.040
		Storm	14/14	0.722		3.56		1.69		1.38		0.0080	0.080
	East Marginal	Dry Base	5/5	2.17		5.40		3.62	J	2.68		0.0080	0.040
		Wet Base	4/4	1.47	J	4.05		2.35	J	1.93		0.038	0.080
		Storm	8/8	0.450		1.74		1.14		1.20		0.0080	0.080
	Brandon Regulator	Dry Base	5/5	1.69	J	3.76		2.93	J	3.52		0.019	0.032
		Wet Base	6/6	1.63		2.98		2.44	J	2.49	J	0.038	0.080
		Storm	14/14	0.451		2.55		1.28		1.05		0.0080	0.080

Table 13, Continued

Analyte	Location	Flow Condition	FOD	Concentration (µg/L)											
				Min Detected		Max Detected		Mean		Median[a]		Min MDL	Max MDL
Dimethyl Phthalate	Utah	Dry Base	3/6	0.0797		0.513		0.226		0.060	J	0.019	0.040
		Wet Base	1/5	NC		0.101		NC		NC		0.038	0.040
		Storm	13/14	0.105		0.297		0.181		0.163	J	0.0080	0.080
	East Marginal	Dry Base	4/5	0.110		0.519		0.318		0.125		0.0080	0.040
		Wet Base	4/4	0.170		0.426		0.314	J	0.330	J	0.038	0.080
		Storm	8/8	0.114		0.736		0.316		0.194		0.0080	0.080
	Brandon Regulator	Dry Base	5/5	0.124	J	0.304		0.211	J	0.236		0.019	0.032
		Wet Base	4/6	0.111		0.331	J	0.206	J	0.168	J	0.038	0.080
		Storm	13/14	0.0801		0.362		0.199	J	0.166		0.0080	0.080
Di-N-Butyl Phthalate	Utah	Dry Base	0/5	NC		NC		NC		NC		0.019	0.040
		Wet Base	2/5	1.29		3.70		2.50		NC		0.038	0.040
		Storm	7/14	0.956		1.81		1.47		1.0	U	0.0080	0.080
	East Marginal	Dry Base	0/4	NC		NC		NC		NC		0.0080	0.040
		Wet Base	0/4	NC		NC		NC		NC		0.038	0.080
		Storm	2/8	1.68		8.17		4.93		NC		0.0080	0.080
	Brandon Regulator	Dry Base	0/4	NC		NC		NC		NC		0.019	0.032
		Wet Base	1/6	NC		4.66		NC		NC		0.038	0.080
		Storm	7/14	1.45		2.57		2.04		1.2	J	0.0080	0.040
Di-N-Octyl Phthalate	Utah	Dry Base	5/6	0.0759		1.20		0.398		0.102		0.0190	0.040
		Wet Base	1/5	NC		0.217		NC		NC		0.038	0.040
		Storm	14/14	0.431		1.85	J	0.758		0.663		0.0080	0.080
	East Marginal	Dry Base	5/5	0.033	J	0.773		0.270	J	0.188		0.0080	0.040
		Wet Base	4/4	0.166		0.362		0.264		0.263		0.038	0.080
		Storm	8/8	0.862		8.86		3.74		3.09		0.0080	0.080
	Brandon Regulator	Dry Base	2/5	0.138		0.635		0.387		NC		0.019	0.032
		Wet Base	6/6	0.507	J	1.45		0.854	J	0.755	J	0.038	0.080
		Storm	14/14	0.445		4.99		2.17	J	1.83		0.0080	0.040

[a] Medians include nondetects, using the MDL for non-detect events. Medians are only calculated when frequency of detection is 50% or greater.
FOD = Frequency of detection; U = nondetect represented by MDL value; J = estimated value; MDL = method detection limit; NC = not calculated.

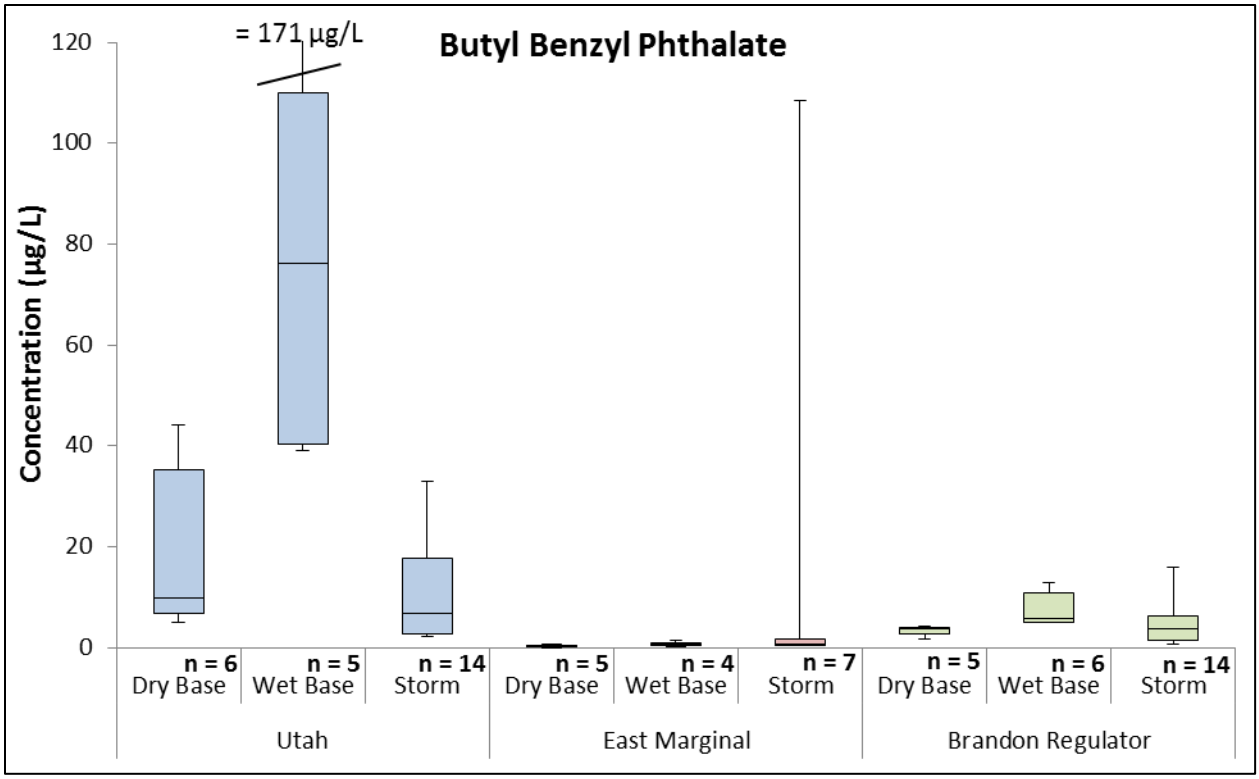

Figure 35. Boxplots of Benzyl Butyl Phthalate Concentration by Location and Flow Condition.

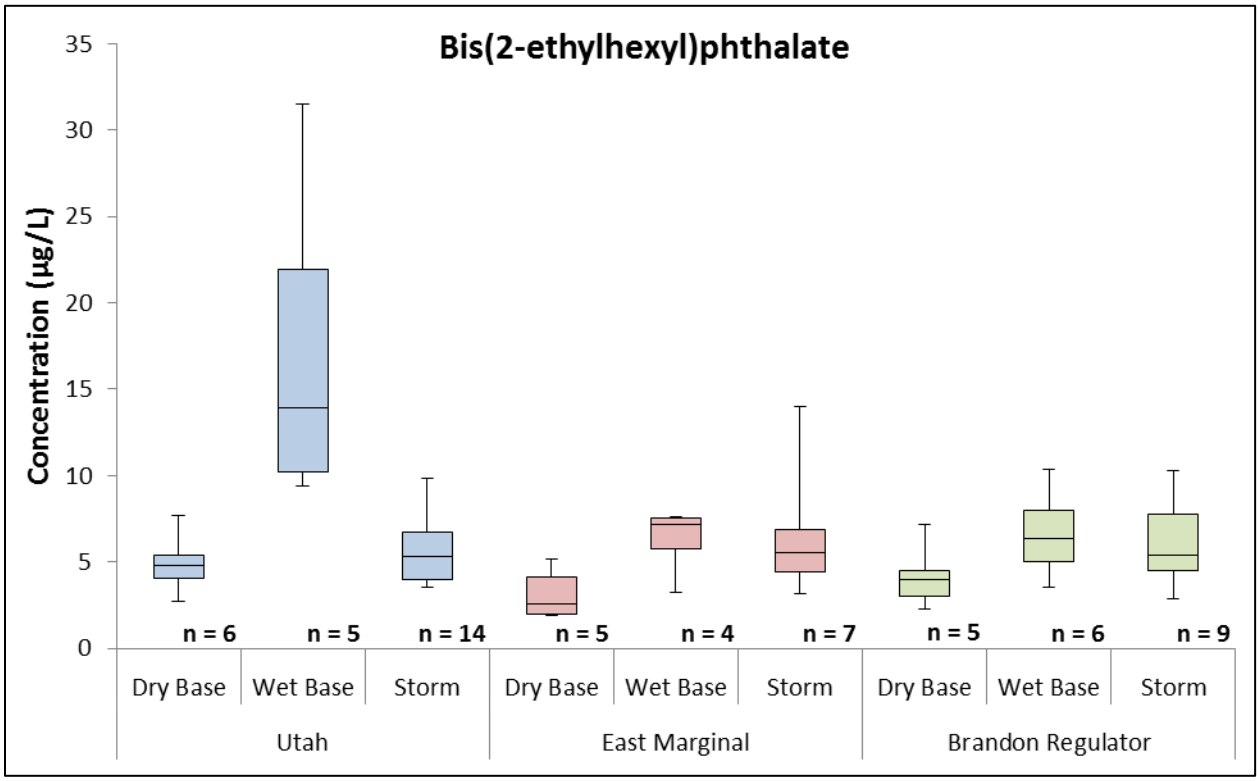

Figure 36. Boxplots of Bis(2-ethylhexyl)phthalate Concentration by Location and Flow Condition.

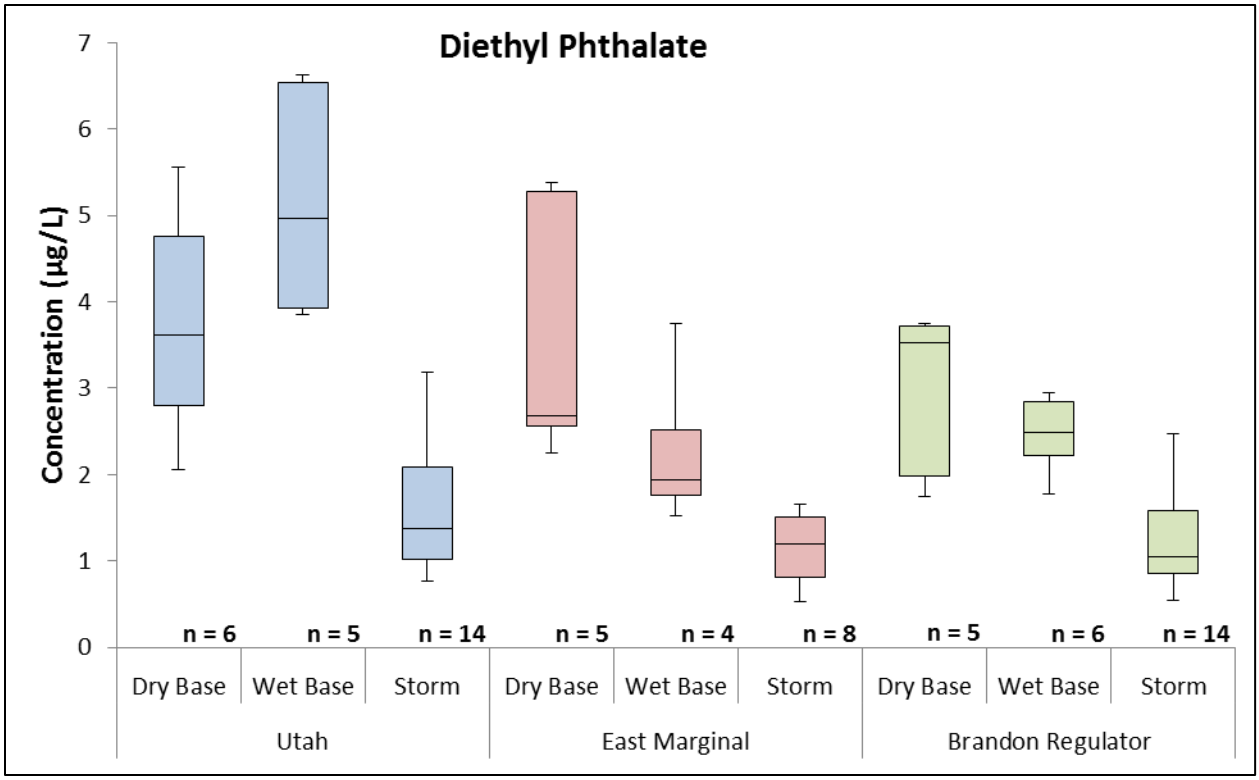

Figure 37. Boxplots of Diethyl Phthalate Concentration by Location and Flow Condition.

5.8 PCBs

PCB concentrations are presented in Table 14 and Figure 38. At least one PCB congener was detected in every sample, resulting in 100% FOD for total PCBs. Total PCBs were comprised of 82 to 139 detected congeners depending on the sample. Of these, less than 7% of the detected PCB congeners across all samples were reported between the LMCLs and SDL and flagged as estimated values. As a result there is some uncertainty for these data, but negligible uncertainty on the reported total PCB concentrations. Total PCBs ranged from 0.0112 µg/L to 0.362 µg/L across all sample types. The greatest variability in total PCB concentrations was observed at Brandon Regulator during stormflow sampling.

Table 14. Summary Statistics for Total PCB Concentrations by Location and Flow Condition.

Analyte	Location	Flow Condition	FOD	Concentration (µg/L)			
				Minimum Detected	Maximum Detected	Mean	Median
Total PCBs	Utah	Dry Base	3/3	0.0219	0.147	0.0668	0.0312
		Wet Base	2/2	0.0139	0.0189	0.0164	0.0164
		Storm	5/5	0.0312	0.0862	0.0659	0.0681
	East Marginal	Dry Base	3/3	0.0112	0.0689	0.0423	0.0468
		Wet Base	2/2	0.0194	0.0204	0.0199	0.0199
		Storm	5/5	0.0198	0.0632	0.0414	0.0358
	Brandon Regulator	Dry Base	2/2	0.0170	0.0330	0.0250	0.0250
		Wet Base	3/3	0.0224	0.0400	0.0287	0.0237
		Storm	5/5	0.0366	0.362	0.151	0.0939

FOD = Frequency of detection

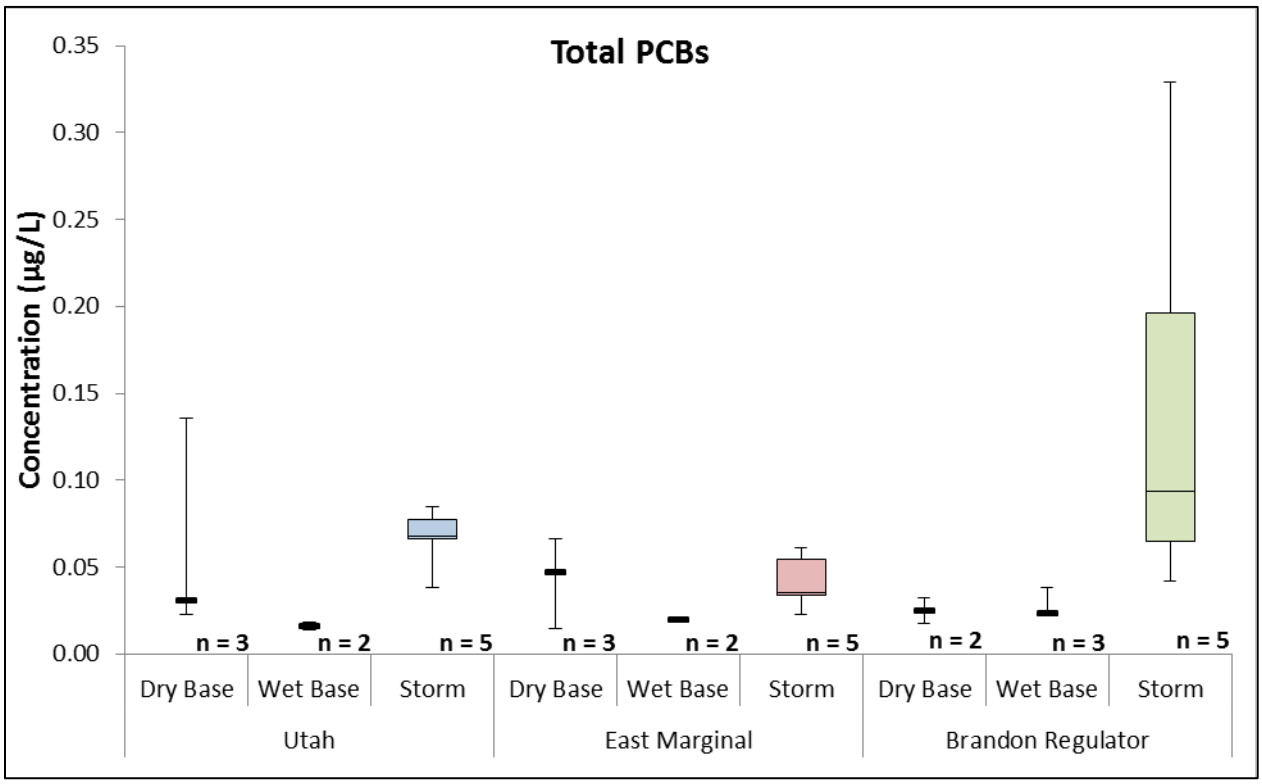

Figure 38. Boxplots of Total PCB Concentrations by Location and Flow Condition.

5.9 Dioxin/furans

Total dioxin/furans and total dioxin TEQ data are summarized in Table 15 and Figures 39 and 40. At least one of the 17 dioxin/furan congeners was detected in every sample, resulting in 100% FOD for total dioxin/furans. Total dioxin/furan concentrations ranged from 57.8 pg/L to 3,370 pg/L across all sample types. Total dioxin TEQs ranged from 0.173

pg TEQ/L to 15.1 pg TEQ/L. The greatest variability and magnitude in concentration was generally observed during stormflow sampling.

Table 15. Statistical Summary of Total Dioxin/Furan and Total Dioxin TEQ Concentrations by Location and Flow Condition.

Analyte	Location	Flow Condition	FOD	Concentration (pg/L)			
				Minimum Detected	Maximum Detected	Mean	Median
Total Dioxin/Furans	Utah	Dry Base	3/3	225	502	348	318
		Wet Base	2/2	57.8	113	85.5	85.5
		Storm	5/5	1,230	2,540	1,900	1,820
	East Marginal	Dry Base	3/3	200	1,500	646	237
		Wet Base	2/2	137	341	239	239
		Storm	5/5	953	1,840	1,220	979
	Brandon Regulator	Dry Base	2/2	139	402	270	270
		Wet Base	3/3	120	491	277	219
		Storm	5/5	577	3,370	2,240	2,250
Total Dioxin TEQs	Utah	Dry Base	3/3	1.44	4.67	2.72	2.04
		Wet Base	2/2	0.173	0.330	0.251	0.251
		Storm	5/5	7.75	14.6	11.0	11.9
	East Marginal	Dry Base	3/3	0.577	6.51	3.68	3.96
		Wet Base	2/2	0.291	0.880	0.585	0.585
		Storm	5/5	4.80	15.1	8.16	7.05
	Brandon Regulator	Dry Base	2/2	1.27	2.84	2.06	2.06
		Wet Base	3/3	0.307	2.90	1.32	0.742
		Storm	5/5	4.12	13.3	10.3	12.4

FOD = Frequency of detection

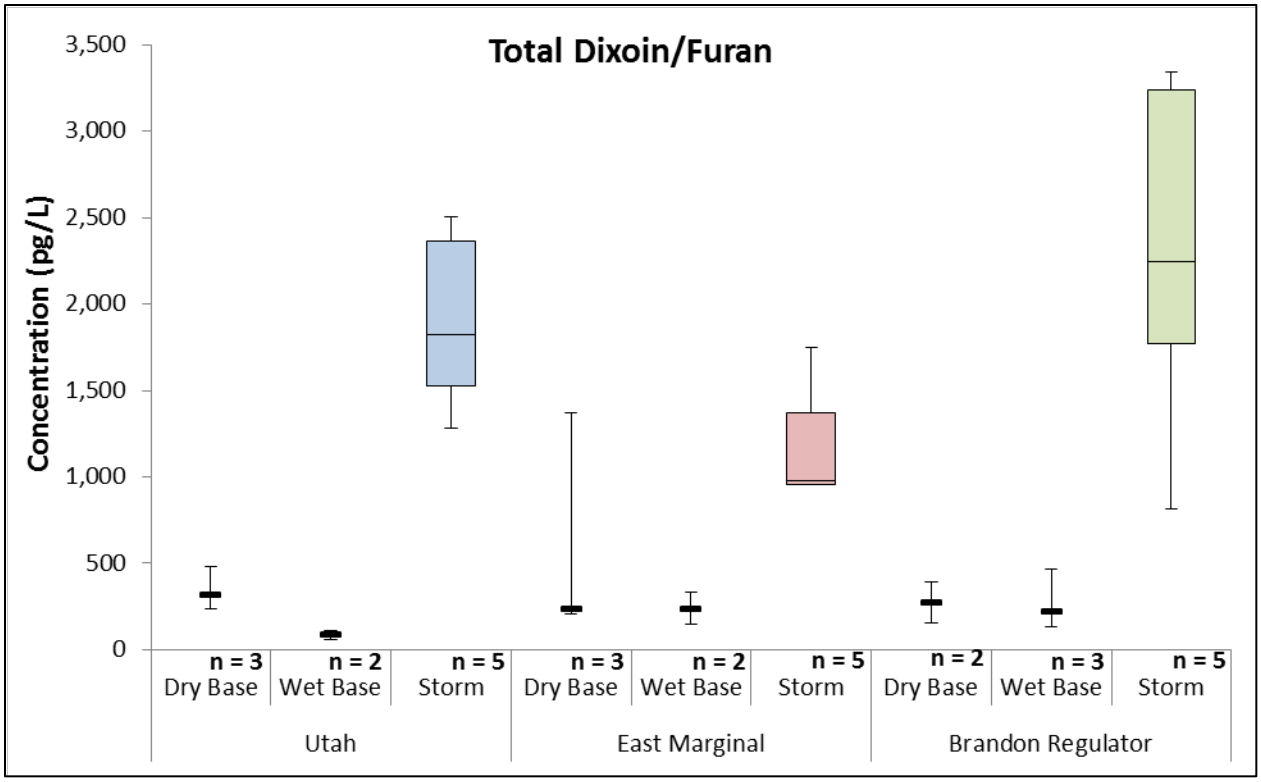

Figure 39. Boxplots of Total Dioxin/Furan Concentrations by Location and Flow Condition.

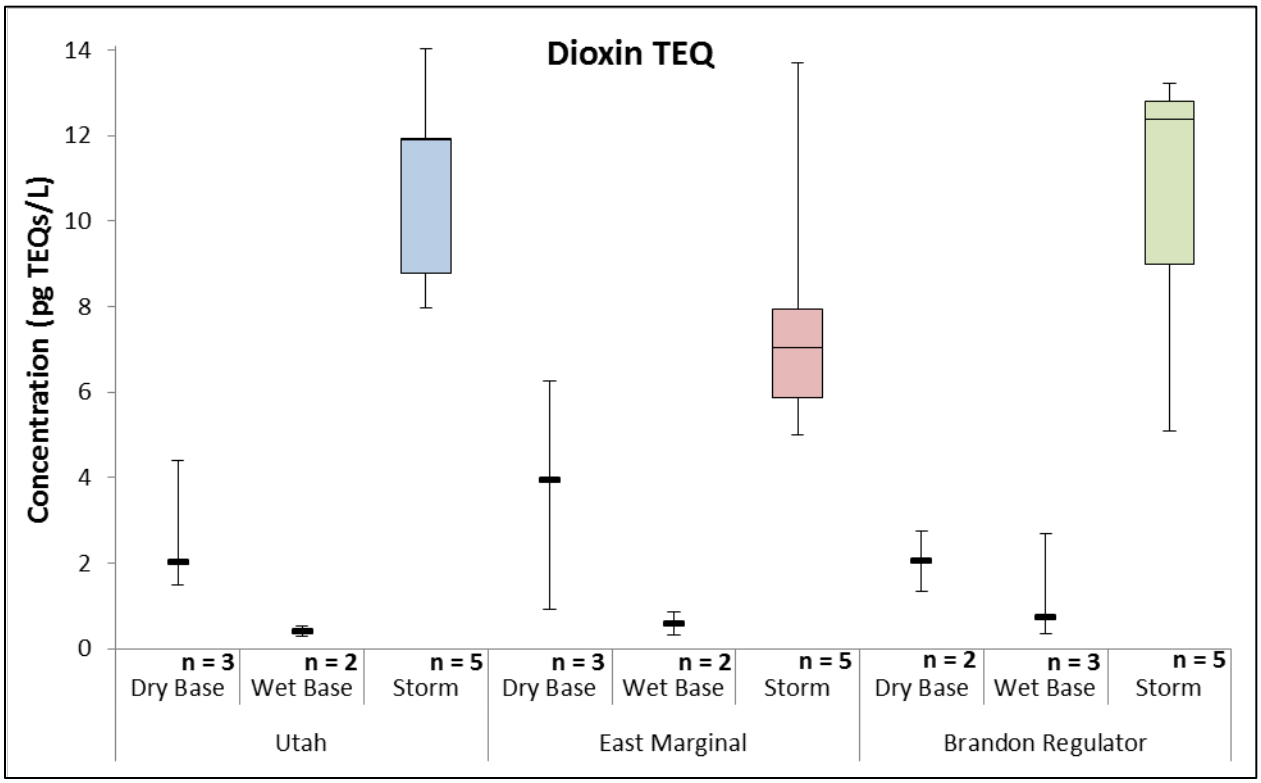

Figure 40. Boxplots of Total Dioxin TEQ Concentrations by Location and Flow Condition.

5.10 Additional Concentration Data

As described in Section 4.5.1, one stormflow sample at East Marginal and one dry baseflow sample at Brandon Regulator lacked the flow data necessary to calculate loadings. While parameter concentrations for these samples were not included in Sections 5.3 through 5.9, the relative percent differences between the means presented and means calculated including these sample results were 17% or less for conventional parameters, metals, phthalates and PCBs, and 33% or less for PAHs and dioxin/furans. Including these sample concentrations would result in slightly lower mean concentrations for conventional parameters, most metals, and most phthalates, and slightly higher mean concentrations for PAHs, PCBs and dioxin/furans. Including these samples only influenced the summary statistics for stormflow concentrations at East Marginal and dry baseflow concentrations at Brandon Regulator.

5.11 Data validation

Conventional parameter, metal, PAH and phthalate data were validated by King County using EPA National Functional Guidelines for Superfund data (EPA 2008 and 2010b) and the SAP (King County 2011d). Details of this validation are described in a data validation technical memorandum (Appendix D, Part 1). Validation of PCB and dioxin/furan congener data was completed by Laboratory Data Consultants, Inc. (LDC) in accordance with EPA Region 10 guidance (EPA 1995 and 1996). PCB congener validation reports are provided in Appendix D, Part 2. This section summarizes the major findings of the chemistry data validation. Materials reviewed included Batch Reports and Analytical Quality Control (QC) Reports downloaded from the KCEL Information Management System (LIMS) database, which are provided in the appendices.

5.11.1 Conventional Parameters, Metals, PAH and Phthalates

KCEL reviewed the conventional parameter, metal (including mercury), PAH and phthalate data by comparing the results to reference methods and SAP requirements, and flagging data with laboratory qualifiers where appropriate. Validation of these data was conducted by Water and Land Resources Division Science Unit staff. The validation process included review of the data anomaly forms, batch reports and analytical QC reports. The following QC parameters were also reviewed: holding time, method blanks, spike blanks and duplicates, matrix spikes and duplicates, laboratory duplicates and surrogates.

QC specifications were met for most conventional parameter, metal and mercury samples, and therefore, most of these analytes did not require qualification. QC results for PAH and phthalate analyses resulted in some data being qualified; a number of samples were qualified as estimates (J) and considered biased due to a variety of matrix influences. During analysis of dry baseflow samples, there was severe matrix suppression of the surrogate, d4-terphenyl. This surrogate is associated with the following target analytes; benzo(a)anthracene, chrysene, pyrene, benzyl butyl phthalate, bis(2-ethylhexyl) phthalate, di-n-butyl phthalate and fluoranthene. This finding suggests the results for these compounds may have an extremely low bias. The data validator recommended that any results less than the MDL for these compounds be rejected and removed from further

analysis. Thus, benzo(a)anthracene and di-n-butyl phthalate results in three samples (L54126-1, L54154-2 and L54154-3) and the chrysene result in sample L54154-3 were rejected (Appendix D for details). All analytical data except those rejected were of acceptable quality based on the data validation process.

Whenever a parameter was detected above the MDL, but below the RDL, the detected values were qualified as "J" or estimated with an unknown bias. Additional issues that resulted in the qualification of data are summarized below.

5.11.1.1 Conventional Parameters

As discussed in Section 2.3, acetone was originally used to decontaminate Teflon autosampler tubing. Following collection of the September baseflow samples, it was determined that the TOC and DOC analyses could be biased high as a result of residual acetone in the silicon tubing. When equipment blanks were tested for another project using the same decontamination methods, it was determined that the acetone rinse was the cause of false positives in the TOC and DOC analyses (Elliott 2013). As a result, the TOC and DOC data for the September baseflow samples were qualified as estimated (J) by the data validator. None of TOC and DOC analyses for samples collected after September 2011 were impacted because the acetone rinse was discontinued prior to their collection.

5.11.1.2 Metals and Mercury

Mercury was flagged as an estimated (J) value in one sample (L55433-2) due to high recovery limits in matrix spike/matrix spike duplicate. Due to the travel time from the sampling site to the KCEL, it was not feasible to filter samples within the required 15-minute holding time. As a result, all dissolved metals and dissolved mercury analyses were qualified with a "J" flag and considered estimated with an unknown bias.

5.11.2 PAHs and Phthalates

Some QC specifications were not met for PAH and phthalate analyses partially because the analytical method used was too sensitive. The method provided very low detection limit goals, but the sewage and stormwater matrices analyzed required dilution (with laboratory water) to ensure the instruments were not damaged by the high levels of organic chemicals in the sample. Sample dilution raised the effective detection limits and in many cases individual PAHs and phthalates were not detected. In addition, many detections were qualified as estimates (J) and considered biased due to a variety of matrix influences. A general summary of the reasons for data qualification are discussed below with the details provided in Appendix D.

Due to insufficient sample volume, neither a laboratory duplicate or matrix spike duplicate were analyzed in association with work groups WG117625, WG118307, and WG118436. However, a spike blank duplicate was analyzed for WG118436. Therefore, only samples associated with work groups WG117625 and WG118307 were qualified as estimated with unknown bias because of the lack of any type of laboratory duplicate sample associated with these samples.

Between four and 12 PAH and phthalate compounds were detected in every method blank associated with the data presented in this report. Many of the detected PAH and phthalate method blank results were at concentrations greater than the RDL, which is the limit of practical quantitation. Current EPA guidance (EPA 2008) rules were applied by the validator and results where the sample concentration was greater than the RDL and greater than five times the method blank concentration remained unqualified. When the detected method blank and sample concentrations were less than the RDL, the sample result was changed to the numeric RDL value and received a "U" validation qualifier. When method blank concentrations were detected and less that the RDL and the sample concentration was greater than the RDL, but less than five times the method blank concentration, the sample result remained as reported but received a "U" validation qualifier. Sample results were treated as not detected when "U" validation qualifiers are applied.

Other QC results that required data qualifications were low or high spike blank or matrix spike recoveries, high relative percent differences for laboratory duplicate results, and low surrogate recoveries. All 22 PAH and phthalate compounds were "J" or "UJ" qualified for one of the reasons listed above in at least one sample. Details are available in Appendix D.

5.11.3 PCBs and Dioxins/Furans

PCB and dioxin/furan data were validated to Level III by LDC. Level III validation includes verification of custody, holding times, reporting limits, sample QC and QC acceptance criteria, frequency of QC samples, instrument performance checks, along with initial and routine calibration checks.

Holding times and instrument performance checks, initial and continuing calibrations were all met for both PCB and dioxins/furans samples. Ongoing precision and recovery samples along with internal standard specifications were also met. Laboratory duplicates were within the SAP specification of 50 percent relative standard deviation (RSD). The compound, 2,3,7,8-TCDF, was sometimes analyzed on a dual column for confirmation. In these cases, LDC rejected the least technically valid result and retained the more technically valid column's detected concentration.

Some PCB and dioxin/furan congeners were detected in all method blank samples. Up to 28 PCB congeners were detected in all the methods blanks with detections across the entire PCB homolog range. Four dioxins and one furan were detected in method blanks as well. The total PCBs detected in method blanks ranged from 175 up to 248 pg/L while total dioxin and furans in method blanks ranged from 0.89 to 12.4 pg/L.

Environmental sample detections were qualified as non-detect by LDC whenever congener concentrations were less than five times the method blank concentration. The "5x rule" reduces the potential for false positives, but raises opportunities for false negatives. This potentially resulted in some low bias for congeners detected above the method blank concentration, but below five times the method blank. Only a few PCB congeners were detected in method blanks within five times the environmental sample concentration, congeners 3, 11, 16, and 35 were those most commonly found within five times the sample concentration.

Numerous PCB and dioxin/furan congeners were qualified by the analytical laboratory as "K" which means that not all identification and qualification criteria were met for these compounds. The maximum potential concentration is reported for "K" flagged congeners. These analytes were qualified by the validator as non-detects (U qualified) according to the EPA Region 10 validation requirements (EPA 1995).

6.0. LOADINGS ANALYSIS

This section presents a summary of the loading rate estimates for the samples that met one of the sample categories (dry baseflow, wet baseflow or stormflow conditions). These sample specific loading rates estimate loads that would be going to the West Point Treatment Plant via the EBI. Different parameters have been reported in kg, mg, or µg per hr loading rates to avoid excessive zeroes in the reported loads. It should be noted that, for consistency, loading rate estimates are presented to three significant figures, regardless of the significant figures associated with the concentration or flow values.

This section addresses the first three study design questions:

1. What are the chemical loadings within the Brandon Basin during dry season baseflow conditions (which represents the sewage component)?
2. What are the chemical loadings within the Brandon Basin during wet season baseflow conditions (which represents both sewage and potential infiltration components)?
3. What are the chemical loadings within the Brandon Basin during stormflow conditions (which represents the sewage and stormwater inflow components and low infiltration due to the hydrostatic pressure gradient)?

To address these questions, summaries of loading rate estimates are provided for sampling events including minimum, maximum, mean, and medians based on detected concentrations by location and flow condition. The methods used to calculate the loading rates are described in Section 4.5.2. By only including detections in the loadings analysis, parameters with lower FOD inherently have greater uncertainty. As described in Section 4.5.4, this does not necessarily result in high bias for the sample set high, rather the bias is unknown.

All analyzed conventional parameters and metals were included in the loading rate analysis because FOD was relatively high for these parameters. Inclusion of organic compounds was based on highest FOD within a chemical group. Phenanthrene and fluoranthene was chosen as the example LPAH and HPAH compound, respectively, both with 84% FOD. Total HPAHs were also included; at least one HPAH compound detected in 87% of the samples. On average, HPAH totals were the sum of six detected compounds. Three phthalates were included in the loading analysis: benzyl butyl phthalate (99% FOD), bis(2-ethylhexyl)phthalate (87% FOD), and diethyl phthalate (100% FOD). Loading calculations for total PCBs and total dioxin/furans were included, because at least one congener was detected in every sample (100% FOD). Loading rates for dioxin TEQs are also included because dioxin/furan source control data are often presented in this format.

In general, when differences between the mean and median are large the data are not normally distributed. Both the mean and median are provided to help illustrate how skews in the data may be influencing the mean loading estimates. At all sites for most parameters, a few high loading rates positively skewed the mean calculated loading rate higher than the median rates, but usually within a factor of two. Parameters with greater differences between means and medians are identified in this section to give the reader an overall

sense of loading rate distributions. General statements about relative differences between sites are based on comparison of means, medians, and the range of loading rates at each location.

All loading rates presented should be considered estimates for each flow condition and location and are not representative of loadings to the LDW (See Section 7.3). Only detected concentrations were used to calculate loading rates; summary statistics should be interpreted with caution as data summaries are increasingly uncertain for datasets with several non-detect values. In addition, a larger sample size would likely improve the accuracy of the reported mean loading rates and provide a better understanding of loading rates, given the high variability.

6.1 Conventional Parameters

Summary statistics for conventional parameter loading rates are summarized in Table 16. The minimum and lowest median loading rates for all conventional parameters (TOC, DOC and TSS) occurred at Utah during baseflow sampling, while the maximum and highest median loading rates almost always occurred at Brandon Regulator during stormflow sampling. Loading rates for all parameters during each flow condition were always lowest at Utah.

Table 16. Summary Statistics for Conventional Loading Rates by Location and Flow Condition.

Analyte	Location	Flow Condition	FOD	Loading Rate (kg/hr)							
				Minimum		Maximum		Mean		Median	
Total Organic Carbon	Utah	Dry Base	6/6	0.0530		0.139	J	0.0982	J	0.104	J
		Wet Base	5/5	0.0882		0.308		0.201		0.230	
		Storm	14/14	0.114		2.00		0.863		0.803	
	East Marginal	Dry Base	5/5	2.58	J	6.57		4.30	J	4.34	J
		Wet Base	5/5	1.35		6.93		4.11		4.59	
		Storm	8/8	2.47		24.4		11.4		9.23	
	Brandon Regulator	Dry Base	5/5	0.487		6.77	J	4.29	J	4.71	
		Wet Base	6/6	3.52		11.9		5.48		3.96	
		Storm	14/14	4.59		35.1		14.3		9.89	
Dissolved Organic Carbon	Utah	Dry Base	6/6	0.0290		0.109	J	0.0667	J	0.0652	J
		Wet Base	5/5	0.0511		0.200		0.118		0.106	
		Storm	14/14	0.0552		0.723		0.319		0.345	
	East Marginal	Dry Base	5/5	0.828	J	4.73		3.33	J	4.24	J
		Wet Base	5/5	1.02		6.36		3.03		2.06	
		Storm	8/8	0.370		20.1		7.23		6.17	
	Brandon Regulator	Dry Base	5/5	0.425		5.87	J	3.38	J	4.17	J
		Wet Base	6/6	2.51		5.04		3.28		2.81	
		Storm	14/14	2.45		22.4		7.81		5.27	

Table 16, Continued

Analyte	Location	Flow Condition	FOD	Loading Rate (kg/hr)			
				Minimum	Maximum	Mean	Median
Total Suspended Solids	Utah	Dry Base	6/6	0.100	0.687	0.285	0.169
		Wet Base	5/5	0.0621	0.284	0.168	0.161
		Storm	14/14	0.409	7.37	3.35	2.99
	East Marginal	Dry Base	5/5	0.953	7.25	3.80	2.55
		Wet Base	5/5	1.06	6.33	3.26	2.57
		Storm	8/8	1.97	24.6	12.1	13.1
	Brandon Regulator	Dry Base	5/5	0.286	7.25	4.61	5.05
		Wet Base	6/6	2.35	20.7	6.44	3.87
		Storm	14/14	10.3	124	39.4	26.6

FOD = frequency of detection; J = estimated value

6.2 Metals

The loading rates for metals are summarized in Table 17. The minimum and lowest median loading rates for all metals occurred at Utah during dry or wet baseflow sampling, except for dissolved silver, for which there were few detections. The maximum and highest median loading rates for metals occurred at Brandon Regulator during stormflow sampling, except for arsenic and chromium where loadings were much higher during a single wet baseflow event at this site. This event had both elevated flows and the highest concentrations of these two metals (Sections 5.2 and 5.4), resulting in loading rates between 30 and 100 times higher than the wet baseflow median. Wet baseflow loading rate means for arsenic and chromium at Brandon Regulator are highly influenced by this one sampling event.

Table 17. Summary Statistics for Metal Loading Rates by location and flow condition.

Analyte	Location	Flow Condition	FOD	Loading Rate (mg/hr)			
				Minimum	Maximum	Mean	Median
Total Arsenic	Utah	Dry Base	6/6	0.488	2.35	1.15	0.973
		Wet Base	5/5	0.658	1.86	1.41	1.46
		Storm	14/14	5.94	108	31.4	16.2
	East Marginal	Dry Base	5/5	6.06	21.1	13.7	15.7
		Wet Base	5/5	6.99	12.4	10.0	9.74
		Storm	8/8	22.1	252	84.8	52.2
	Brandon Regulator	Dry Base	5/5	2.13	57.1	33.6	46.3
		Wet Base	6/6	18.1	8,350	1420	39.0
		Storm	14/14	63.3	869	363	256

Table 17, Continued

Analyte	Location	Flow Condition	FOD	Loading Rate (mg/hr)							
				Minimum		Maximum		Mean		Median	
Dissolved Arsenic	Utah	Dry Base	6/6	0.325	J	1.06	J	0.728	J	0.726	J
		Wet Base	5/5	0.653	J	1.89	J	1.29	J	1.40	J
		Storm	14/14	3.82	J	41.8	J	14.6	J	9.57	J
	East Marginal	Dry Base	4/4	4.61	J	8.48	J	6.08	J	5.61	J
		Wet Base	4/4	6.03	J	8.30	J	7.43	J	7.70	J
		Storm	7/7	13.2	J	219	J	59.7	J	37.0	J
	Brandon Regulator	Dry Base	4/4	1.79	J	37.4	J	27.2	J	34.8	J
		Wet Base	6/6	13.9	J	8,630	J	1,460	J	23.1	J
		Storm	13/13	42.1	J	500	J	186	J	164	J
Total Cadmium	Utah	Dry Base	6/6	0.100	J	0.795		0.344	J	0.233	J
		Wet Base	5/5	0.0980	J	0.358	J	0.233	J	0.259	J
		Storm	14/14	1.31	J	23.4		7.03	J	4.53	
	East Marginal	Dry Base	4/5	0.741	J	5.23		2.55	J	2.11	
		Wet Base	5/5	1.13	J	3.1		2.08	J	2.14	
		Storm	8/8	3.72		58.6		21.1		13.9	
	Brandon Regulator	Dry Base	5/5	1.15		10.5		6.28		7.33	
		Wet Base	6/6	3.61		131		26.8		6.92	
		Storm	14/14	16.3		213		77.7		52.5	
Dissolved Cadmium	Utah	Dry Base	3/6	0.0378	J	0.0689	J	0.0508	J	0.0457	J
		Wet Base	4/5	0.0500	J	0.169	J	0.111	J	0.112	J
		Storm	10/14	0.250	J	4.53	J	1.22	J	0.752	J
	East Marginal	Dry Base	0/4	NC		NC		NC		NC	
		Wet Base	1/4	NC		0.501	J	NC		NC	
		Storm	5/7	0.763	J	15.4	J	4.95	J	2.88	J
	Brandon Regulator	Dry Base	4/4	0.470	J	2.38	J	1.78	J	2.14	J
		Wet Base	6/6	0.673	J	51.3	J	9.74	J	1.59	J
		Storm	9/9	3.05	J	58.8	J	14.2	J	9.40	J
Total Chromium	Utah	Dry Base	6/6	0.879		9.93		3.82		1.48	
		Wet Base	5/5	1.06		12.9		3.83	J	1.56	J
		Storm	14/14	20.0		464		139		81.3	
	East Marginal	Dry Base	5/5	9.21		61.4		28.2		10.6	
		Wet Base	5/5	25.3		57.0		42.7		42.7	
		Storm	8/8	73.6		449		205		179	
	Brandon Regulator	Dry Base	5/5	11.6		279		166		171	
		Wet Base	6/6	50.1		15,300		2,610		86.7	
		Storm	14/14	270		5,140		1,570		900	

Table 17, Continued

Analyte	Location	Flow Condition	FOD	Loading Rate (mg/hr)							
				Minimum		Maximum		Mean		Median	
Dissolved Chromium	Utah	Dry Base	6/6	0.184	J	0.534	J	0.355	J	0.352	J
		Wet Base	5/5	0.453	J	8.62	J	2.21	J	0.580	J
		Storm	14/14	3.02	J	60.9	J	14.3	J	5.69	J
	East Marginal	Dry Base	4/4	3.32	J	5.59	J	4.32	J	4.19	J
		Wet Base	4/4	11.7	J	35.1	J	19.0	J	14.7	J
		Storm	7/7	16.4	J	39.3	J	28.9	J	33.5	J
	Brandon Regulator	Dry Base	4/4	4.93	J	63.3	J	44.7	J	55.3	J
		Wet Base	6/6	19.7	J	12,200	J	2,050	J	21.2	J
		Storm	13/13	50.3	J	453	J	179	J	141	J
Total Copper	Utah	Dry Base	6/6	26.5		114		55.5		30.1	
		Wet Base	5/5	19.6		63.6		44.1		51.8	
		Storm	14/14	141		2,490		845		641	
	East Marginal	Dry Base	5/5	22.1		854		374		185	
		Wet Base	5/5	235		526		387		368	
		Storm	8/8	508		2,510		1,530		1,450	
	Brandon Regulator	Dry Base	5/5	82.8		1,700		1,100		1,470	
		Wet Base	6/6	679		4,250		1,420		863	
		Storm	14/14	2,820		46,600		10,300		5,650	
Dissolved Copper	Utah	Dry Base	6/6	7.95	J	16.5	J	11.4	J	10.8	J
		Wet Base	5/5	7.42	J	36.5	J	21.5	J	23.0	J
		Storm	14/14	48.8	J	623	J	186	J	125	J
	East Marginal	Dry Base	4/4	41.6	J	69.4	J	57.0	J	58.6	J
		Wet Base	4/4	55.0	J	176	J	105	J	95	J
		Storm	7/7	173	J	554	J	420	J	476	J
	Brandon Regulator	Dry Base	4/4	37.6	J	566	J	398	J	494	J
		Wet Base	6/6	74.5	J	1,460	J	464	J	304	J
		Storm	13/13	621	J	4,050	J	2,010	J	1,990	J
Total Lead	Utah	Dry Base	6/6	2.14		48.3		14.7		6.84	
		Wet Base	5/5	3.60		14.2		8.88		9.79	
		Storm	14/14	66.4		1,260		418		253	
	East Marginal	Dry Base	5/5	6.65		220		102		43.8	
		Wet Base	5/5	34.7		102		66.7		50.0	
		Storm	8/8	186		1,380		628		483	
	Brandon Regulator	Dry Base	5/5	5.46		346		200		252	
		Wet Base	6/6	63.7		1,910		464		221	
		Storm	14/14	467		10,400		3,610		2,230	

Table 17, Continued

Analyte	Location	Flow Condition	FOD	Loading Rate (mg/hr)							
				Minimum		Maximum		Mean		Median	
Dissolved Lead	Utah	Dry Base	6/6	0.503	J	1.56	J	1.04	J	1.07	J
		Wet Base	5/5	0.952	J	4.28	J	2.30	J	2.45	J
		Storm	14/14	4.50	J	35.7	J	14.6	J	9.45	J
	East Marginal	Dry Base	4/4	3.63	J	7.56	J	5.15	J	4.71	J
		Wet Base	4/4	7.50	J	13.0	J	9.67	J	9.08	J
		Storm	7/7	24.7	J	102	J	51.9	J	43.2	J
	Brandon Regulator	Dry Base	4/4	1.16	J	67.5	J	38.8	J	43.3	J
		Wet Base	6/6	5.89	J	206	J	58.5	J	34.4	J
		Storm	13/13	43.1	J	546	J	186	J	182	J
Total Nickel	Utah	Dry Base	6/6	2.43		11.4		5.67		3.23	
		Wet Base	5/5	2.75		6.30		4.10		4.06	
		Storm	14/14	23.6		487		149		90.6	
	East Marginal	Dry Base	5/5	20.8		79.9		42.2		26.2	
		Wet Base	5/5	22.3		46.1		36.6		35.4	
		Storm	8/8	85.1		403		206		175	
	Brandon Regulator	Dry Base	5/5	37.1		820		532		603	
		Wet Base	6/6	350		9,580		2,130		482	
		Storm	14/14	1,100		82,600		9,890		2,820	
Dissolved Nickel	Utah	Dry Base	6/6	1.21	J	3.39	J	2.21	J	2.10	J
		Wet Base	5/5	2.11	J	5.42	J	3.28	J	3.00	J
		Storm	14/14	9.76	J	97.1	J	36.9	J	27.5	J
	East Marginal	Dry Base	4/4	14.0	J	32.2	J	21.8	J	20.4	J
		Wet Base	4/4	17.9	J	29.7	J	24.5	J	25.3	J
		Storm	7/7	32.5	J	108	J	83.8	J	95.7	J
	Brandon Regulator	Dry Base	4/4	32.5	J	677	J	440	J	525	J
		Wet Base	6/6	306	J	9,330	J	1,910	J	362	J
		Storm	13/13	528	J	68,400	J	7,560	J	1,770	J
Total Silver	Utah	Dry Base	6/6	0.0328	J	2.11		0.483	J	0.195	
		Wet Base	5/5	0.0894	J	2.61		0.608	J	0.0980	J
		Storm	14/14	0.908	J	21.7		4.88	J	3.12	
	East Marginal	Dry Base	4/5	0.225	J	1.78		0.850	J	0.697	J
		Wet Base	5/5	0.350	J	1.06	J	0.620	J	0.434	J
		Storm	8/8	0.694	J	4.85	J	3.15	J	3.46	J
	Brandon Regulator	Dry Base	5/5	0.433		12.0		7.00		7.30	
		Wet Base	6/6	2.11	J	35.3		9.67	J	4.97	
		Storm	14/14	10.5	J	337		72.7	J	26.3	J

Table 17, Continued

Analyte	Location	Flow Condition	FOD	Loading Rate (mg/hr)			
				Minimum	Maximum	Mean	Median
Dissolved Silver	Utah	Dry Base	1/6	NC	0.452 J	NC	NC
		Wet Base	1/5	NC	1.91 J	NC	NC
		Storm	5/14	0.295 J	3.42 J	1.64 J	1.65 J
	East Marginal	Dry Base	0/4	NC	NC	NC	NC
		Wet Base	0/4	NC	NC	NC	NC
		Storm	0/7	NC	NC	NC	NC
	Brandon Regulator	Dry Base	2/4	1.78 J	1.97 J	1.87 J	NC
		Wet Base	3/6	0.633 J	2.00 J	1.14 J	0.799 J
		Storm	3/13	2.98 J	26.2 J	12.5 J	8.33 J
Total Vanadium	Utah	Dry Base	6/6	1.14	6.84	2.91	1.93
		Wet Base	5/5	1.14	16.9	5.17	2.41
		Storm	14/14	19.5	515	143	62.0
	East Marginal	Dry Base	5/5	13.4	73.1	37.1	29.1
		Wet Base	5/5	14.6	38.2	25.5	21.5
		Storm	8/8	71.3	444	189	149
	Brandon Regulator	Dry Base	5/5	3.84	156	81.2	86.5
		Wet Base	6/6	27.0	1,030	206	46.5
		Storm	14/14	159	2,760	1,020	791
Dissolved Vanadium	Utah	Dry Base	6/6	0.399 J	2.00 J	1.08 J	1.04 J
		Wet Base	5/5	0.653 J	2.05 J	1.33 J	1.41 J
		Storm	14/14	4.20 J	66.4 J	24.2 J	13.5 J
	East Marginal	Dry Base	4/4	5.34 J	13.6 J	8.44 J	7.39 J
		Wet Base	4/4	7.33 J	9.57 J	8.09 J	7.73 J
		Storm	7/7	17.1 J	73.9 J	35.8 J	29.1 J
	Brandon Regulator	Dry Base	4/4	1.21 J	75.5 J	53.3 J	68.3 J
		Wet Base	6/6	12.2 J	394 J	82.3 J	19.7 J
		Storm	13/13	35.1 J	397 J	158 J	126 J
Total Zinc	Utah	Dry Base	6/6	63.1	343	140	73.7
		Wet Base	5/5	50.6	155	102	91.4
		Storm	14/14	544	11,300	3,260	2,150
	East Marginal	Dry Base	5/5	75.2	2,930	1,270	477
		Wet Base	5/5	799	2,820	1,350	912
		Storm	8/8	2,280	11,200	7,210	7,590
	Brandon Regulator	Dry Base	5/5	164	3,590	2,330	2,920
		Wet Base	6/6	1,470	11,300	3,480	2,030
		Storm	14/14	8,150	94,200	31,000	19,800

Table 17, Continued

Analyte	Location	Flow Condition	FOD	Loading Rate (mg/hr)							
				Minimum		Maximum		Mean		Median	
Dissolved Zinc	Utah	Dry Base	6/6	12.9	J	22.5	J	17.7	J	17.7	J
		Wet Base	5/5	27.3	J	85.3	J	47.3	J	44.7	J
		Storm	14/14	223	J	2,800	J	908	J	495	J
	East Marginal	Dry Base	4/4	167	J	287	J	216	J	206	J
		Wet Base	4/4	301	J	481	J	384	J	377	J
		Storm	7/7	734	J	3,550	J	2,590	J	2,750	J
	Brandon Regulator	Dry Base	4/4	68.1	J	1,270	J	801	J	933	J
		Wet Base	6/6	766	J	5,700	J	1,690	J	917	J
		Storm	13/13	2,330	J	20,000	J	8,630	J	6,360	J

FOD = frequency of detection; J = estimated value
Means calculated only with two or more detections; medians calculated only with three or more detections.

6.3 Mercury

Total and dissolved mercury loading rates ranged from 0.0149 mg/hr to 124 mg/hr and 0.00296 mg/hr to 3.31 mg/hr, respectively (Table 18). The maximum and highest median loading rates always occurred at Brandon Regulator during stormflow conditions, while the loading rates for each flow condition were always lowest at Utah.

Table 18. Summary Statistics for Mercury Loading Rates by location and flow condition.

Analyte	Location	Flow Condition	FOD	Loading Rate (mg/hr)			
				Minimum	Maximum	Mean	Median
Total Mercury	Utah	Dry Base	6/6	0.0212	0.126	0.0553	0.0310
		Wet Base	5/5	0.0149	0.0605	0.0317	0.0263
		Storm	14/14	0.123	2.77	0.845	0.525
	East Marginal	Dry Base	5/5	0.125	0.975	0.410	0.256
		Wet Base	5/5	0.243	0.524	0.434	0.490
		Storm	8/8	0.361 J	3.89	1.76 J	1.33
	Brandon Regulator	Dry Base	5/5	0.0421	1.67	0.994	1.15
		Wet Base	6/6	0.270	4.67	1.29	0.602
		Storm	14/14	1.62	124	19.4 J	7.00
Dissolved Mercury	Utah	Dry Base	5/6	0.00296 J	0.00947 J	0.00649 J	0.00668 J
		Wet Base	4/5	0.00604 J	0.0164 J	0.0104 J	0.00957 J
		Storm	6/14	0.0306 J	0.165 J	0.0843 J	0.0625 J
	East Marginal	Dry Base	1/4	NC	0.0629 J	NC	NC
		Wet Base	4/4	0.0553 J	0.200 J	0.109 J	0.0897 J
		Storm	3/7	0.136 J	0.662 J	0.373 J	0.320 J
	Brandon Regulator	Dry Base	4/4	0.0115 J	0.245 J	0.129 J	0.129 J
		Wet Base	4/6	0.0722 J	0.966 J	0.328 J	0.136 J
		Storm	7/13	0.242 J	3.31 J	1.12 J	0.410 J

FOD = frequency of detection; J = estimated value; NC = not calculated
Means calculated only with two or more detections; medians calculated only with three or more detections.

6.4 PAHs

Phenanthrene loading rates ranged from 0.0289 mg/hr to 57.4 mg/hr, fluoranthene loading rates ranged from 0.0232 mg/hr to 73.7 mg/hr, and total HPAH loading rates ranged from 0.0299 mg/hr to 310 mg/hr (Table 19). The maximum and highest median loading rates always occurred at Brandon Regulator during stormflow sampling.

Table 19. Summary Statistics for PAH Loading Rates by location and flow condition.

Analyte	Location	Flow Condition	FOD	Loading Rate (mg/hr)							
				Minimum		Maximum		Mean		Median	
Phenanthrene	Utah	Dry Base	4/6	0.0289		0.149		0.0830		0.0772	
		Wet Base	4/5	0.0808		0.147	J	0.106	J	0.0977	J
		Storm	14/14	0.268	J	8.00		2.26		1.62	
	East Marginal	Dry Base	2/5	0.514		0.799	J	0.656	J	NC	
		Wet Base	2/4	0.481		0.728	J	0.604	J	NC	
		Storm	7/8	2.54		8.40		4.59		4.01	
	Brandon Regulator	Dry Base	4/5	0.0939	J	2.44		1.68		2.09	
		Wet Base	5/6	0.733	J	1.93		1.20	J	1.11	J
		Storm	14/14	3.16		57.4		22.1		15.6	
Fluoranthene	Utah	Dry Base	6/6	0.0232	J	0.168	J	0.0620	J	0.0338	J
		Wet Base	2/5	0.0622	J	0.0793	J	0.0708	J	NC	
		Storm	14/14	0.320		11.3	J	3.79	J	2.46	
	East Marginal	Dry Base	4/5	0.101	J	0.582	J	0.321	J	0.301	J
		Wet Base	1/4	NC		0.276	J	NC		NC	
		Storm	7/8	2.59		8.63		4.57		4.02	
	Brandon Regulator	Dry Base	5/5	0.0527	J	1.78		1.04	J	1.36	J
		Wet Base	3/6	0.692	J	2.19		1.21	J	0.748	J
		Storm	14/14	2.79	J	73.7		27.7	J	19.4	
Total HPAHs	Utah	Dry Base	6/6	0.0299	J	0.541	J	0.177	J	0.0777	J
		Wet Base	2/5	0.194	J	0.239	J	0.216	J	NC	
		Storm	14/14	1.23	J	68.0	J	18.9	J	11.3	J
	East Marginal	Dry Base	4/5	0.157	J	1.67	J	0.895	J	0.875	J
		Wet Base	2/4	0.276	J	0.510	J	0.393	J	NC	J
		Storm	7/8	8.78	J	35.4	J	17.4	J	12.6	J
	Brandon Regulator	Dry Base	5/5	0.0527	J	3.25	J	2.19	J	2.33	J
		Wet Base	4/6	1.78	J	8.10	J	5.01	J	5.08	J
		Storm	14/14	9.63	J	310	J	124	J	80.9	J

FOD = frequency of detection; J = estimated value; NC = not calculated
Means calculated only with two or more detections; medians calculated only with three or more detections.

6.5 Phthalates

Benzyl butyl phthalate loading rates ranged from 0.930 mg/hr to 2,940 mg/hr, bis(2-ethylhexyl)phthalate loading rates ranged from 1.76 mg/hr to 2,570 mg/hr, and diethyl phthalate loading rates ranged from 1.19 mg/hr to 345 mg/hr (Table 20). The maximum and highest median loading rates almost always occurred at Brandon Regulator during stormflow sampling.

Table 20. Summary Statistics for Benzyl Butyl Phthalate Loading Rates by location and flow condition.

Analyte	Location	Flow Condition	FOD	Loading Rate (mg/hr)							
				Minimum		Maximum		Mean		Median	
Benzyl Butyl Phthalate	Utah	Dry Base	6/6	2.40	J	37.5	J	15.9	J	8.96	J
		Wet Base	5/5	31.7		308		134	J	104	
		Storm	14/14	9.76	J	349		128	J	122	
	East Marginal	Dry Base	5/5	0.930	J	3.56	J	1.96	J	1.26	J
		Wet Base	4/4	1.32		8.11		4.51	J	4.31	J
		Storm	7/8	6.41		3,090		463		18.4	
	Brandon Regulator	Dry Base	5/5	6.75	J	107		56.1	J	67.2	J
		Wet Base	6/6	55.7		351		141	J	104	J
		Storm	14/14	112		2,940		577	J	254	
Bis(2-ethylhexyl)phthalate	Utah	Dry Base	6/6	1.76	J	7.31	J	3.85	J	2.90	J
		Wet Base	5/5	16.9	J	32.0	J	21.7	J	19.3	J
		Storm	11/14	20.2	J	262	J	80.4	J	59.2	J
	East Marginal	Dry Base	5/5	8.66	J	28.8	J	16.6	J	10.7	J
		Wet Base	4/4	14.6	J	56.1	J	38.7	J	42.0	J
		Storm	7/8	86.7	J	337	J	181	J	167	J
	Brandon Regulator	Dry Base	5/5	3.89	J	191	J	83.3	J	96.6	J
		Wet Base	6/6	59.7	J	213	J	108	J	92.0	J
		Storm	9/14	170	J	2,570	J	870	J	342	J
Diethyl Phthalate	Utah	Dry Base	6/6	1.19		4.96		2.84		2.68	
		Wet Base	5/5	3.61		14.0		7.75	J	6.49	
		Storm	14/14	6.64		51.1		23.6		24.4	
	East Marginal	Dry Base	5/5	8.27		28.8		18.8	J	16.5	
		Wet Base	4/4	8.92	J	22.8		14.2	J	12.6	
		Storm	8/8	12.4		56.0		33.0		30.4	
	Brandon Regulator	Dry Base	5/5	3.18	J	90.3		56.2	J	86.3	
		Wet Base	6/6	27.3	J	113		44.4	J	29.8	
		Storm	14/14	53.6		345		145		98.0	

FOD = frequency of detection; J = estimated value
Means calculated only with two or more detections; medians calculated only with three or more detections.

6.6 PCBs and Dioxin/Furans

Total PCB loading rates ranged from 12.2 µg/hr to 56,800 µg/hr, while total dioxin/furan loading rates ranged from 0.0957 µg/hr to 568 µg/hr. (Table 21). The maximum and highest mean loading rates always occurred at Brandon Regulator during stormflow sampling.

Table 21. Summary Statistics for PCBs and Total Dioxin Loading Rates by location and flow condition.

Analyte	Location	Flow Condition	FOD	Loading Rate (µg/hr)			
				Minimum	Maximum	Mean	Median
Total PCBs	Utah	Dry Base	3/3	12.2	128	55.8	26.9
		Wet Base	2/2	23.0	30.6	26.8	NC
		Storm	5/5	231	5,510	1,700	746
	East Marginal	Dry Base	3/3	51.7	424	244	255
		Wet Base	2/2	115	145	130	NC
		Storm	5/5	468	1,960	1,180	1,150
	Brandon Regulator	Dry Base	2/2	31.9	800	416	NC
		Wet Base	3/3	263	2,760	1,100	279
		Storm	5/5	1,800	56,800	22,300	23,700
Total Dioxin/Furans	Utah	Dry Base	3/3	0.177	0.437	0.269	0.194
		Wet Base	2/2	0.0957	0.183	0.140	NC
		Storm	5/5	9.07	180	51.5	19.3
	East Marginal	Dry Base	3/3	0.928	9.21	3.81	1.29
		Wet Base	2/2	0.775	2.54	1.66	NC
		Storm	5/5	19.0	66.2	35.1	30.7
	Brandon Regulator	Dry Base	2/2	0.261	9.75	5.00	NC
		Wet Base	3/3	1.33	33.9	12.7	2.73
		Storm	5/5	28.3	568	333	400

FOD = frequency of detection; J = estimated value
Means calculated only with two or more detections; medians calculated only with three or more detections.

Total dioxin TEQ loading rates ranged from 0.0100 ng 2,3,7,8-TCDD TEQ/hr a to 44.8 ng 2,3,7,8-TCDD TEQ/hr (Table 22).

Table 22. Summary Statistics for Total Dioxin TEQ Loading Rates by location and flow condition.

Analyte	Location	Flow Condition	FOD	Loading Rate (ng TEQ/hr)			
				Minimum	Maximum	Mean	Median
Total Dioxin TEQs	Utah	Dry Base	3/3	1.14	4.07	2.15	1.24
		Wet Base	2/2	0.286	0.533	0.410	NC
		Storm	5/5	57.4	845	263	119
	East Marginal	Dry Base	3/3	2.67	40.0	21.4	21.6
		Wet Base	2/2	1.64	6.57	4.11	NC
		Storm	5/5	110	544	244	189
	Brandon Regulator	Dry Base	2/2	5.35	30.91	18.13	NC
		Wet Base	3/3	3.41	200	71.0	9.3
		Storm	5/5	202	3236	1552	1532

FOD = frequency of detection; J = estimated value; NC = not calculated
Means calculated only with two or more detections; medians calculated only with three or more detections.

6.7 Stormflow Loading Rates Normalized to Drainage Area

To better understand the differences in stormflow loading rates between sampling locations, sample loading rates were divided by the contributing drainage area, generating a loading rate by unit area. This analysis was only conducted for stormflow loading rates and did not address differences in impervious surface area or other potential influences on stormflow loading rates because distinguishing these influences was not a study objective. A more detailed discussion, including summary tables and box plot figures are included as Appendix E. This analysis found that normalizing by area decreases the influence of flow differences between sites, which results in loading rates that are more similar between sites on a per acre basis with the exception of TOC, DOC and benzyl butyl phthalate.

7.0. DISCUSSION

This section explores the differences between dry and wet baseflow samples as well as between baseflow and stormflow samples. Through these comparisons, this section addresses the last two study design questions:

4. What are the chemical loadings within the Brandon Basin from infiltration to the collection system pipes (which represents the wet season baseflow condition minus the sewage [dry season baseflow] component)?
5. What are the chemical loadings within the Brandon Basin from stormwater inflow (which represents the stormflow condition minus the sewage [baseflow] component)?

As noted previously, these sample specific loading rate estimates represent loads that would be going to the West Point Treatment Plant via the EBI, and are not estimates of CSO discharge loading rates. Section 7.1 addresses question four with statistical comparisons of loading rate estimates between dry and wet baseflow samples. Section 7.2 addresses study question five with statistical comparisons of loading estimates between baseflow and stormflow samples. These questions support the study objective of estimating the relative magnitude of pathways during storm events (sewage versus stormwater) as presented in Section 7.3. Finally, an uncertainty assessment is performed for the primary pathway estimates in Section 7.4.

7.1 Dry versus Wet Baseflow Samples (Infiltration)

To evaluate chemical loadings due to possible groundwater infiltration, statistical differences in flows, and conventional parameter and chemical loading rates between dry and wet baseflow samples were evaluated. This section presents some of these data to illustrate the relative magnitude of the differences between the two flow regimes.

7.1.1 Flow

Both the instantaneous five minute flow data and the mean flow at Utah and East Marginal locations showed statistical differences ($p<0.05$) between dry and wet baseflow samples at each site. There were no statistical differences between dry and wet baseflow samples at Brandon Regulator. Figure 41 illustrates mean flow during sampling for each site and flow condition.

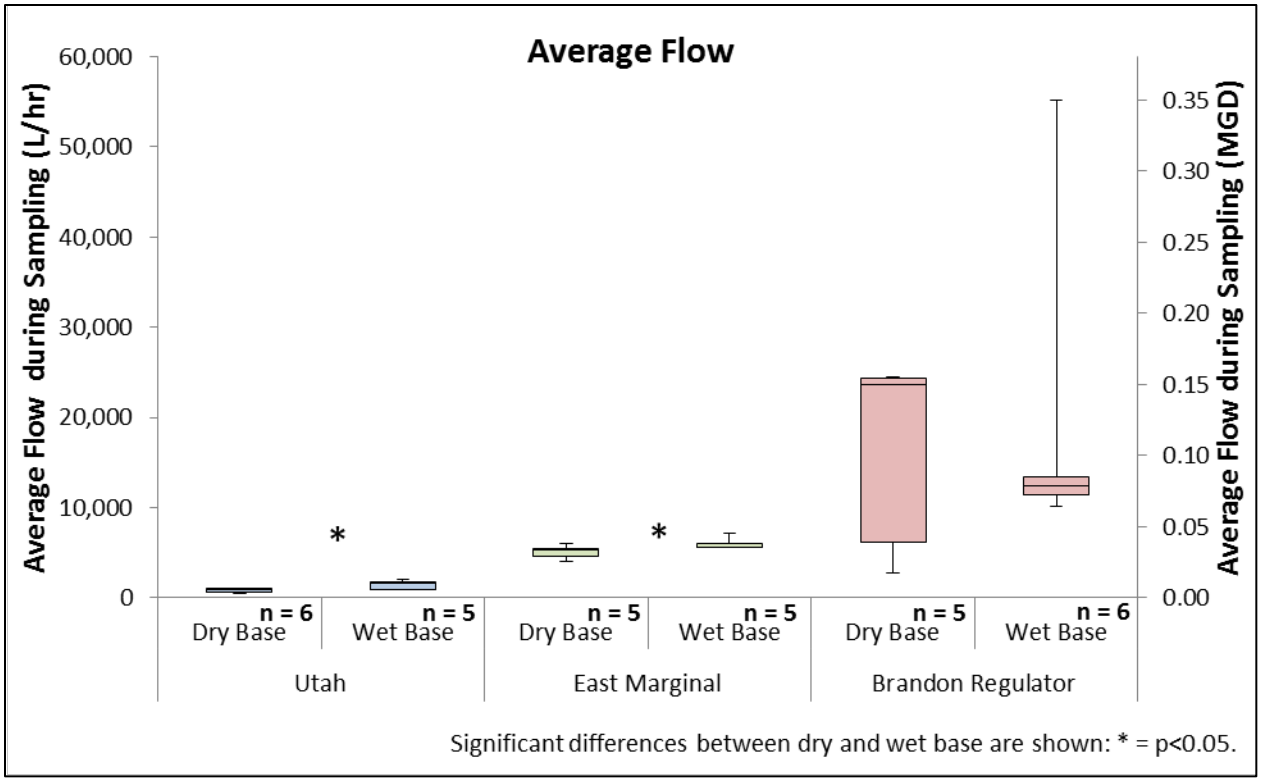

Figure 41. Boxplots of Dry and Wet Baseflow by Location and Flow Condition.

7.1.2 Conventionals

There were no statistical differences between loading rates for TSS, TOC and DOC during dry and wet baseflow conditions at each site. However, for many of these statistical tests the power was less than 0.80, indicating a relatively high likelihood of not detecting potential differences.

7.1.3 Chemicals

There were few statistical differences between dry and wet baseflow sample loading rates for chemicals at each site. Statistical differences in dry and wet baseflow sample loading rates were found at Utah for dissolved chromium ($p<0.01$), dissolved zinc ($p<0.01$), bis(2-ethylhexyl) phthalate ($p<0.001$), butyl benzyl phthalate ($p<0.05$), and diethyl phthalate ($p<0.05$). Statistical differences in dry and wet baseflow sample loading rates were found at East Marginal for dissolved copper ($p<0.05$), dissolved lead ($p<0.05$), dissolved zinc ($p<0.001$), and bis(2-ethylhexyl) phthalate ($p<0.05$). When statistical differences were detected, mean and median loading rates were greater during wet baseflow sampling than dry baseflow sampling.

7.1.4 Summary of Dry versus Wet Baseflow Samples

There were statistically significant differences between dry and wet baseflow mean flows at both Utah and East Marginal, but means (and medians) for the two flow conditions were within a factor of two. No differences were observed at Brandon Regulator. In addition, some statistically significant differences between median loading rates during dry and wet

baseflow sampling were observed for dissolved chromium, dissolved zinc, bis(2-ethylhexyl)phthalate, butyl benzyl phthalate and diethyl phthalate at Utah, and dissolved chromium, copper, lead, zinc and bis(2-ethylhexyl)phthalate at East Marginal. With the exception of bis(2-ethylhexyl)phthalate, differences were between medians (data were not normally distributed which precluded using parametric statistical tests of the means).

In addition, flow during dry and wet baseflow conditions was heavily influenced by activities from individual industrial dischargers within the relatively small combined sewer basin, further complicating comparisons between flow conditions due to increased variability. For this reason, infiltration loading rates were not estimated and were not included in the relative magnitude of pathway estimates (Section 7.3). However, results suggest some potential inputs from infiltration in localized areas of subbasins for several metals and phthalates.

7.2 Baseflow versus Stormflow Samples (Stormwater)

To evaluate loadings within the Brandon Basin from stormwater, statistical differences between baseflow and stormflow sample loading rates were determined for conventional parameters and chemicals. As discussed above, while mean flows were statistically different between wet and dry baseflow samples for both Utah and East Marginal, there were very few statistical differences in chemical loading rate estimates at either site (Section 7.1). Therefore, to enhance power and the ability to identify statistical differences in baseflow versus stormflow loading rates, dry and wet baseflow loadings data were combined. The larger sample size increased the statistical power and thus the ability to identify differences in loading rates between baseflow and stormflow samples.

If a parameter was not detected, mass loading rates were not calculated, nor included in further analysis. While there are common methods for substituting concentrations for non-detects (e.g., using the MDL or half the MDL value), the uncertainty in this value would be further propagated by a loadings calculation. This method has the potential to result in highly uncertain loading rates for parameters with low FOD; therefore, differences between loading rates for baseflow and stormflow samples were only analyzed for parameters with at least a 75% FOD at a given location. Non-detect values could not be reliably substituted because many of these samples have highly elevated MDLs due to dilution of the original sample matrix.

7.2.1 Flow

Mean flows were statistically different between baseflow and stormflow sampling with higher mean and median values during stormflow at all locations ($p<0.001$) (Figure 42). This result is not surprising given that stormwater inputs substantially increase during rain events in combined sewer basins.

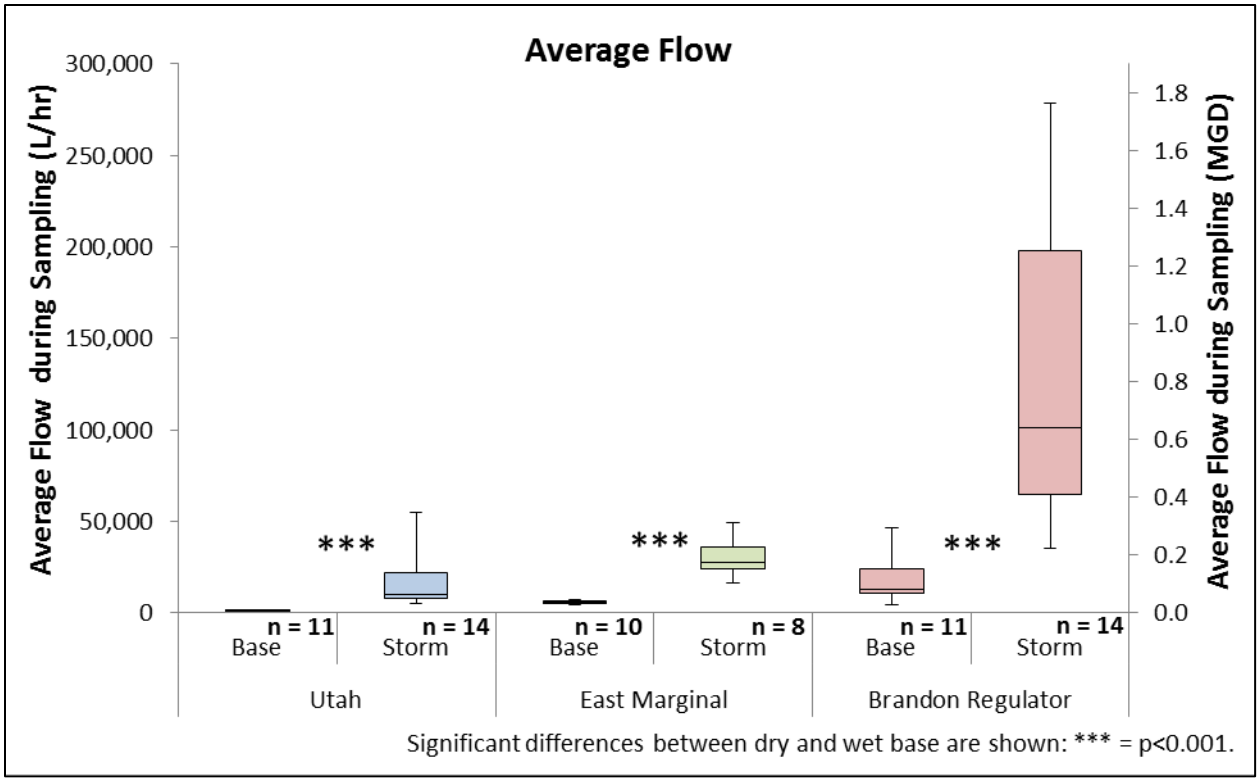

Figure 42. Boxplots of Mean Flow During Baseflow and Stormflow by Location.

7.2.2 Conventional Parameters

Loading rates of TOC were statistically different between baseflow and stormflow samples at all locations, with higher mean and median values during stormflow ($p<0.01$) (Figure 43). This was also true for DOC loading rates at Utah and Brandon Regulator ($p<0.05$) (Figure 44). While the mean and median DOC loading rates at East Marginal were higher during stormflow sampling, they were not statistically different than baseflow sample loading rates; likely due to the greater variability in DOC sample loading rates at East Marginal compared to the other locations. Loading rates of TSS were statistically different between baseflow and stormflow samples at all locations, with higher mean and median values for stormflow ($p<0.01$) (Figure 45).

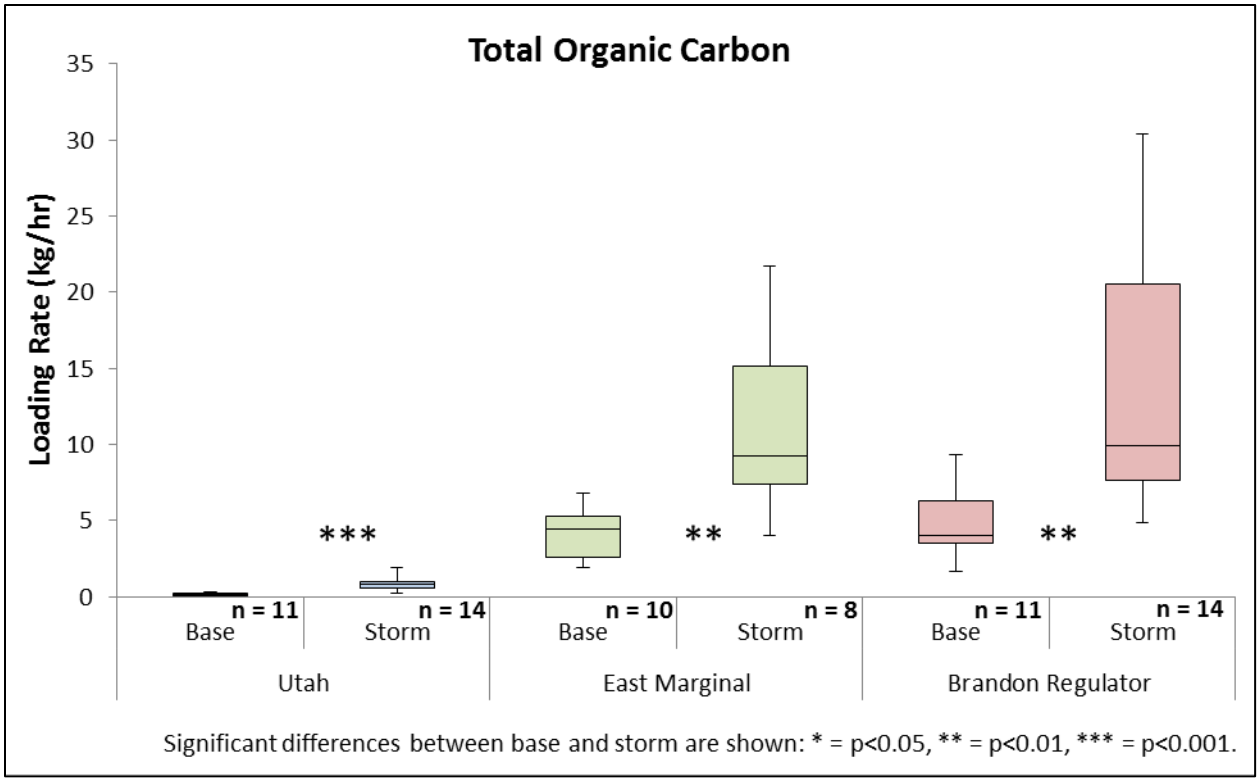

Figure 43. Boxplots of Total Organic Carbon Loading Rates by Location and Flow Condition.

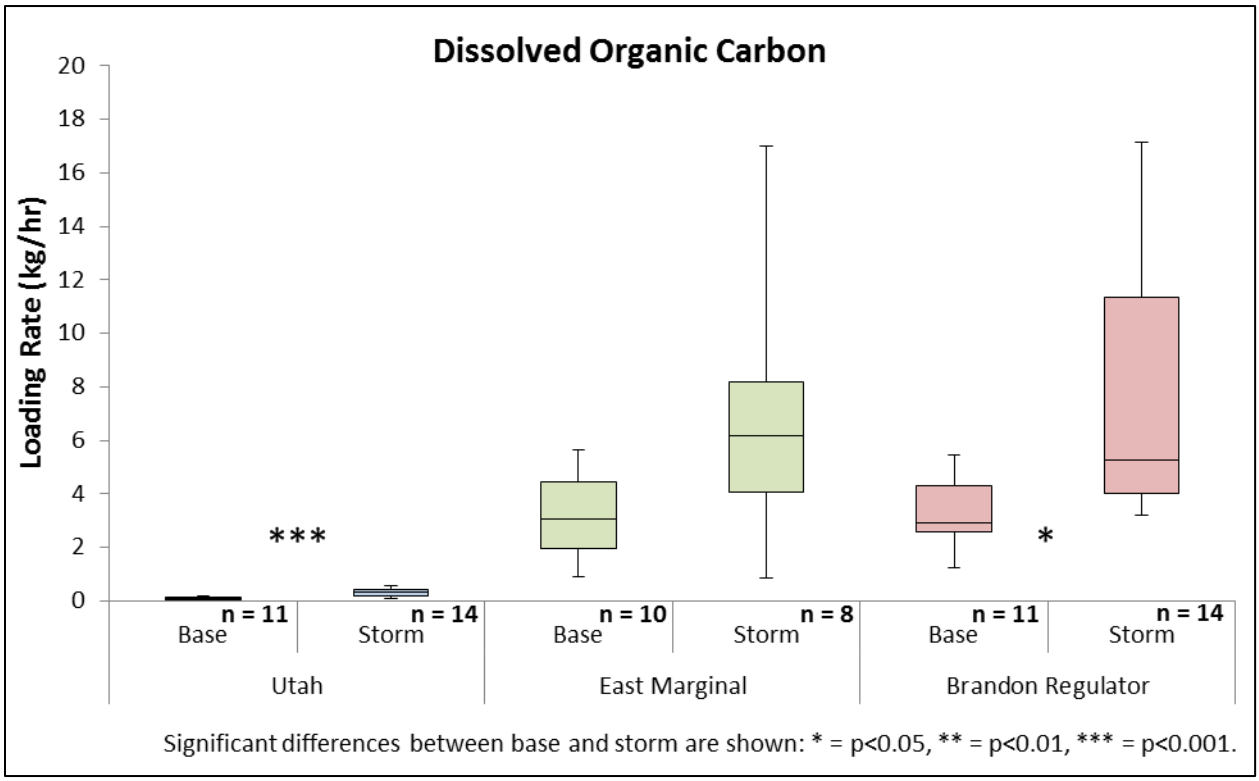

Figure 44. Boxplots of Dissolved Organic Carbon Loading Rates by Location and Flow Condition.

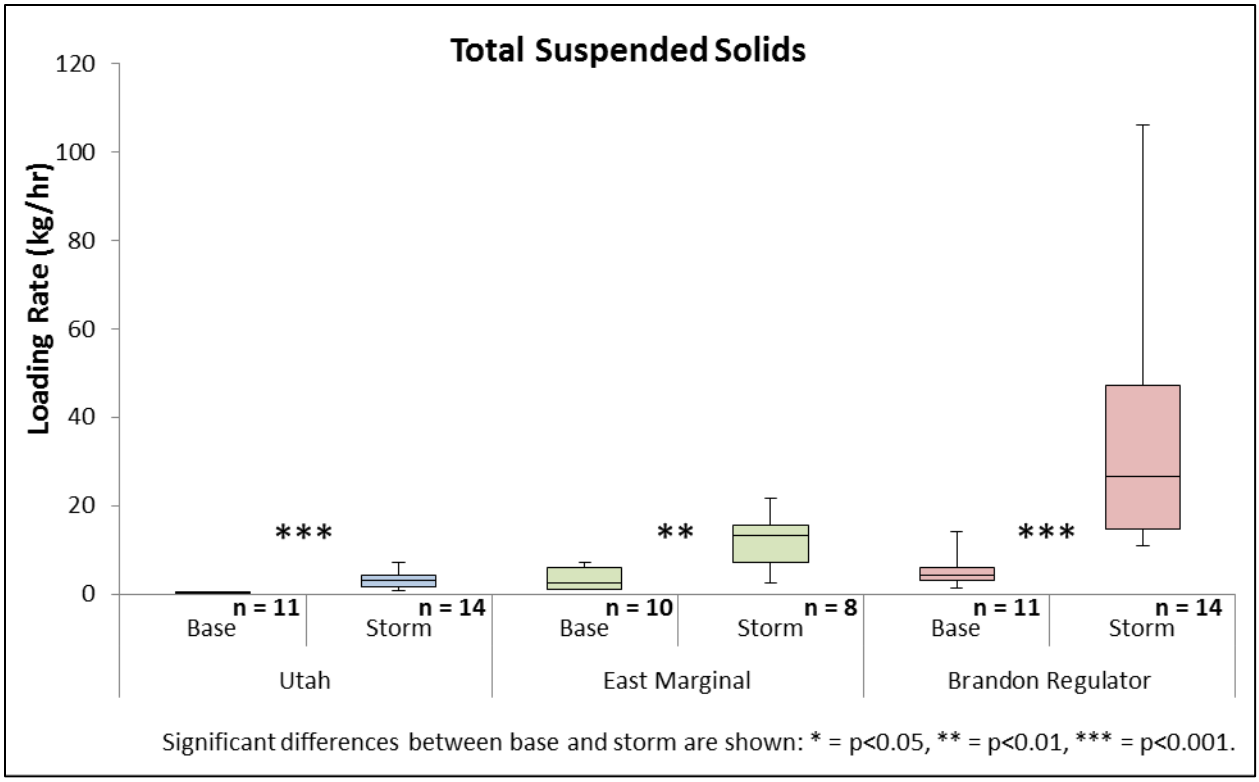

Figure 45. Boxplots of Total Suspended Solids Loading Rates by Location and Flow Condition.

7.2.3 Metals

For all metals with over 75% FOD at a given location, loading rates were statistically different between baseflow and stormflow samples, with higher median values during stormflow ($p<0.01$ or $p<0.001$). These included total and dissolved arsenic, cadmium, chromium, copper, lead, nickel and zinc, as well as total silver and vanadium. For all but total and dissolved arsenic and dissolved chromium, mean stormflow sample loading rates were also higher than mean baseflow sample loading rates. Statistical analysis was not performed for dissolved cadmium loading rates at Utah and East Marginal, nor dissolved silver and vanadium loading rates at all sites, because FOD was less than 75%. Figures 46 through 63 illustrate sample loading rate distributions for metals by location and flow condition.

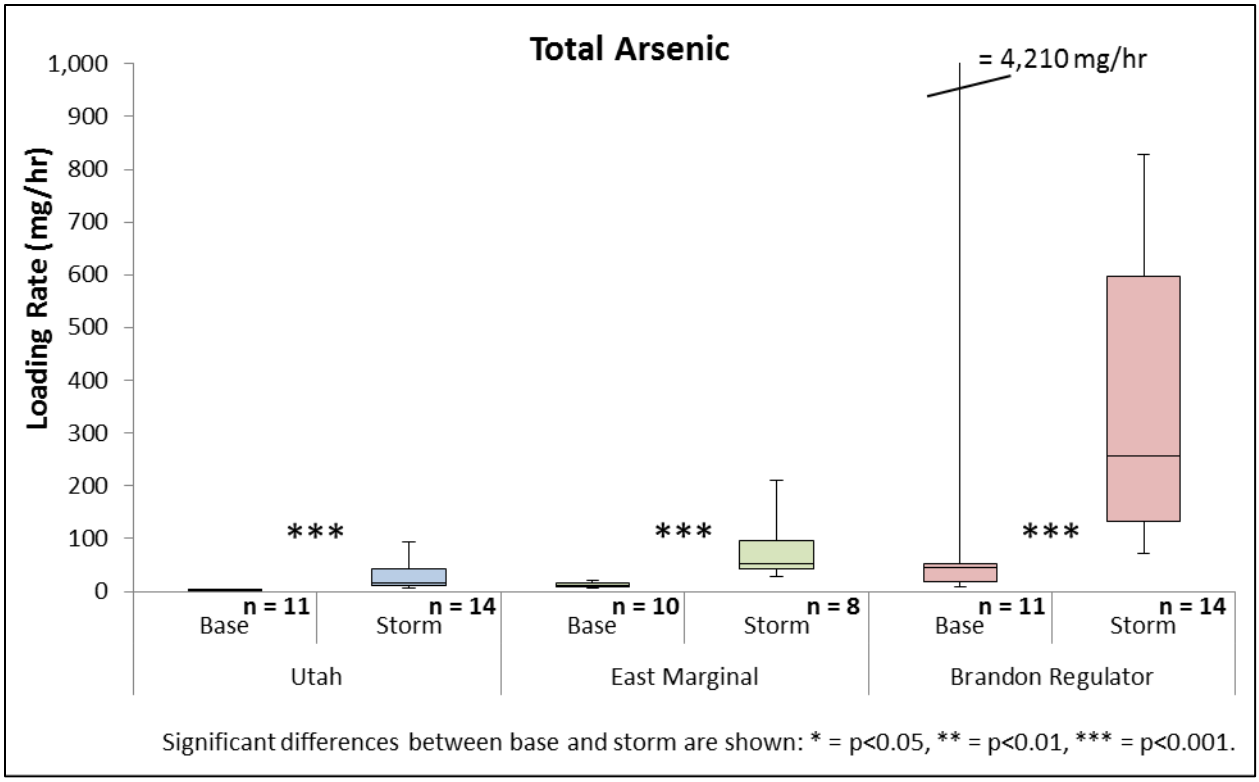

Figure 46. Boxplots of Total Arsenic Loading Rates by Location and Flow Condition.

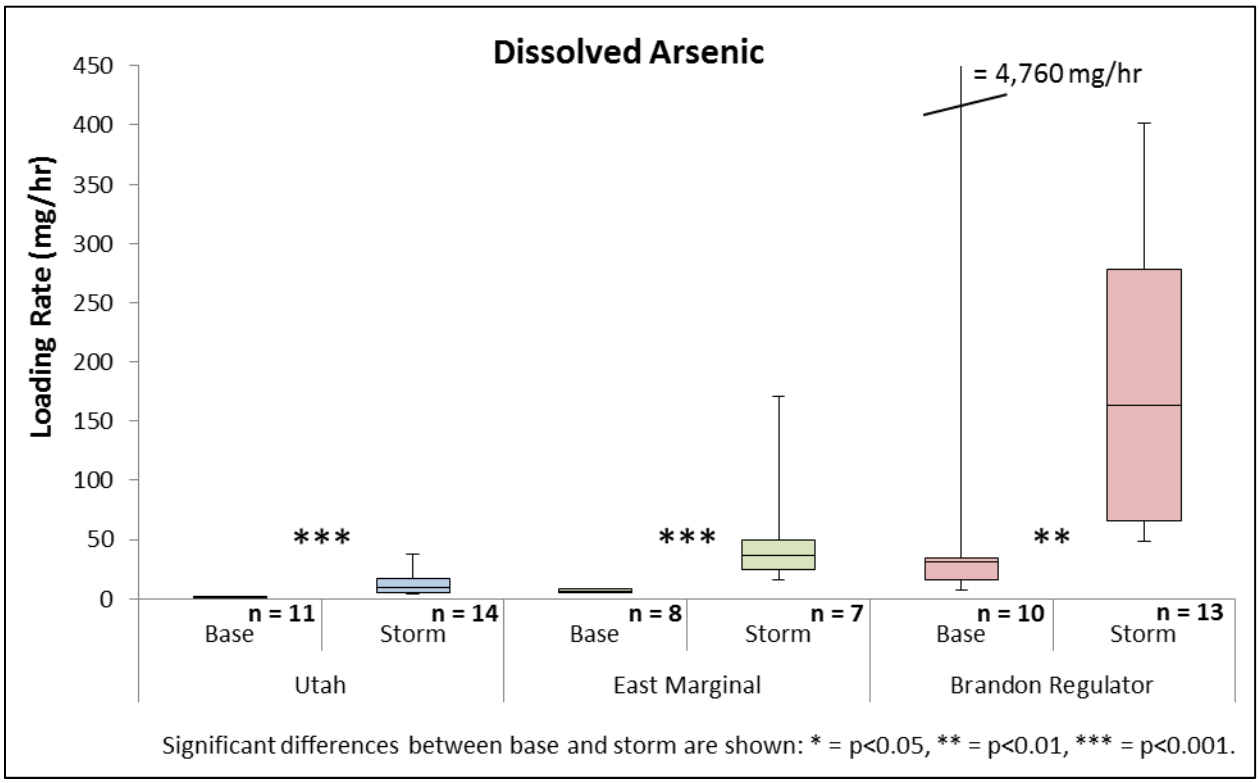

Figure 47. Boxplots of Dissolved Arsenic Loading Rates by Location and Flow Condition.

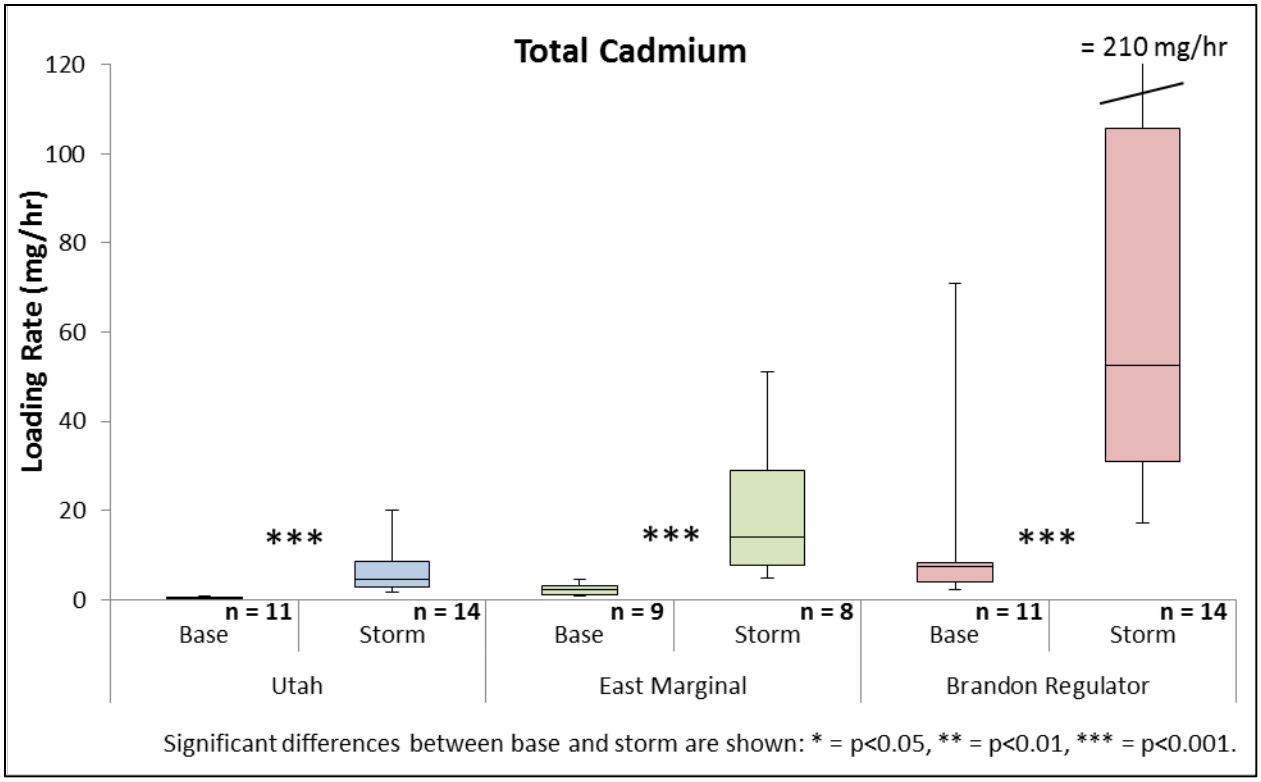

Figure 48. Boxplots of Total Cadmium Loading Rates by Location and Flow Condition.

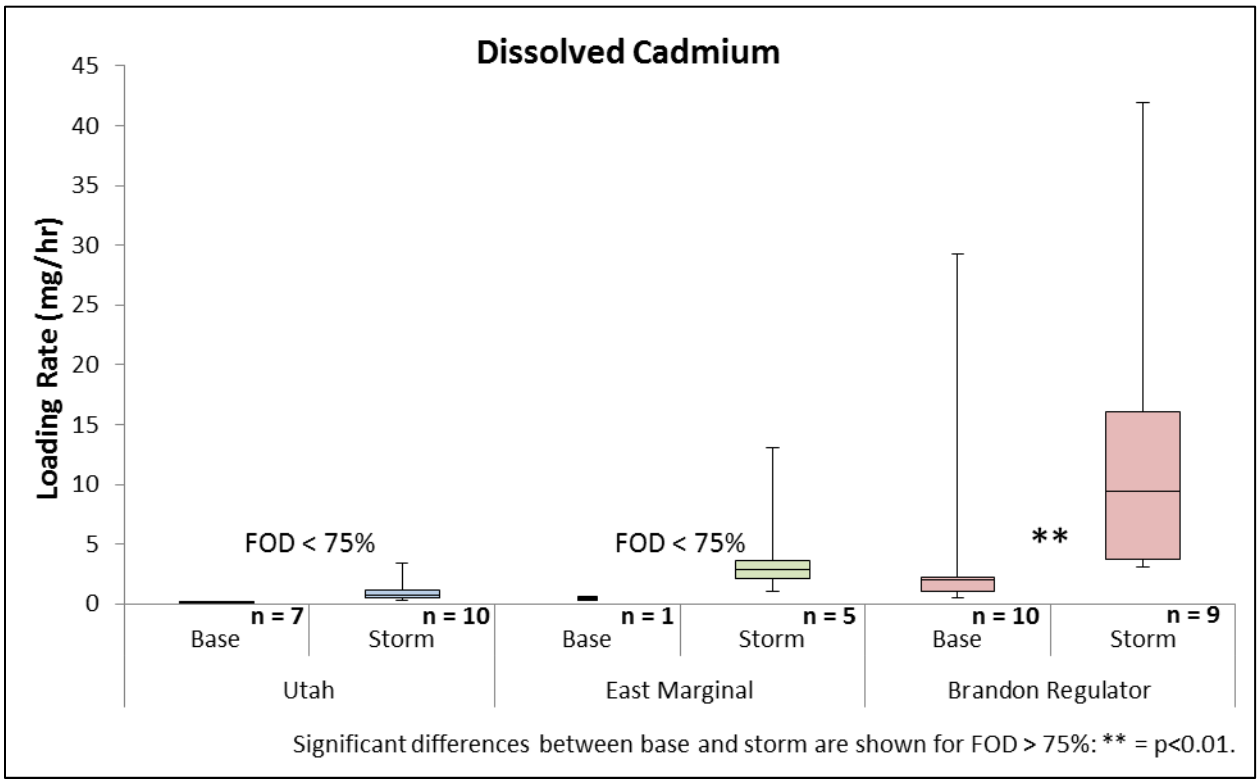

Figure 49. Boxplots of Dissolved Cadmium Loading Rates by Location and Flow Condition.

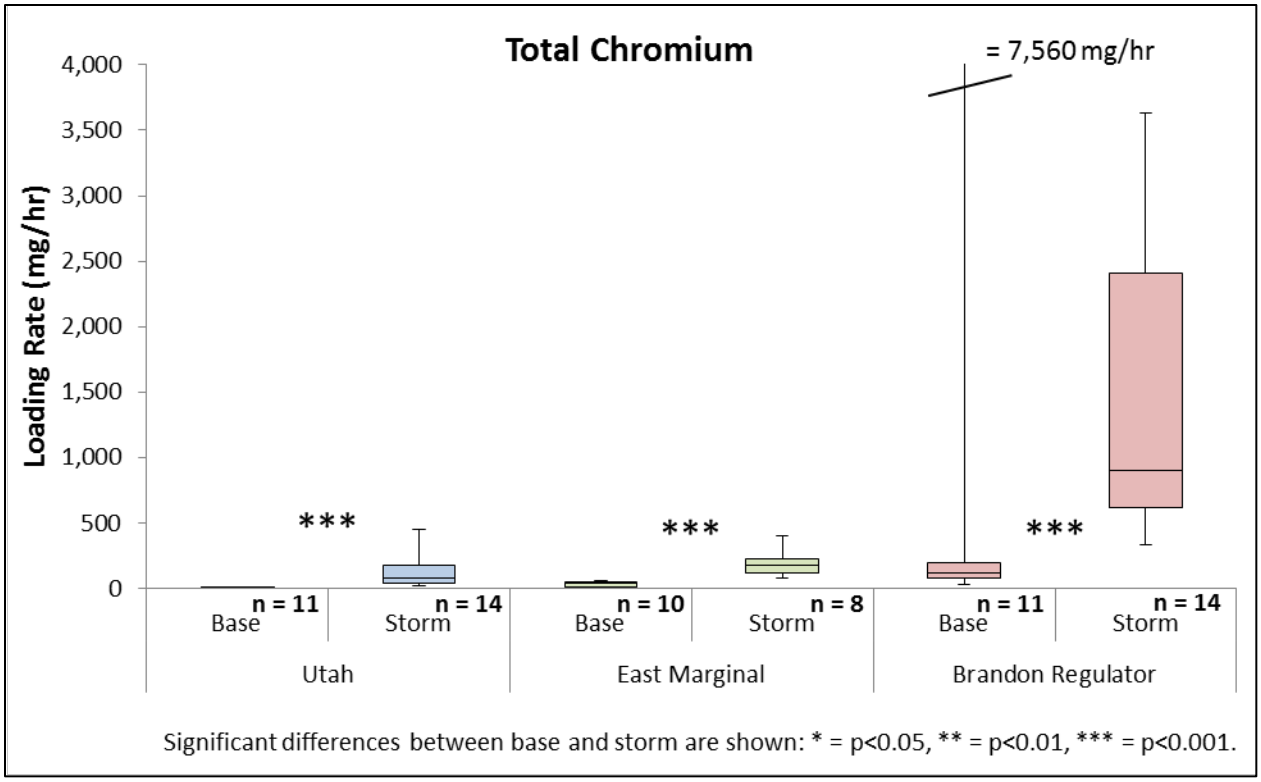

Figure 50. Boxplots of Total Chromium Loading Rates by Location and Flow Condition.

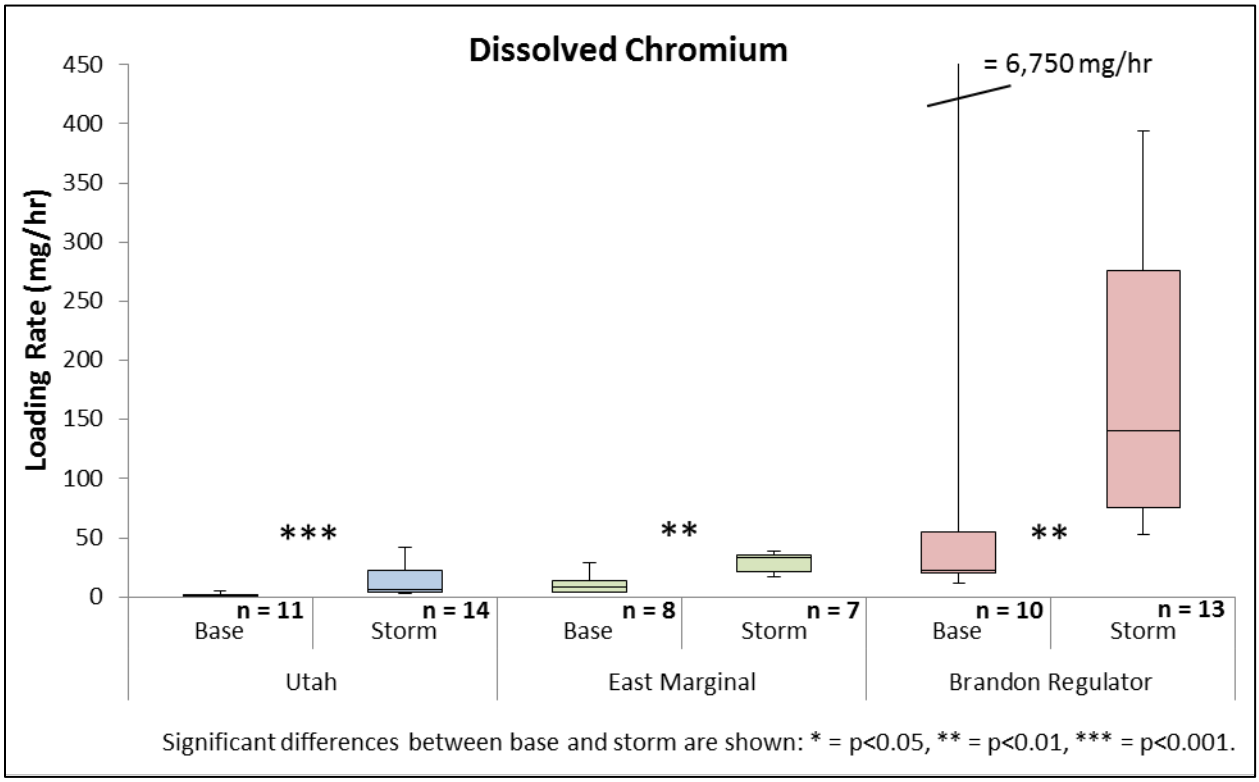

Figure 51. Boxplots of Dissolved Chromium Loading Rates by Location and Flow Condition.

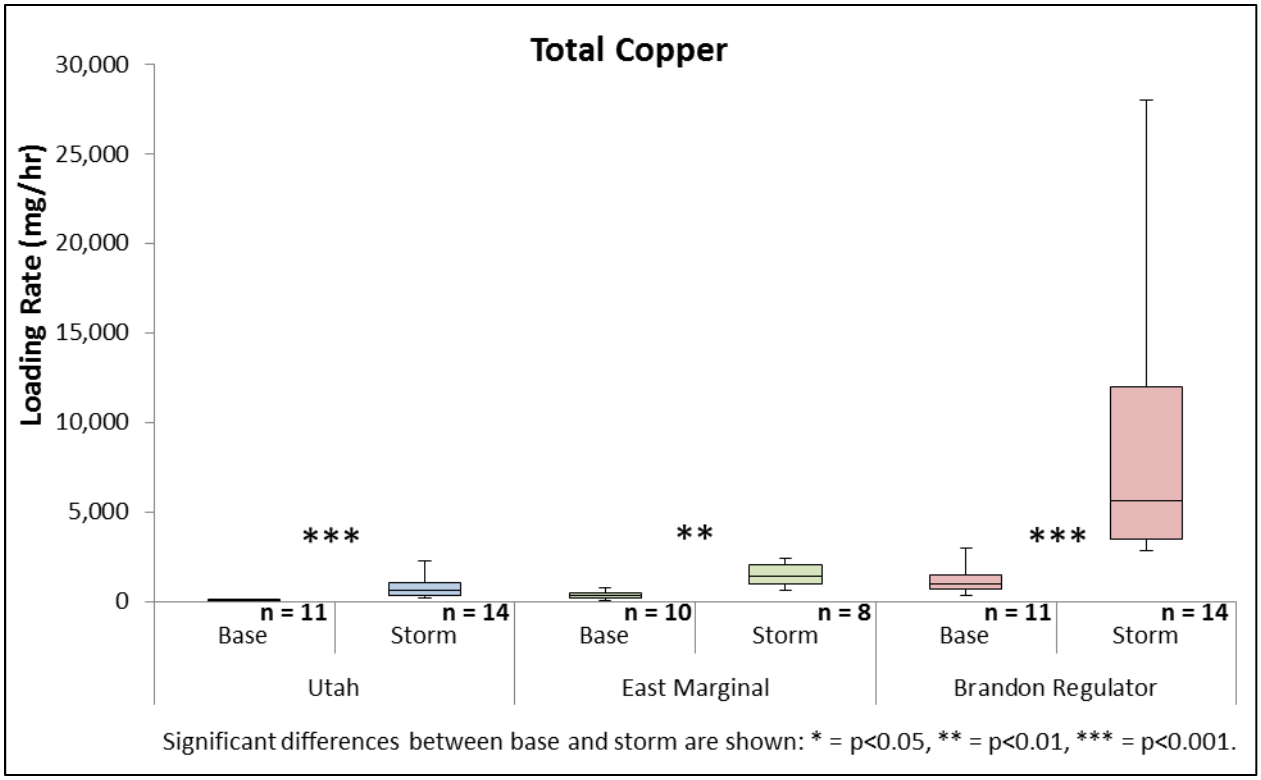

Figure 52. Boxplots of Total Copper Loading Rates by Location and Flow Condition.

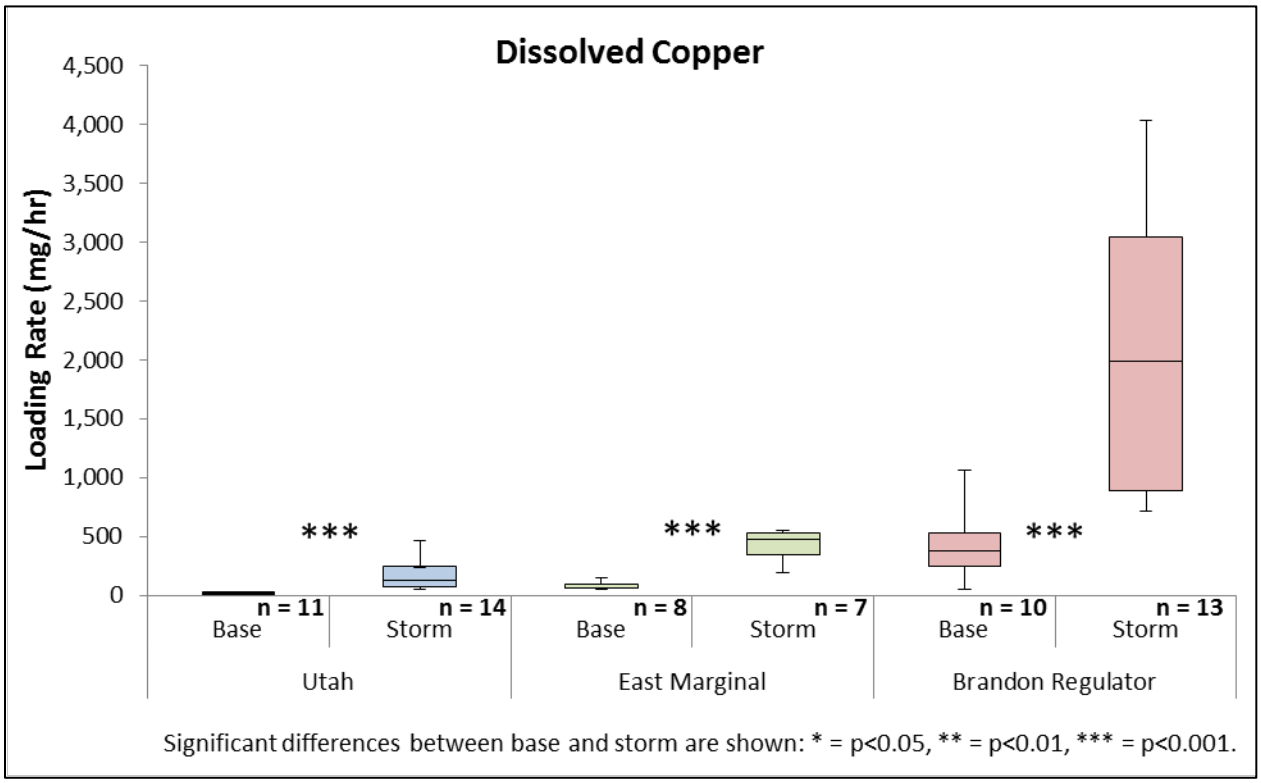

Figure 53. Boxplots of Dissolved Copper Loading Rates by Location and Flow Condition.

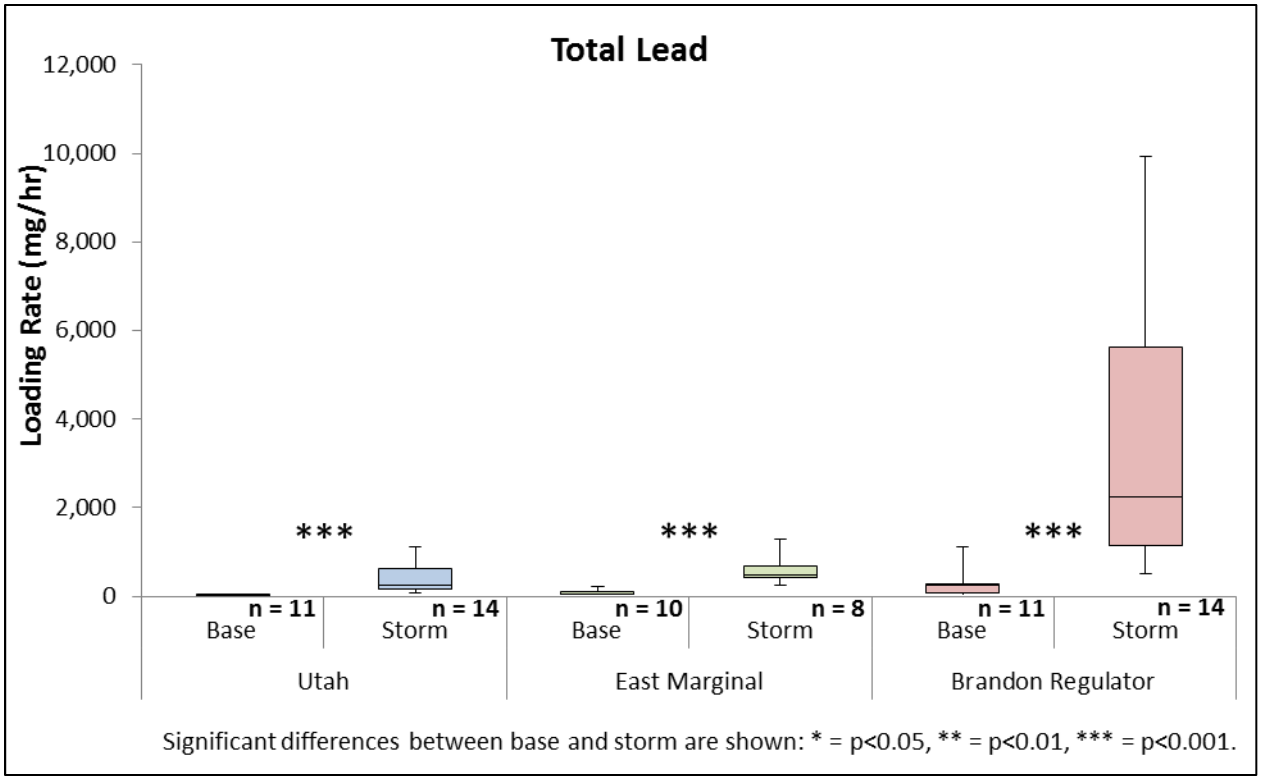

Figure 54. Boxplots of Total Lead Loading Rates by Location and Flow Condition.

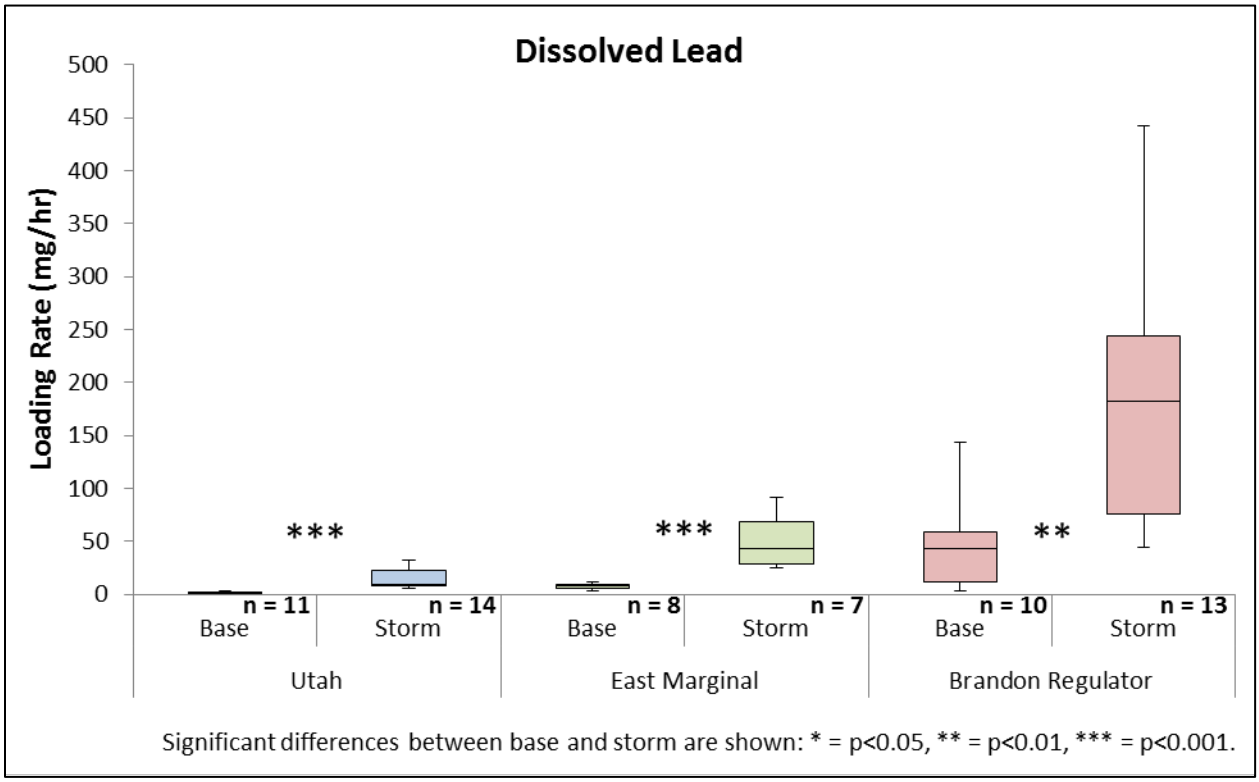

Figure 55. Boxplots of Dissolved Lead Loading Rates by Location and Flow Condition.

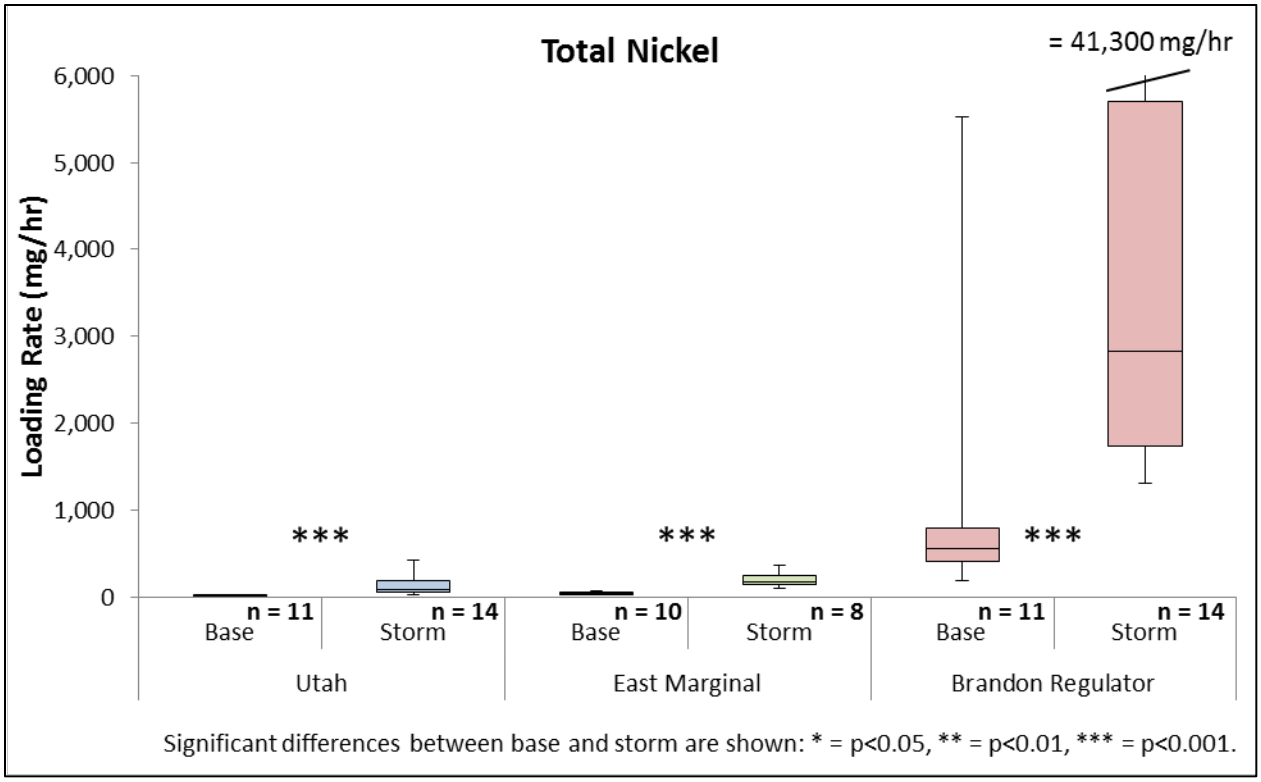

Figure 56. Boxplots of Total Nickel Loading Rates by Location and Flow Condition.

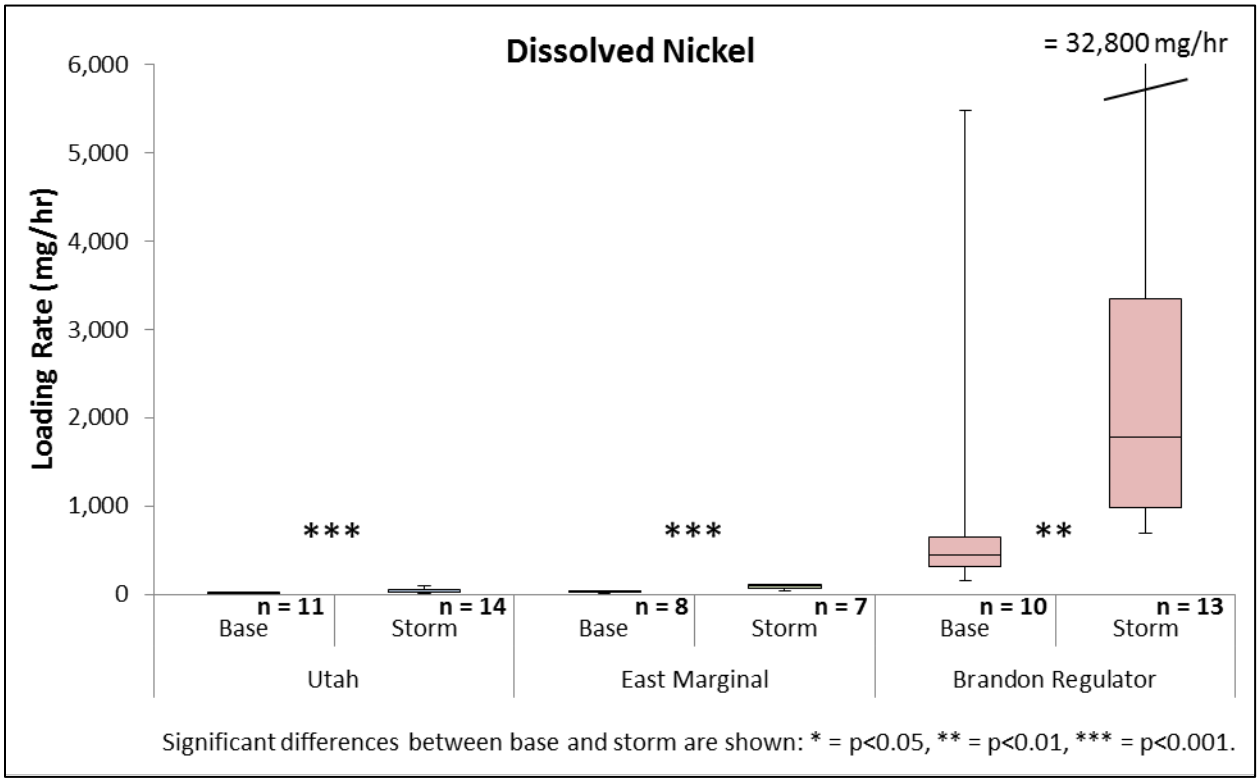

Figure 57. Boxplots of Dissolved Nickel Loading Rates by Location and Flow Condition.

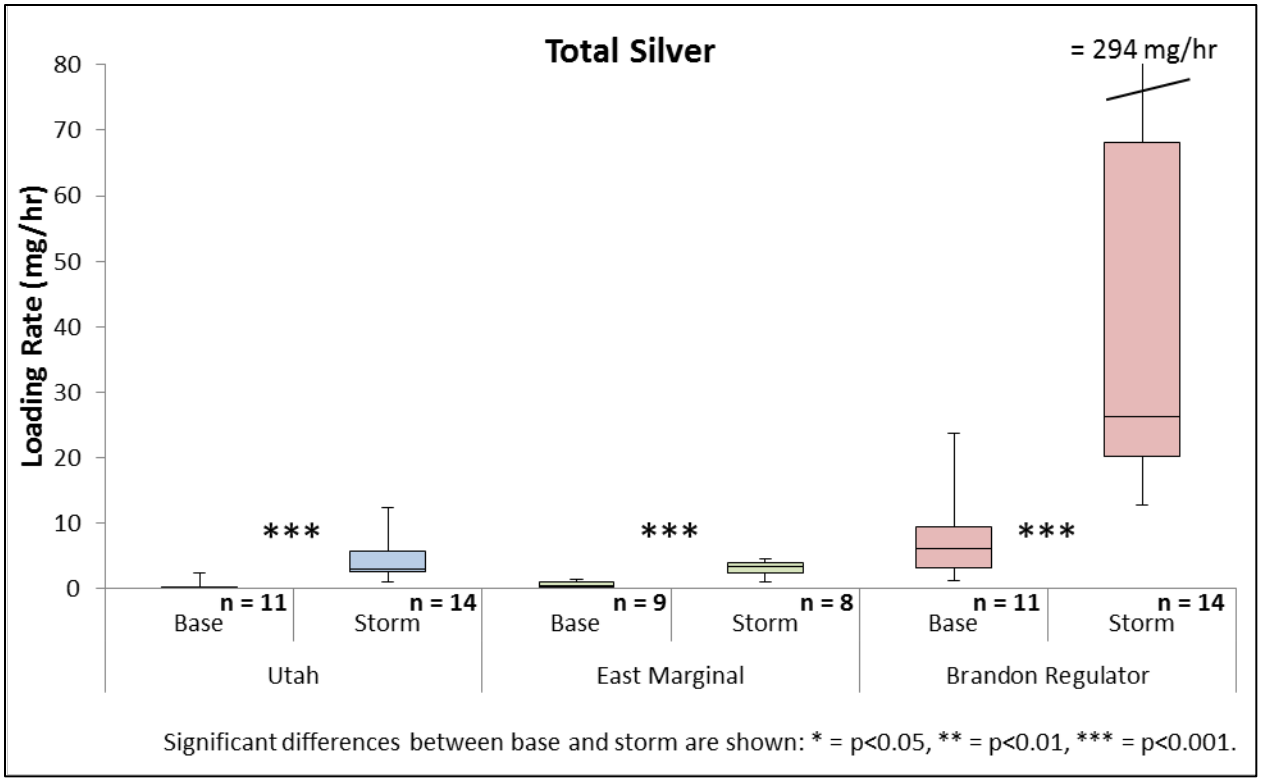

Figure 58. Boxplots of Total Silver Loading Rates by Location and Flow Condition.

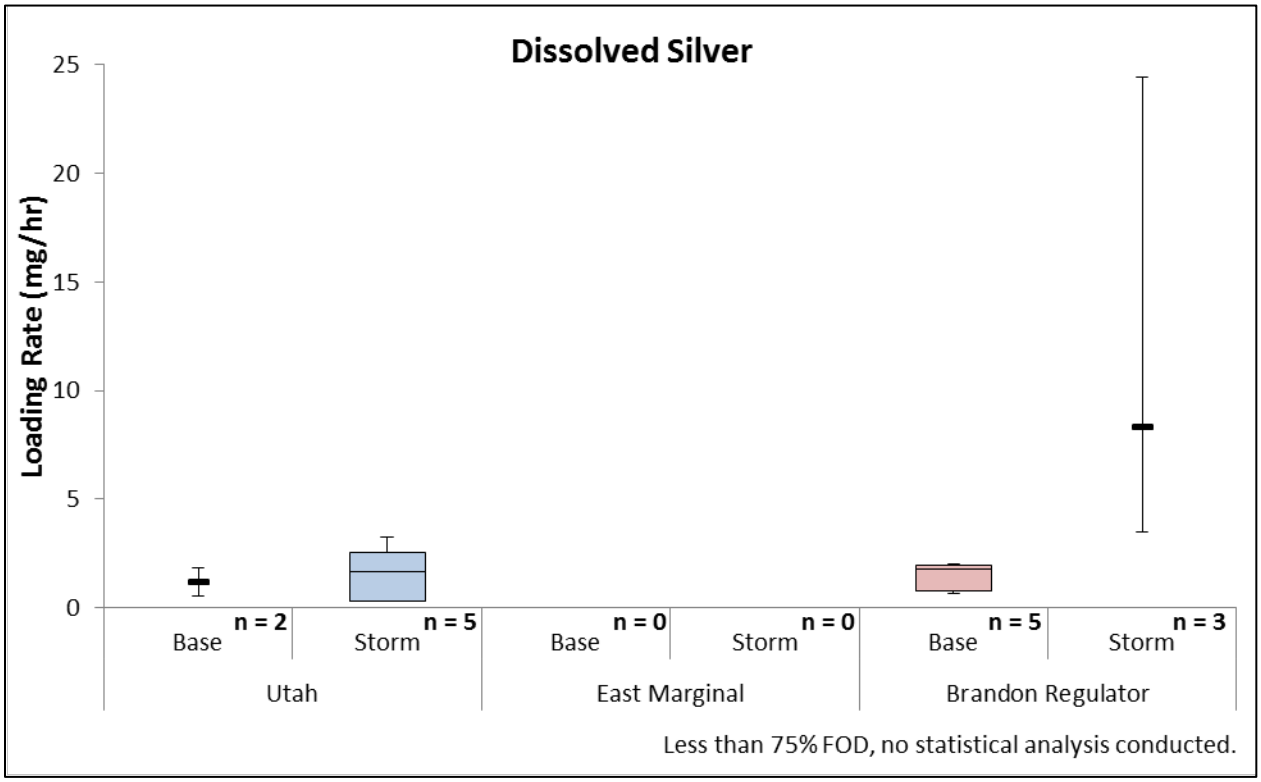

Figure 59. Boxplots of Dissolved Silver Loading Rates by Location and Flow Condition.

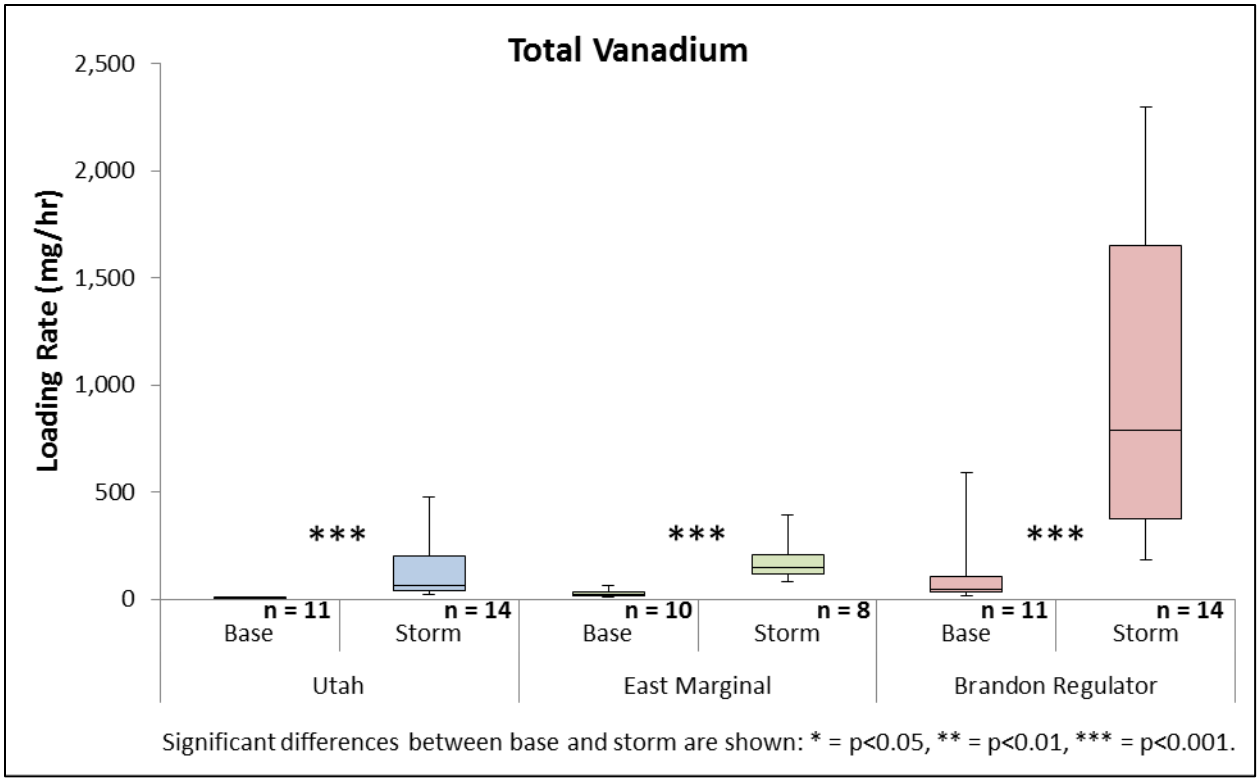

Figure 60. Boxplots of Total Vanadium Loading Rates by Location and Flow Condition.

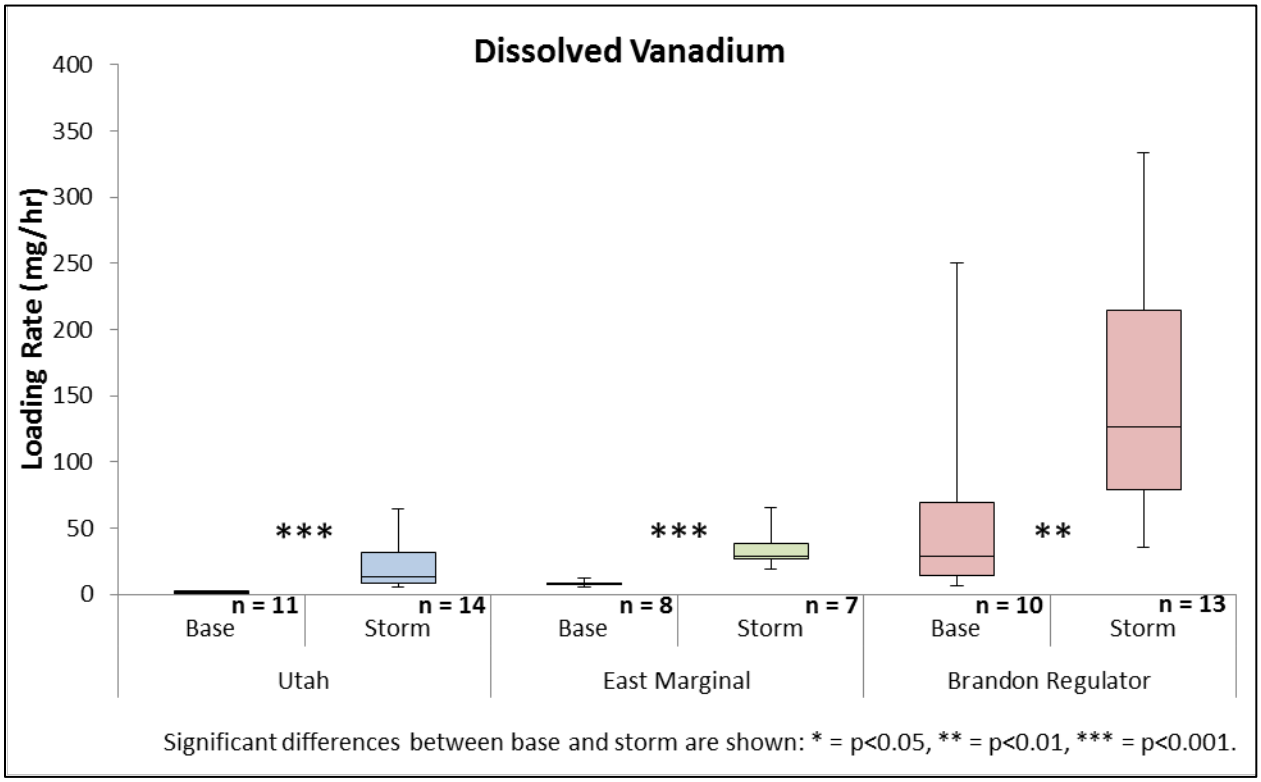

Figure 61. Boxplots of Dissolved Vanadium Loading Rates by Location and Flow Condition.

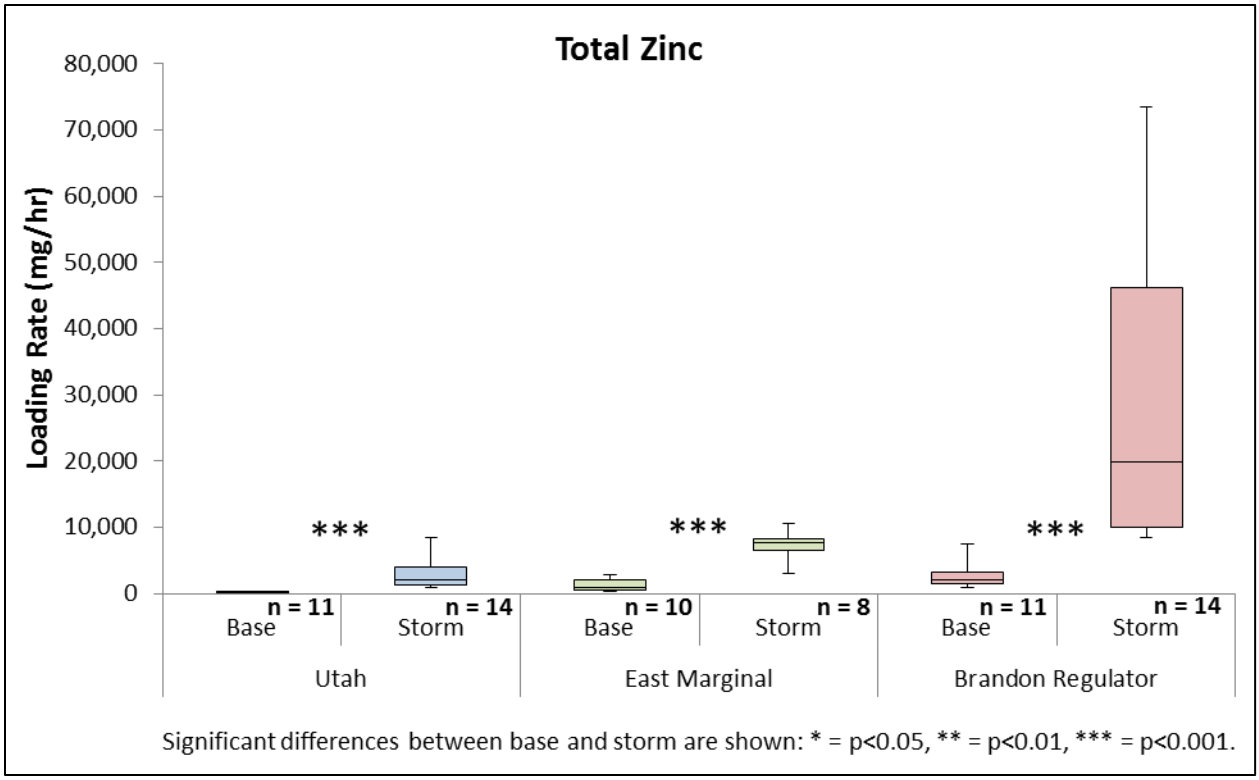

Figure 62. Boxplots of Total Zinc Loading Rates by Location and Flow Condition.

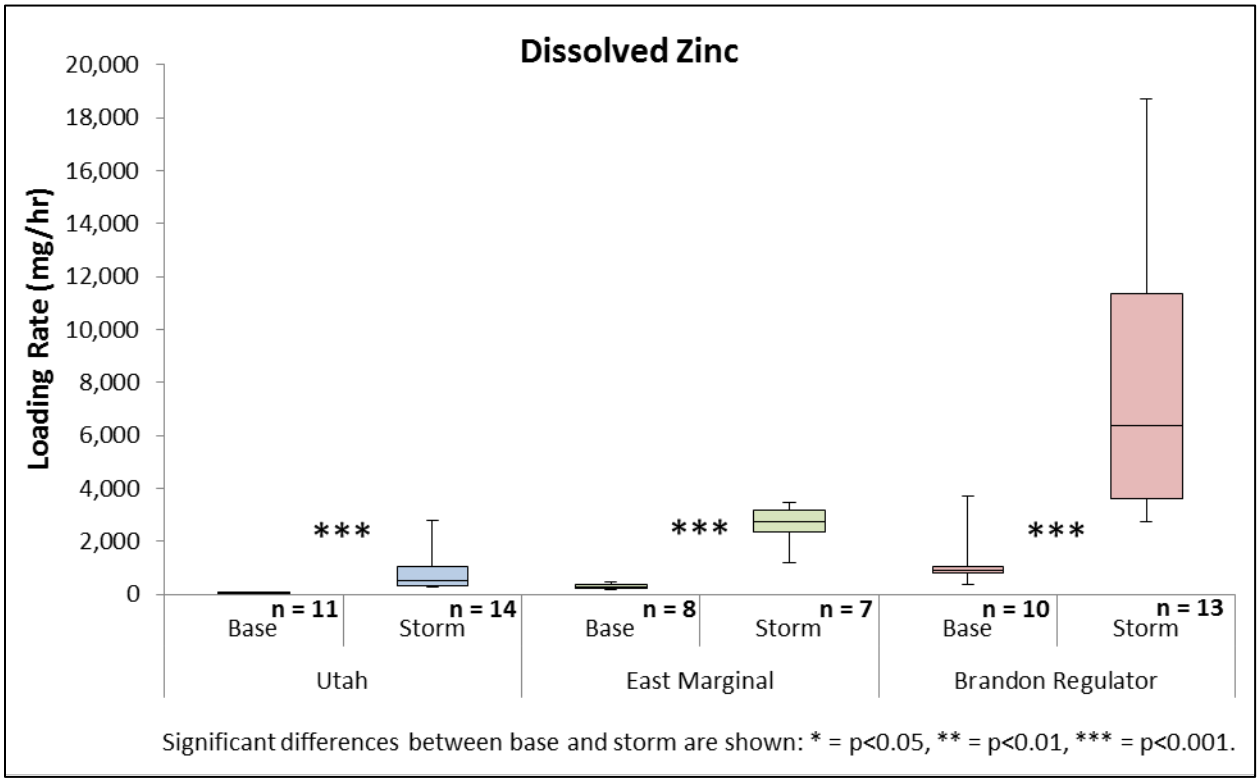

Figure 63. Boxplots of Dissolved Zinc Loading Rates by Location and Flow Condition.

7.2.4 Mercury

Total mercury loading rates during baseflow and stormflow sampling were statistically different at all locations with higher median loading rates during stormflow ($p<0.01$ or $p<0.001$) (Figure 64). Statistical analyses were not conducted for dissolved mercury due to low FOD (<75%) (Figure 65).

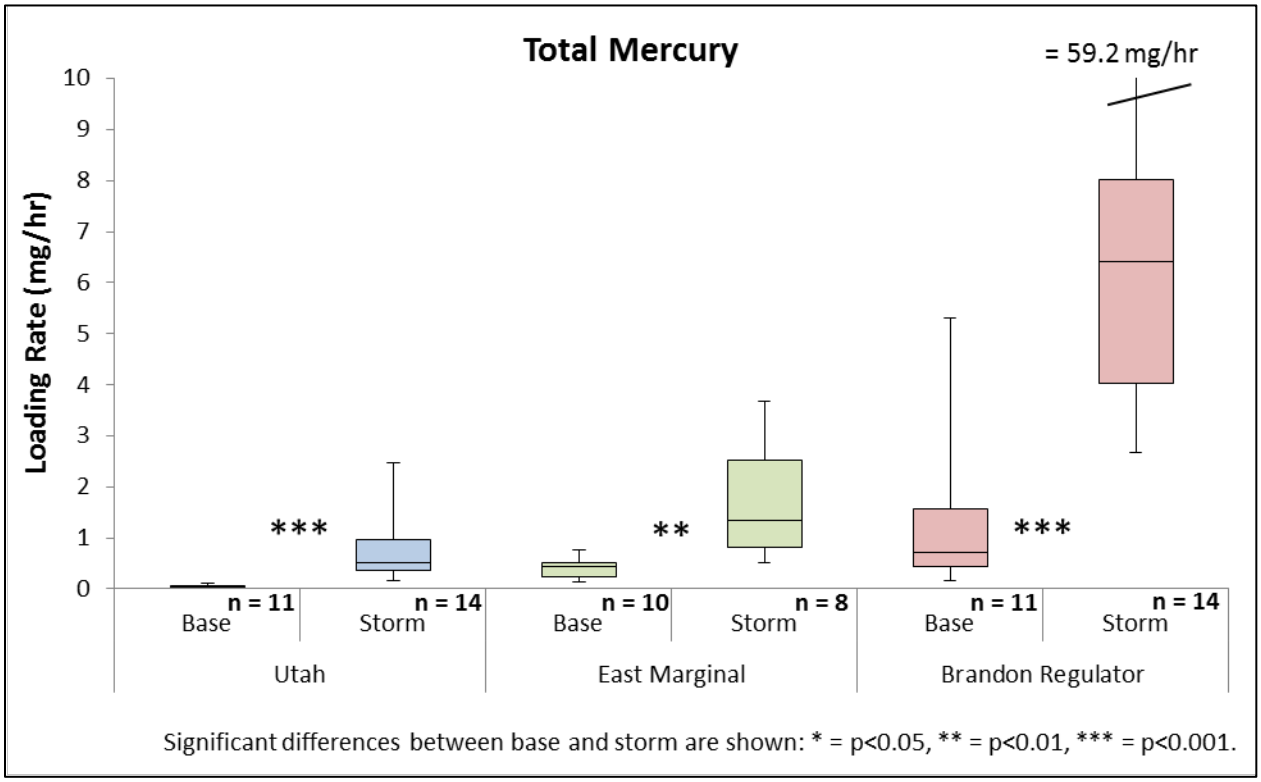

Figure 64. Boxplots of Total Mercury Loading Rates by Location and Flow Condition.

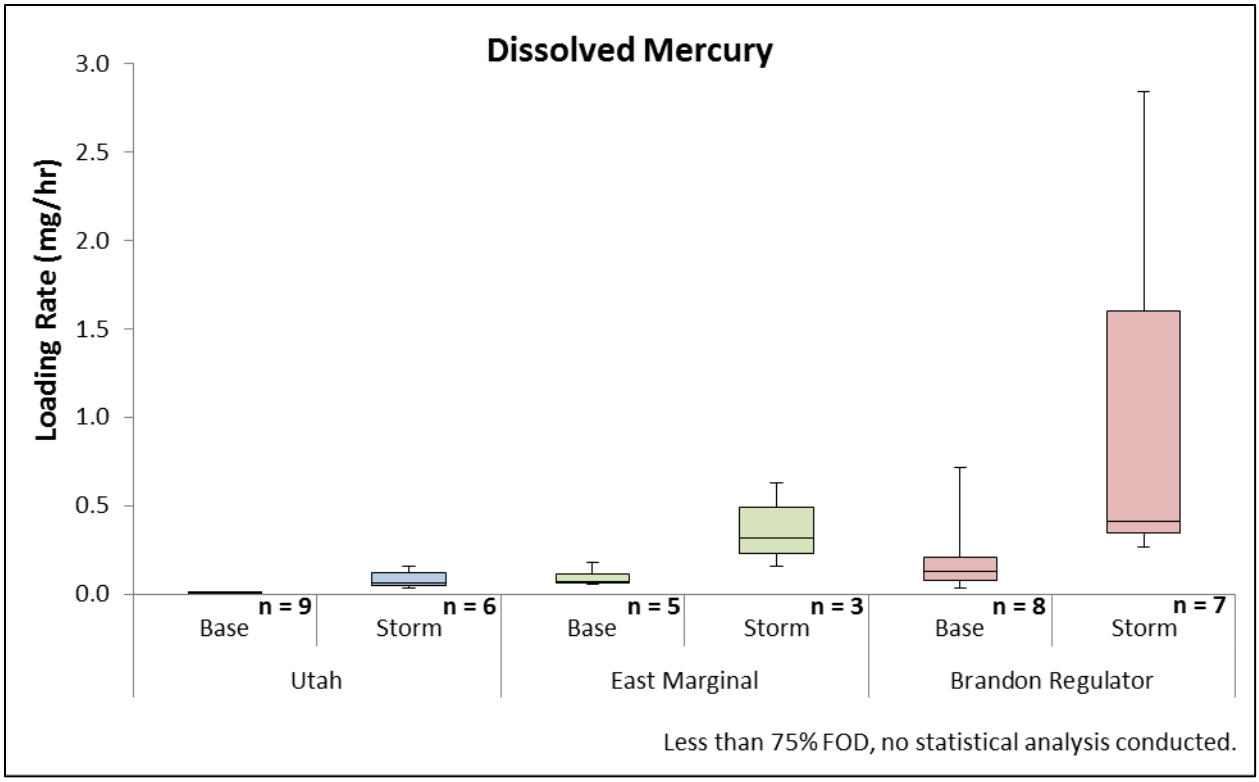

Figure 65. Boxplots of Dissolved Mercury Loading Rates by Location and Flow Condition.

7.2.5 PAHs

Statistical analysis to assess differences between baseflow and stormflow sample loading rates was only performed for two individual PAHs with high FODs and total HPAHs. Phenanthrene and fluoranthene were detected in all but one storm sample, but were detected less frequently in baseflow samples. Overall, there was greater than 75% FOD at both Utah and Brandon Regulator for both compounds and loading rates during baseflow and stormflow sampling were statistically different at both locations, with higher mean and median loading rates observed during stormflow ($p<0.001$) (Figures 66 and 67). Results were similar for total HPAHs (Figure 68).

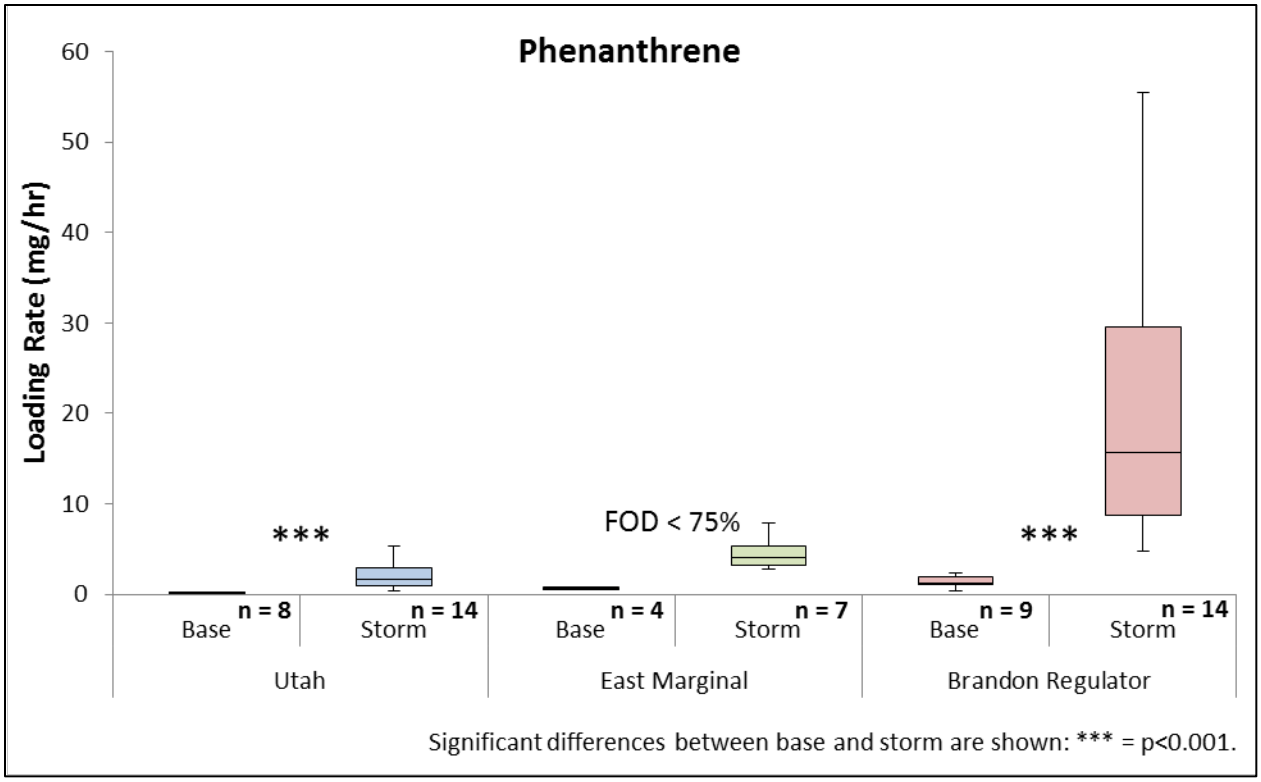

Figure 66. Boxplots of Phenanthrene Loading Rates by Location and Flow Condition.

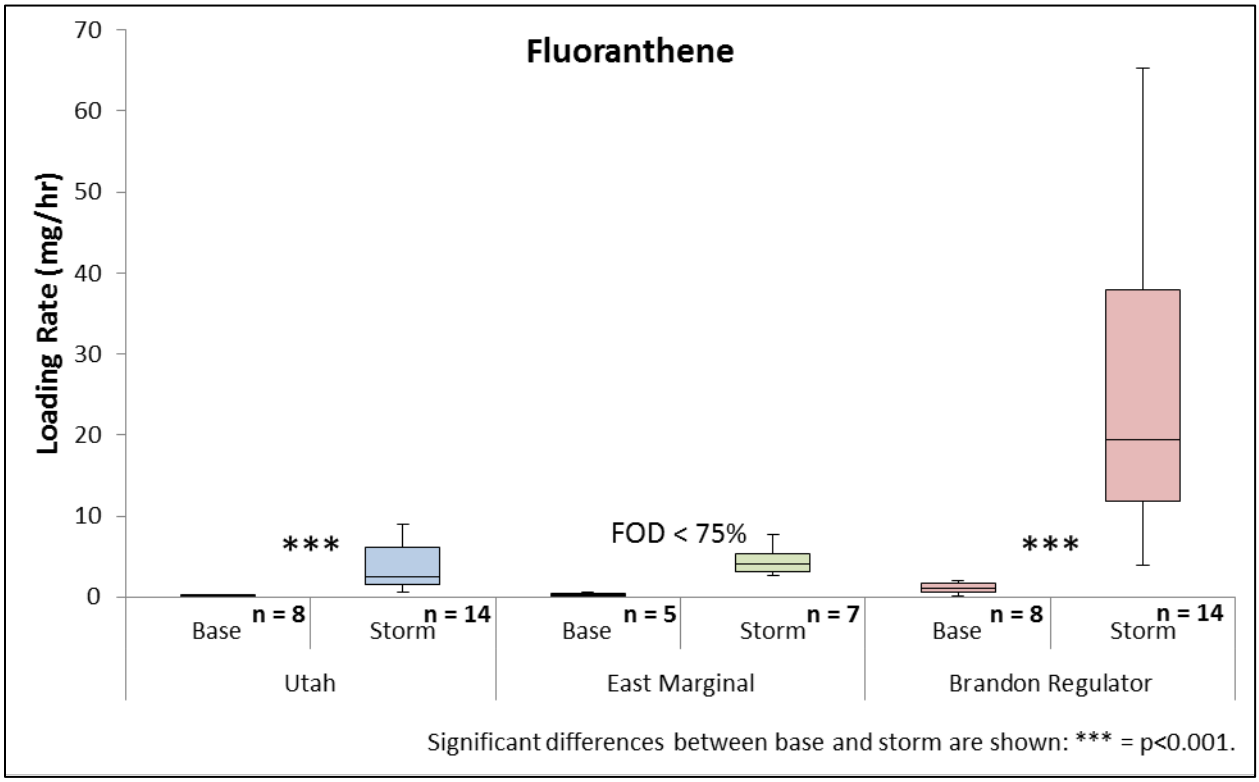

Figure 67. Boxplots of Chrysene Loading Rates by Location and Flow Condition.

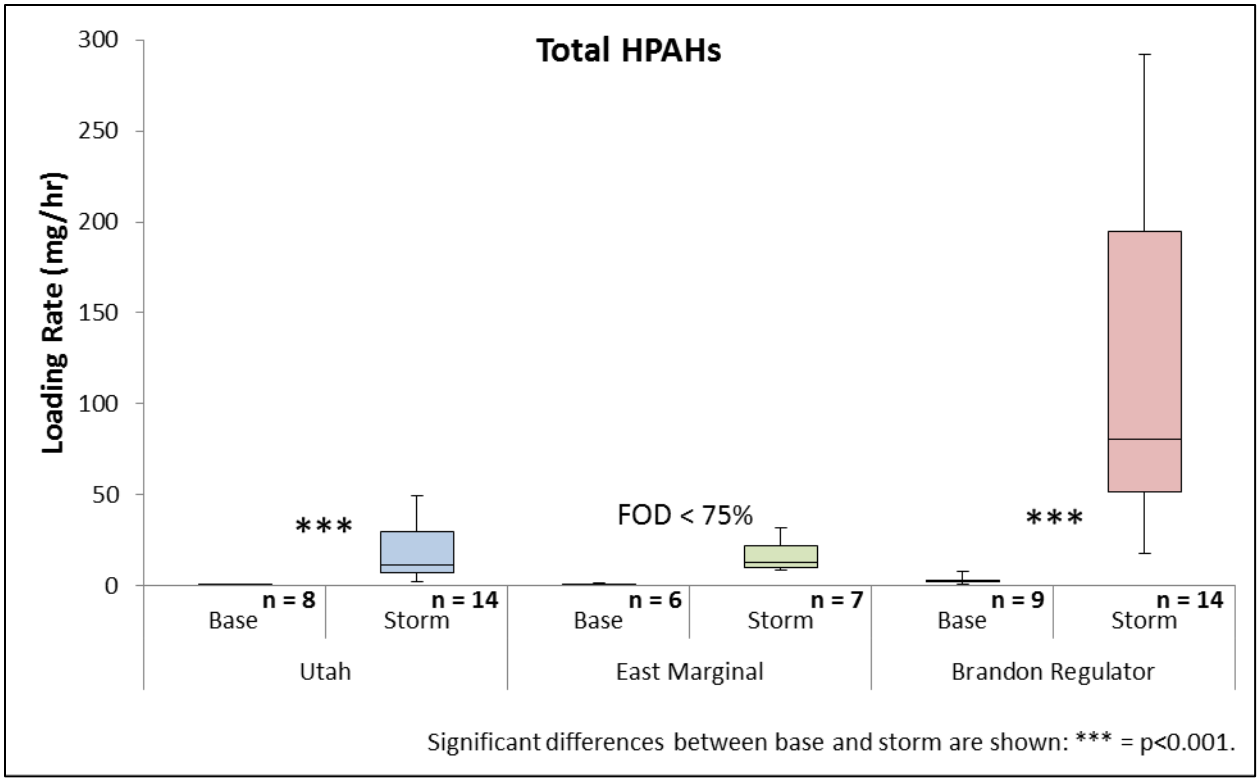

Figure 68. Boxplots of Total HPAH Loading Rates by Location and Flow Condition.

7.2.6 Phthalates

Statistical analysis evaluating differences between baseflow and stormflow sample loading rates was only performed for three phthalates with high FOD (benzyl butyl phthalate, bis(2-ethylhexyl)phthalate, and diethyl phthalate). Loading rates during baseflow and stormflow sampling for these phthalates (based on detected concentrations) were statistically different at all sites, with higher mean and median loading rates during stormflow (Figures 69 through 71).

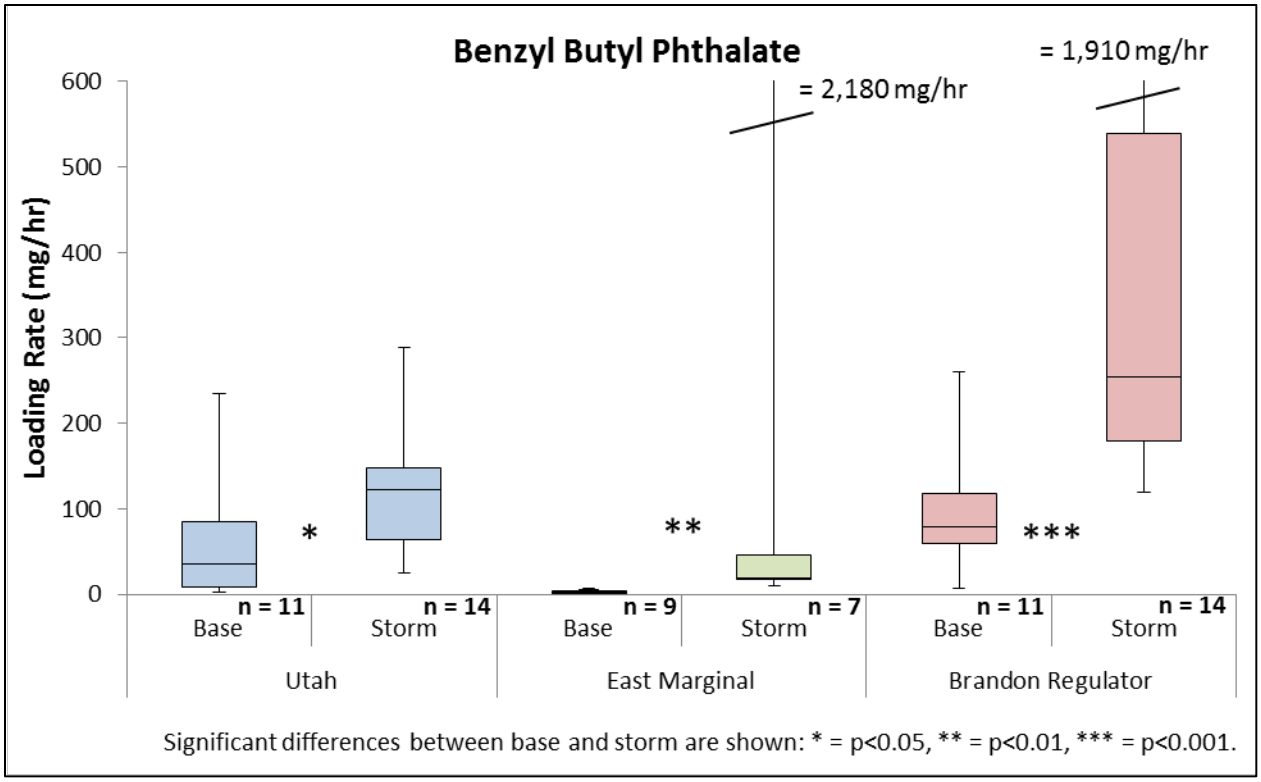

Figure 69. Boxplots of Benzyl Butyl Phthalate Loading Rates by Location and Flow Condition.

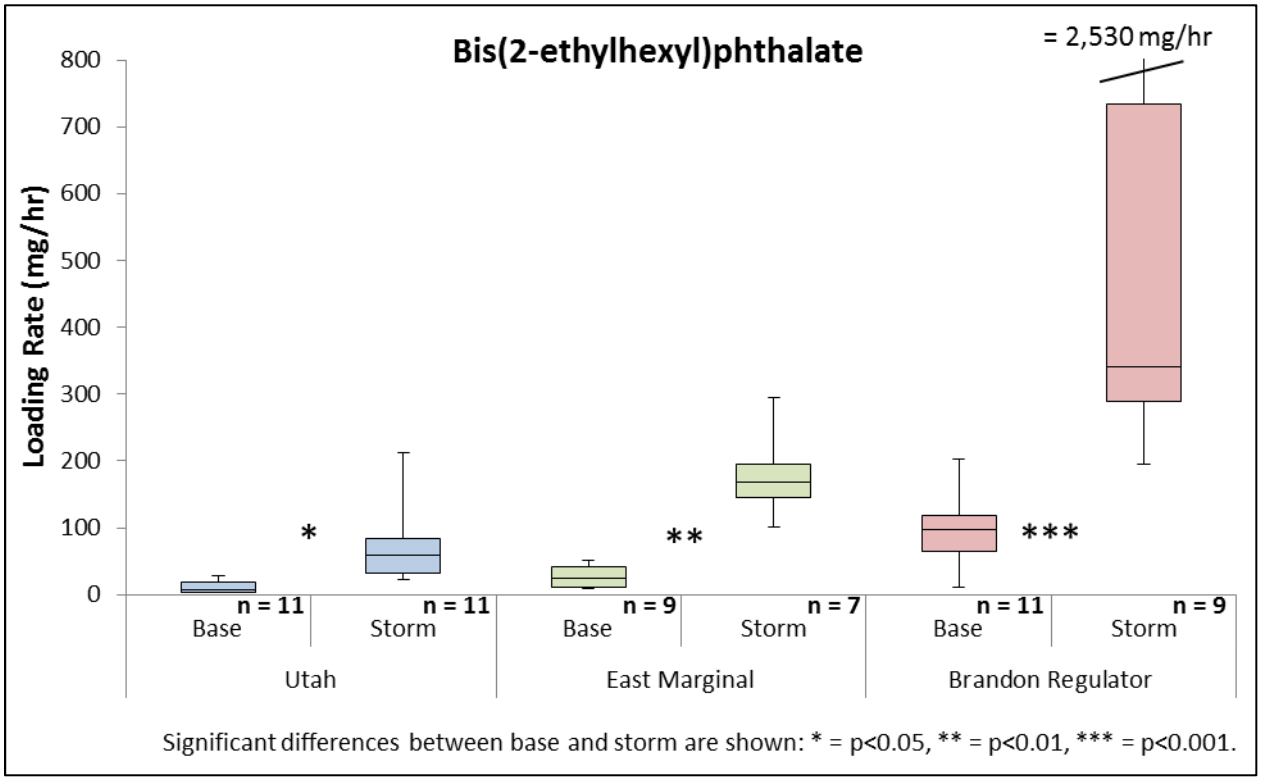

Figure 70. Boxplots of Bis(2-ethylhexyl)phthalate Loading Rates by Location and Flow Condition.

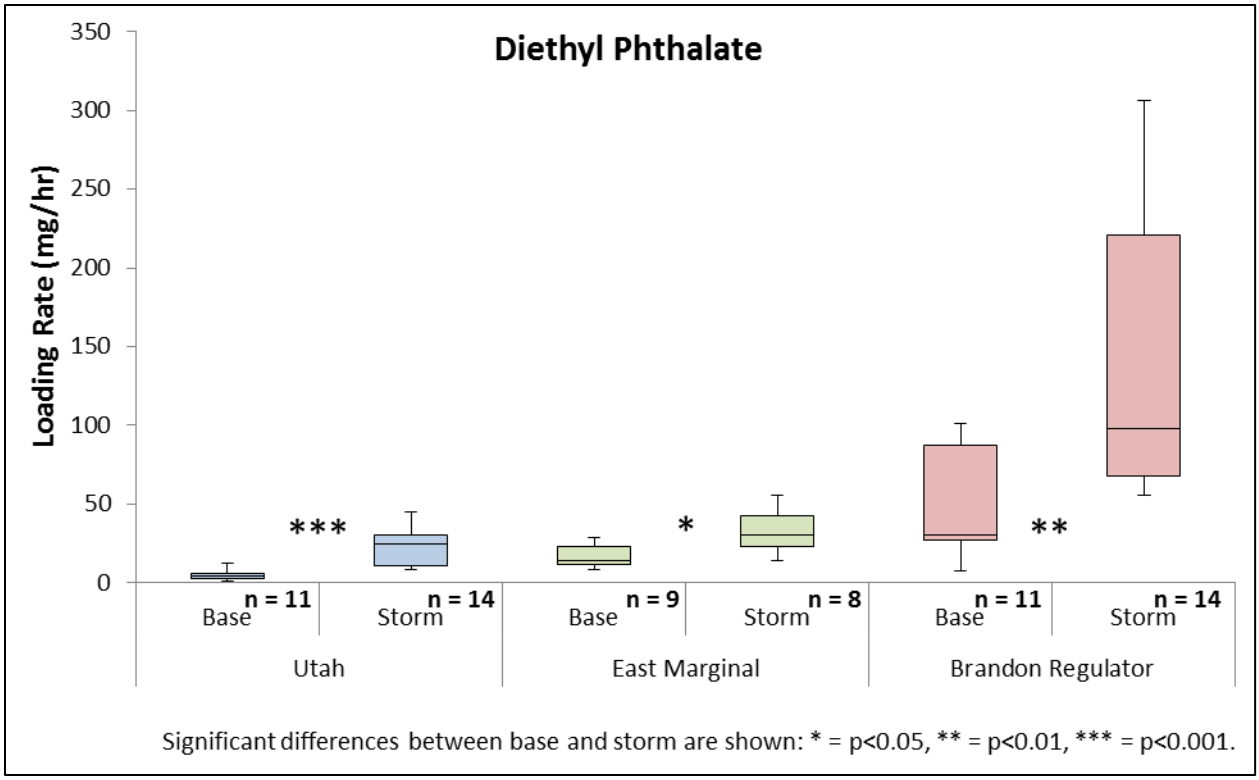

Figure 71. Boxplots of Diethyl Phthalate Loading Rates by Location and Flow Condition.

7.2.7 PCBs and Dioxins/Furans

Total PCB loading rates during baseflow and stormflow sampling were statistically different at all locations, with higher means and medians for stormflow ($p<0.05$) (Figure 72). Total dioxin/furan and total dioxin TEQ loading rates during baseflow and stormflow sampling were statistically different at all locations, with higher means and medians for stormflow ($p<0.05$ and $p<0.01$ respectively) (Figures 73 and 74).

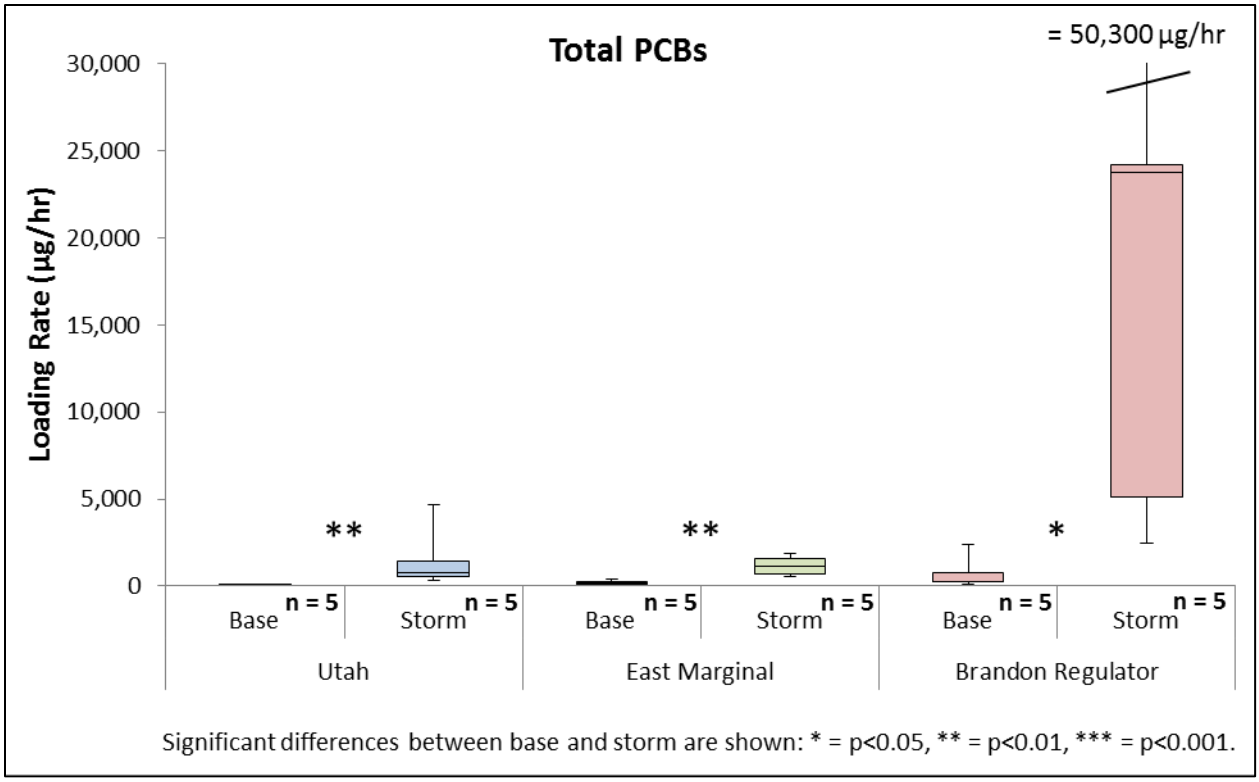

Figure 72. Boxplots of Total PCB Loading Rates by Location and Flow Condition.

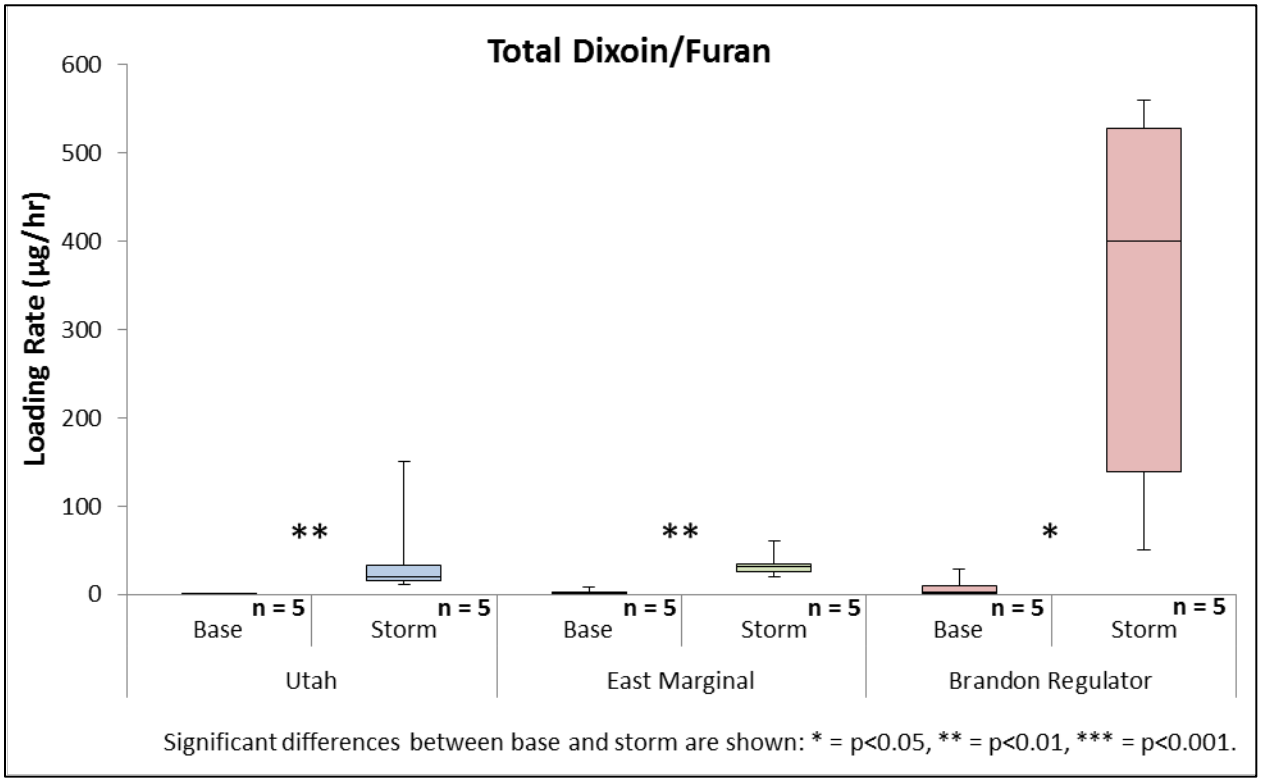

Figure 73. Boxplots of Total Dioxin/Furan Loading Rates by Location and Flow Condition.

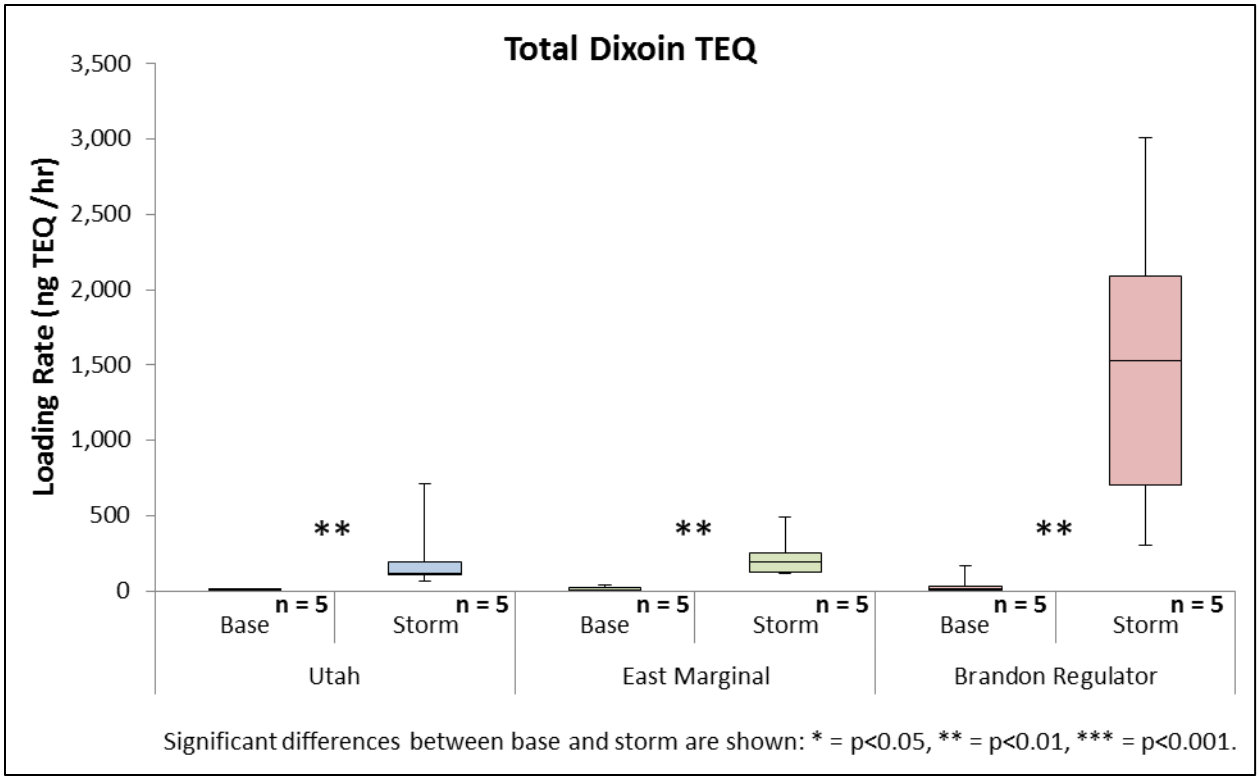

Figure 74. Boxplots of Total Dioxin TEQ Loading Rates by Location and Flow Condition.

7.2.8 Summary of Baseflow versus Stormflow

When data were sufficient to make statistical comparisons (FOD >75%), stormflow sample loading rates were always significantly different than baseflow sample loading rates; the highest mean and median loading rate values were observed during stormflow. This suggests stormwater contributes a significant load of each parameter during stormflow conditions. The relative magnitude of each pathway (sewage versus stormwater) is evaluated in the next section.

7.3 Relative Magnitude of Pathways during Storm Events

Using these data, the relative magnitude of each pathway (sewage versus stormwater) was estimated for each parameter with greater than 75% FOD. The study objective was to help inform any source control work in combined basins prior to CSO control. Infiltration was not estimated as a pathway, because it was not consistently observed in the available data.

The mean loading of chemicals from baseflow (sewage) versus stormwater (stormflow minus sewage) is important for understanding sources within the combined system, but it does not represent the loading of a CSO discharge. The vast majority of stormflow volume is directed to the West Point Treatment Plant through the EBI. Under select circumstances, generally very large storms, stormflow from this basin may be discharged through the CSO

until the EBI has capacity to accept the flow again. Study samples were not collected during CSO events, and the smaller storms sampled in this study are not representative of typical CSO discharge conditions. This analysis is constrained by the limited number of storms sampled, the storm intensities, number of non-detect results, limitations of the baseflow data, and other constraints of this initial investigation. There are likely several other types of flow conditions not adequately represented in the data set, for instance during the highest flow periods, re-suspension of deposited solids may occur. Therefore, the relative magnitudes of pathways presented here are estimates and should only be used to generalize potential sources of sewage (domestic and industrial wastewater) relative to stormwater. They do not estimate loads to the LDW from the Brandon combined sewer basin, nor any other combined sewer basin. However, they could suggest primary pathways during releases, especially for parameters estimated to be sourced primarily from stormwater at Brandon Regulator, as this pathway would be an even greater contributor during larger storms.

Dry and wet baseflow results were combined to represent the sewage component in order to increase statistical power for this analysis. This approach is reasonable because there were few statistical differences in chemical loading rates between dry and wet baseflow samples, which suggests wet baseflow in this combined basin is still largely comprised of domestic and industrial sewage.

To estimate mean stormwater loading rates, the mean baseflow loading rate (based on dry and wet baseflow samples combined) was subtracted from the mean stormflow sample loading rate. This was done because stormflow includes both the sewage and stormwater components and the objective of this analysis was to separate the stormflow loadings attributable to sewage versus those attributable to stormwater. Parameters with less than 75% FOD were not included in this analysis due to the greater uncertainty in the loading rate estimate; only detected concentrations were used in loading calculations.

When the sewage or stormwater loading rates fall within 40%-60% of the total loading rate (as illustrated with a gray bar in the figures shown below), the chemical is considered evenly sourced between the sewage and stormwater pathways. This range was selected because of the uncertainties in the assumptions used to estimate the mean loading rates. Uncertainties associated with the loading rates are presented in Section 7.4.

7.3.1 Relative Magnitude of Pathways during Storm Events for Conventional Parameters

The mean sewage and stormwater loading rate estimates during stormflow for conventional parameters are summarized in Table 23 and Figure 75. Stormwater was estimated to be the primary pathway during stormflow for all three conventional parameters, except for DOC at East Marginal and Brandon Regulator, where estimated stormwater and sewage contributions were fairly similar.

Table 23. Mean Loading Rates by Pathway for Conventional Parameters.

Analyte	Location	Mean Loading Rates (kg/hr)		
		Baseflow[a] (N)	Stormflow (N)	Stormwater Component[b]
Total Organic Carbon	Utah	0.145 (11)	0.863 (14)	0.718
	East Marginal	4.20 (10)	11.4 (8)	7.20
	Brandon Regulator	4.94 (11)	14.3 (14)	9.34
Dissolved Organic Carbon	Utah	0.0900 (11)	0.319 (14)	0.229
	East Marginal	3.18 (10)	7.23 (8)	4.05
	Brandon Regulator	3.33 (11)	7.81 (14)	4.48
Total Suspended Solids	Utah	0.232 (11)	3.35 (14)	3.12
	East Marginal	3.53 (10)	12.1 (8)	8.6
	Brandon Regulator	5.61 (11)	39.4 (14)	33.8

[a] Baseflow results represent the sewage pathway.
[b] Stormwater loading rates were estimated by subtracting mean baseflow loading rates from mean stormflow loading rates.
N is number of baseflow or stormflow samples on which the mean is based (detections only)

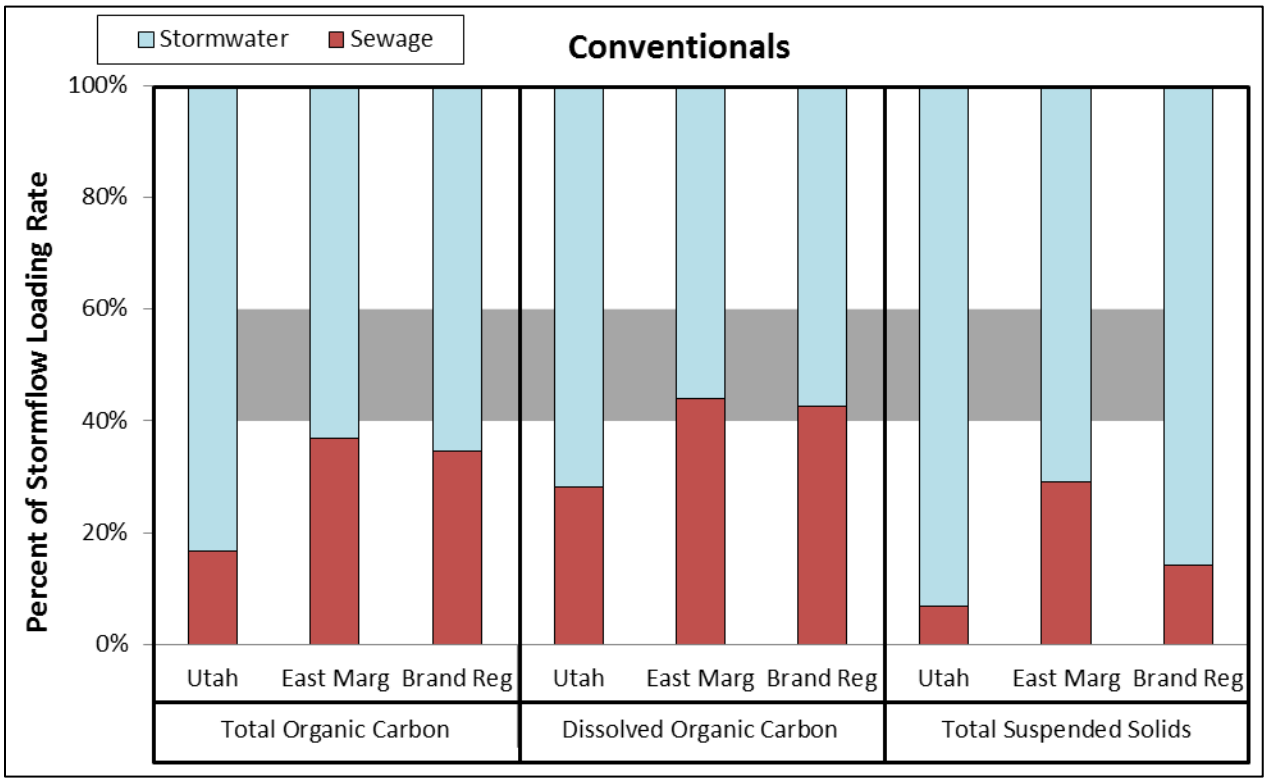

Figure 75. Relative Magnitude of Pathways (Sewage versus Stormwater) for Conventional Parameters by Location.

7.3.2 Relative Magnitude of Pathways during Storm Events for Metals and Mercury

The mean sewage and stormwater loading rate estimates during stormflow for metals and mercury are summarized in Table 24. The relative magnitudes of pathways during stormflow (sewage versus stormwater) for total and dissolved metals are summarized in Figures 76 and 77, respectively. These figures illustrate the relative loading estimates derived from the mean loading rates. For those metals with negative stormwater loading rate estimates, the figures simply assume 100% of the loading is from baseflow. Figure 78 is included to illustrate the relative magnitude of pathway estimate using median loading rates instead of means for the metals with highly skewed means, as presented in Table 24.

Arsenic and chromium at Brandon Regulator were the only instances where sewage was estimated to be the primary pathway, and this was heavily influenced by one event, as described below. However, when median rates are used, then stormwater is the primary pathway for arsenic and chromium. For all other total metals and all dissolved metals except vanadium at Brandon Regulator, stormwater was estimated to be the primary pathway.

One baseflow sampling event at Brandon Regulator detected very high concentrations of arsenic and chromium (Sections 5.2 and 5.4). These concentrations were more than an order of magnitude greater than any other reported detection. There is no evidence to suggest these concentrations were outliers for the system as a whole, because different industrial and commercial dischargers are known to have sporadic waste inputs into the combined system. However, these very high concentrations translated into high loading rates for this baseflow sample, which resulted in mean sewage loading rates that exceeded the mean stormflow loading rates for these metals. As a result, calculation of the stormwater only fraction (via subtraction) resulted in negative estimates for stormwater inputs. The negative stormwater loading rate estimates are included in Table 24; however, an additional row is included to report the stormwater estimates using median loading rates for baseflow and stormflow. Since the frequency of these higher loading events is unknown, the less skewed loading rates (calculated with medians) are not necessarily better estimates, but explore how the skewed distribution affects the pathway estimates. Section 7.4 presents the uncertainty of the pathway estimates.

Table 24. Mean Loading Rates by Pathway for Metals and Mercury.

Analyte	Location	Mean Loading Rates (mg/hr)		
		Baseflow[a] (N)	Stormflow (N)	Stormwater Component[b]
Total Arsenic	Utah	1.27 (11)	31.4 (14)	30.1
	East Marginal	11.8 (10)	84.8 (8)	73.0
	Brandon Regulator	790 (11)	363 (14)	-427
		Median: 46.3	Median: 256	Median: 210

Table 24, Continued

Analyte	Location	Mean Loading Rates (mg/hr)		
		Baseflow[a] (N)	Stormflow (N)	Stormwater Component[b]
Dissolved Arsenic	Utah	0.981 (11)	14.6 (14)	13.6
	East Marginal	6.75 (8)	59.7 (7)	53.0
	Brandon Regulator	885 (10)	186 (13)	-699
		Median: 30.8	Median: 164	Median: 133
Total Cadmium	Utah	0.294 (11)	7.03 (14)	6.74
	East Marginal	2.29 (9)	21.1 (8)	18.8
	Brandon Regulator	17.5 (11)	77.7 (14)	60.2
Dissolved Cadmium	Utah	0.0850 (7)	1.22 (10)	1.14’
	East Marginal	0.501 (1)	4.95 (5)	4.45
	Brandon Regulator	6.56 (10)	14.2 (9)	7.64
Total Chromium	Utah	3.82 (11)	139 (14)	135
	East Marginal	35.4 (10)	205 (8)	170
	Brandon Regulator	1,500 (11)	1,570 (14)	70.0
		Median: 118	Median: 900	Median: 782
Dissolved Chromium	Utah	1.20 (11)	14.3 (14)	13.1
	East Marginal	11.7 (8)	28.9 (7)	17.2
	Brandon Regulator	1,250 (10)	179 (13)	-1,070
		Median: 22.1	Median: 141	Median: 119
Total Copper	Utah	50.3 (11)	845 (14)	795
	East Marginal	380 (10)	1,530 (8)	1,150
	Brandon Regulator	1,280 (11)	10,300 (14)	9,020
Dissolved Copper	Utah	16.0 (11)	186 (14)	170
	East Marginal	81.1 (8)	420 (7)	339
	Brandon Regulator	438 (10)	2,010 (13)	1,570
Total Lead	Utah	12.1 (11)	418 (14)	406
	East Marginal	84.6 (10)	628 (8)	543
	Brandon Regulator	344 (11)	3,610 (14)	3,270
Dissolved Lead	Utah	1.61 (11)	14.6 (14)	13.0
	East Marginal	7.41 (8)	51.9 (7)	44.5
	Brandon Regulator	50.6 (10)	186 (13)	135
Total Nickel	Utah	4.95 (11)	149 (14)	144
	East Marginal	39.4 (10)	206 (8)	167
	Brandon Regulator	1,400 (11)	9,890 (14)	8,490

Table 24, Continued

Analyte	Location	Mean Loading Rates (mg/hr)		
		Baseflow[a] (N)	Stormflow (N)	Stormwater Component[b]
Dissolved Nickel	Utah	2.70 (11)	36.9 (14)	34.2
	East Marginal	23.2 (8)	83.8 (7)	60.6
	Brandon Regulator	1,320 (10)	7,560 (13)	6,240
Total Silver	Utah	0.540 (11)	4.88 (14)	4.34
	East Marginal	0.722 (9)	3.15 (8)	2.43
	Brandon Regulator	8.46 (11)	72.7 (14)	64.2
Dissolved Silver	Utah	1.18 (2)	1.64 (5)	0.456
	East Marginal	NC	NC	NC
	Brandon Regulator	1.43 (5)	12.5 (3)	11.1
Total Vanadium	Utah	3.94 (11)	143 (14)	139
	East Marginal	31.3 (10)	189 (8)	158
	Brandon Regulator	149 (11)	1,020 (14)	871
Dissolved Vanadium	Utah	1.19 (11)	24.2 (14)	23.0
	East Marginal	8.27 (8)	35.8 (7)	27.5
	Brandon Regulator	70.7 (10)	158 (13)	87.3
Total Zinc	Utah	123 (11)	3,260 (14)	3,140
	East Marginal	1,310 (10)	7,210 (8)	5,900
	Brandon Regulator	2,960 (11)	31,000 (14)	28,000
Dissolved Zinc	Utah	31.2 (11)	908 (14)	877
	East Marginal	300 (8)	2,590 (7)	2,290
	Brandon Regulator	1,330 (10)	8,630 (13)	7,300
Total Mercury	Utah	0.0446 (11)	0.845 (14)	0.800
	East Marginal	0.422 (10)	1.76 (8)	1.34
	Brandon Regulator	1.16 (11)	19.4 (14)	18.2
Dissolved Mercury	Utah	0.00823 (9)	0.0843 (6)	0.0761
	East Marginal	0.0994 (6)	0.373 (3)	0.274
	Brandon Regulator	0.228 (8)	1.12 (7)	0.892

[a] Baseflow results represent the sewage pathway.
[b] Stormwater loading rates were estimated by subtracting mean baseflow loading rates from mean stormflow loading rates N is number of baseflow or stormflow samples on which the mean is based (detections only)
NC = not calculated due to < 75% frequency of detection.

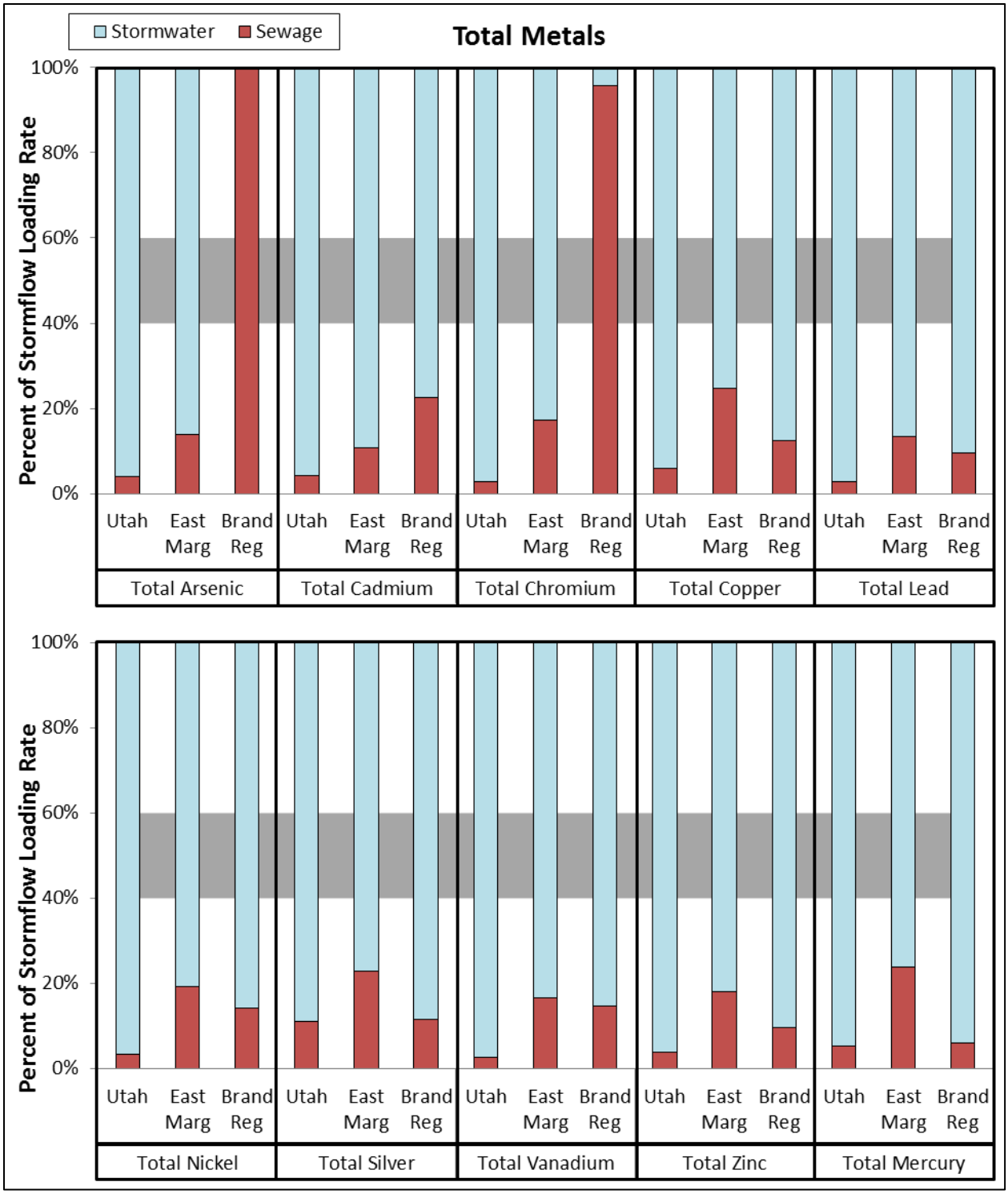

Figure 76. Relative Magnitude of Pathways (Sewage versus Stormwater) for Total Metals by Location.

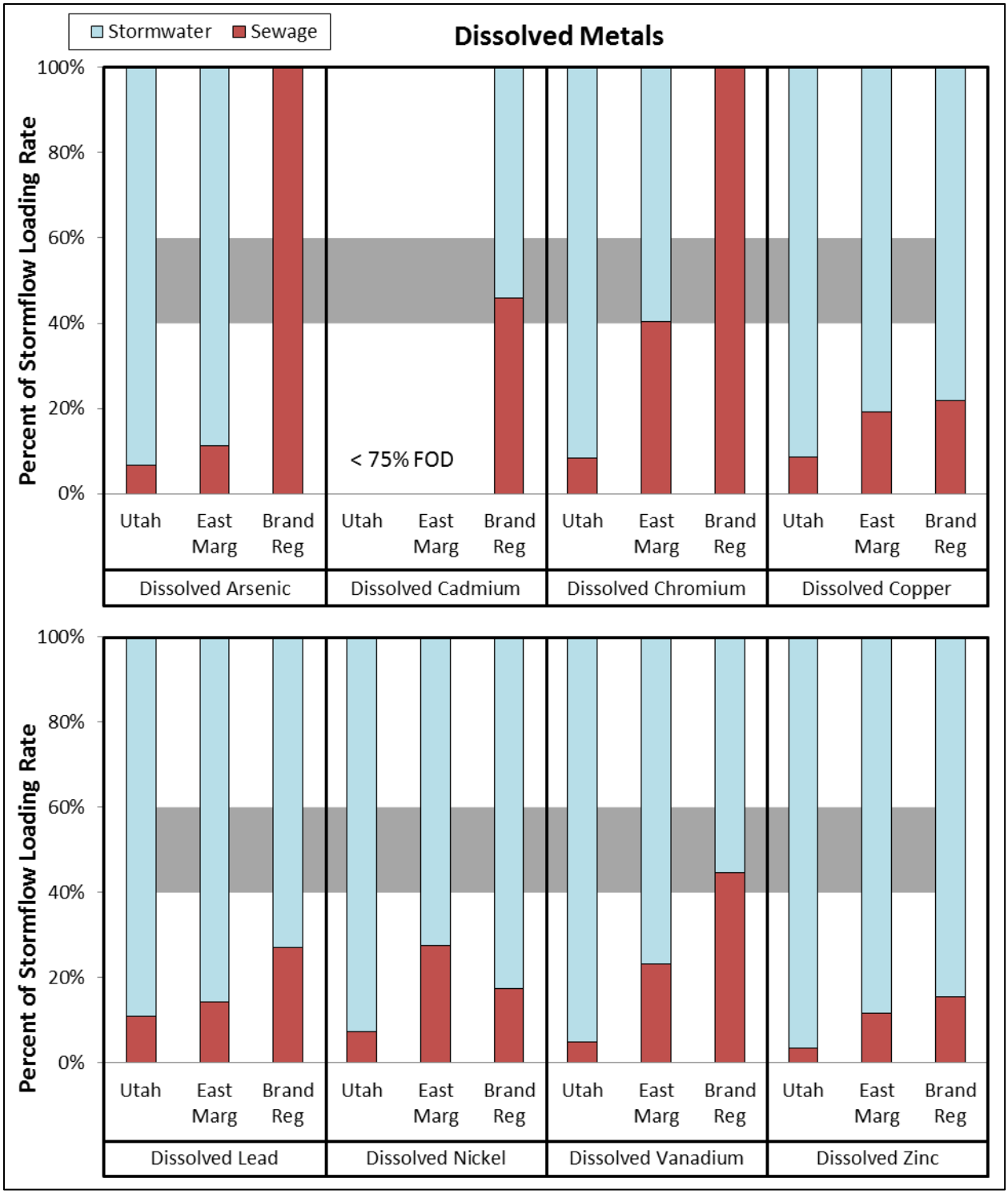

Figure 77. Relative Magnitude of Pathways (Sewage versus Stormwater) for Dissolved Metals by Location.

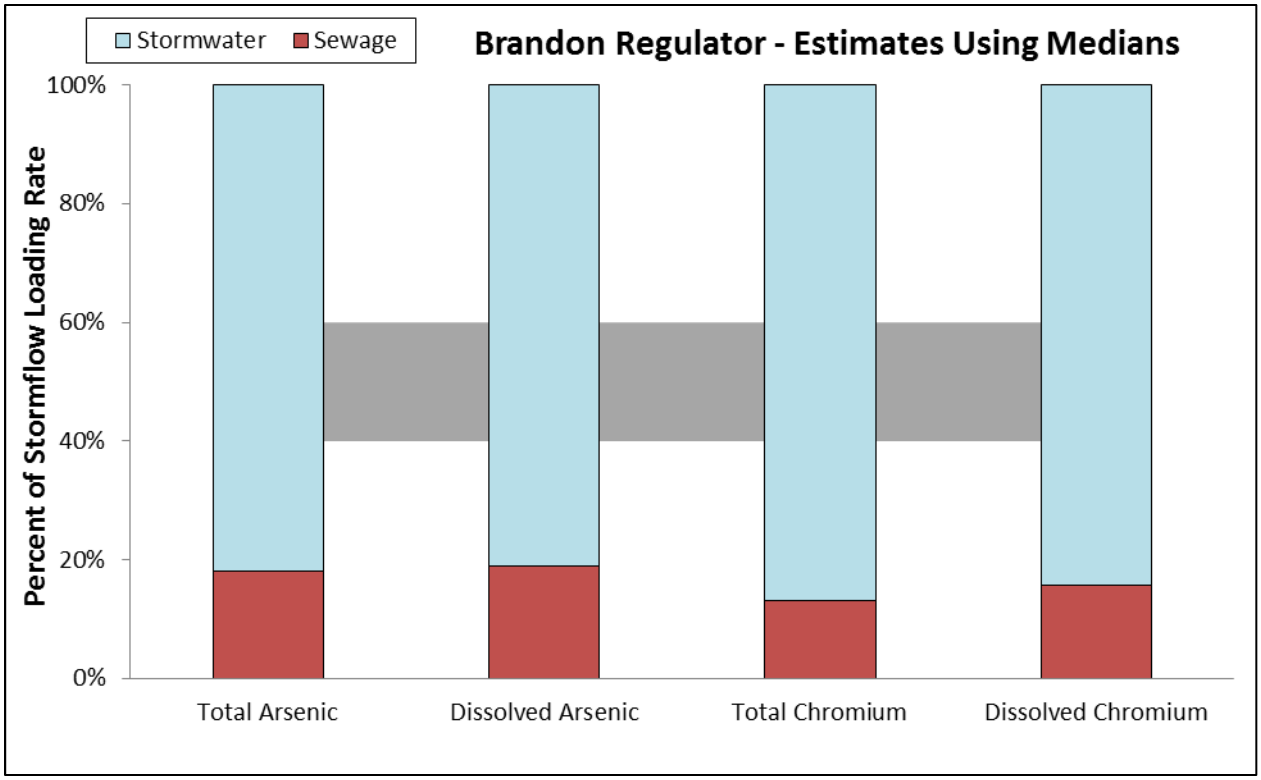

Figure 78. Relative Magnitude of Pathways (Sewage versus Stormwater) Using Medians for Total and Dissolved Arsenic and Chromium at Brandon Regulator.

Determining whether the one high dry baseflow concentration for arsenic and chromium and resulting loadings are outliers would require further study. If these high concentrations occur at a regular frequency, then Figures 76 and 77 are more representative of actual loads. However, if elevated concentrations are a rare occurrence, then Figure 78 is a more accurate representation of these two metals.

7.3.3 Relative Magnitude of Pathways during Storm Events for Organic Chemicals

Mean loading rates from sewage and stormwater for select organic chemicals are summarized in Tables 25 through 27 and Figures 79 through 81; note that the units vary by table. Stormwater was estimated to be the primary pathway for the selected organic chemicals, except for benzyl butyl phthalate at Utah and diethyl phthalate at East Marginal where estimated stormwater and sewage contributions were fairly similar.

Table 25. Mean Loading Rates by Pathway for Select PAHs and Phthalates.

Analyte	Location	Mean Loading Rates (µg/hr)		
		Baseflow[a] (N)	Stormflow (N)	Stormwater Component[b]
Phenanthrene	Utah	0.0945 (8)	2.26 (14)	2.17
	East Marginal	0.630 (4)	4.59 (7)	3.96
	Brandon Regulator	1.41 (9)	22.1 (14)	20.7
Fluoranthene	Utah	0.0642 (8)	3.79 (14)	3.73
	East Marginal	0.312 (5)	4.57 (7)	4.26
	Brandon Regulator	1.10 (8)	27.7 (14)	26.6
Total HPAHs	Utah	0.187 (8)	18.9 (14)	18.7
	East Marginal	0.728 (6)	17.4 (7)	16.7
	Brandon Regulator	3.45 (9)	124 (14)	121
Benzyl Butyl Phthalate	Utah	69.5 (11)	128 (14)	58.5
	East Marginal	3.09 (9)	463 (7)	460
	Brandon Regulator	102 (11)	577 (14)	475
Bis (2-ethylhexyl) phthalate	Utah	12.0 (11)	80.4 (11)	68.4
	East Marginal	26.4 (9)	181 (7)	155
	Brandon Regulator	96.7 (11)	870 (9)	773
Diethyl Phthalate	Utah	5.07 (11)	23.6 (14)	18.5
	East Marginal	16.8 (9)	33.0 (8)	16.2
	Brandon Regulator	49.8 (11)	145 (14)	95.2

[a] Baseflow results represent the sewage pathway.
[b] Stormwater loading rates were estimated by subtracting mean baseflow loading rates from mean stormflow loading rates
N is number of baseflow or stormflow samples on which the mean is based (detections only)
NC = not calculated due to < 75% frequency of detection.

Table 26. Mean Loading Rates by Pathway for Total PCB and Total Dioxin/Furan.

Analyte	Location	Mean Loading Rates (µg/hr)		
		Baseflow[a] (N)	Stormflow (N)	Stormwater Component[b]
Total PCBs	Utah	44.2 (5)	1,700 (5)	1,660
	East Marginal	198 (5)	1,180 (5)	982
	Brandon Regulator	827 (5)	22,300 (5)	21,500
Total Dioxin/Furans	Utah	0.217 (5)	51.5 (5)	51.3
	East Marginal	2.95 (5)	35.1 (5)	32.1
	Brandon Regulator	9.59 (5)	333 (5)	323

[a] Baseflow results represent the sewage pathway.
[b] Stormwater loading rates were estimated by subtracting mean baseflow loading rates from mean stormflow loading rates
N is number of baseflow or stormflow samples on which the mean is based (detections only)

Table 27. Mean Loading Rates by Pathway for Total Dioxin TEQs.

Analyte	Location	Mean Loading Rates (ng TEQ/hr)		
		Baseflow[a] (N)	Stormflow (N)	Stormwater Component[b]
Total Dioxin TEQs	Utah	1.45 (5)	263 (5)	262
	East Marginal	14.5 (5)	244 (5)	230
	Brandon Regulator	49.9 (5)	1,550 (5)	1,500

[a] Baseflow results represent the sewage pathway.
[b] Stormwater loading rates were estimated by subtracting mean baseflow loading rates from mean stormflow loading rates
N is number of baseflow or stormflow samples on which the mean is based (detections only)

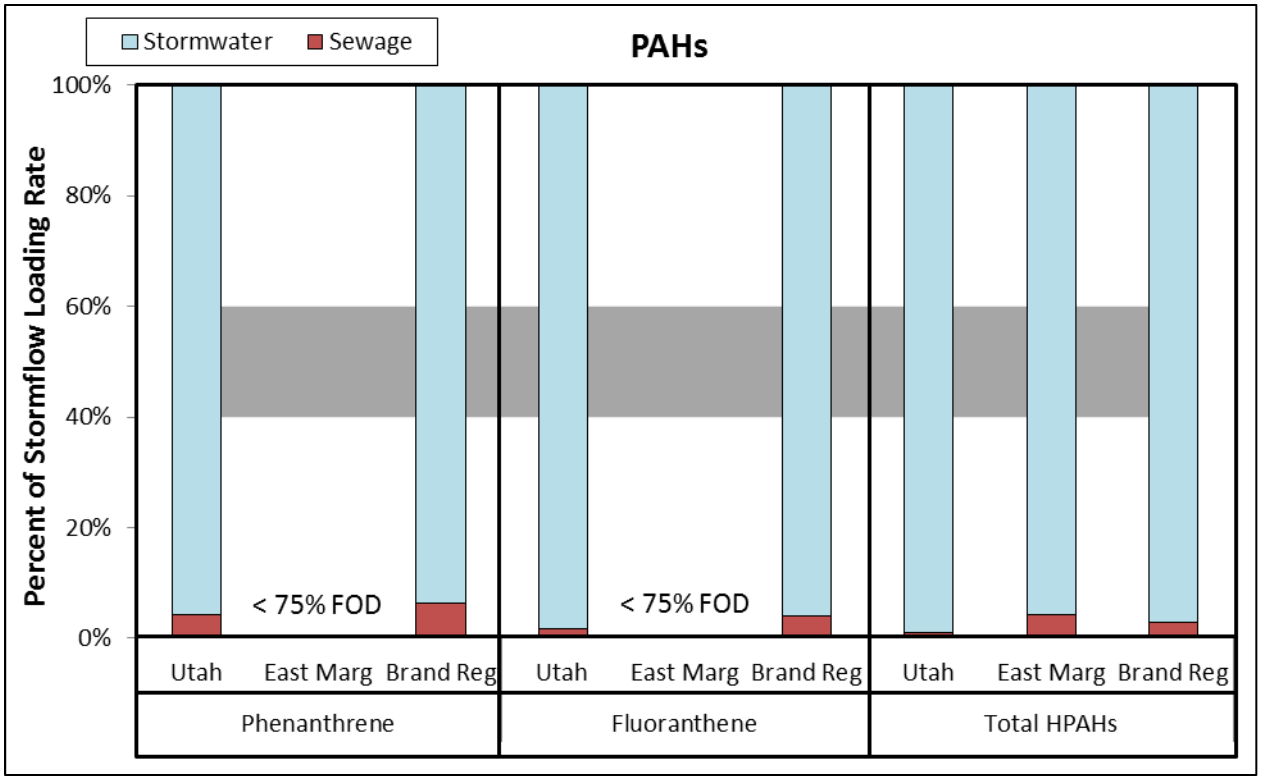

Figure 79. Relative Magnitude of Pathways (Sewage versus Stormwater) for PAHs by Location.

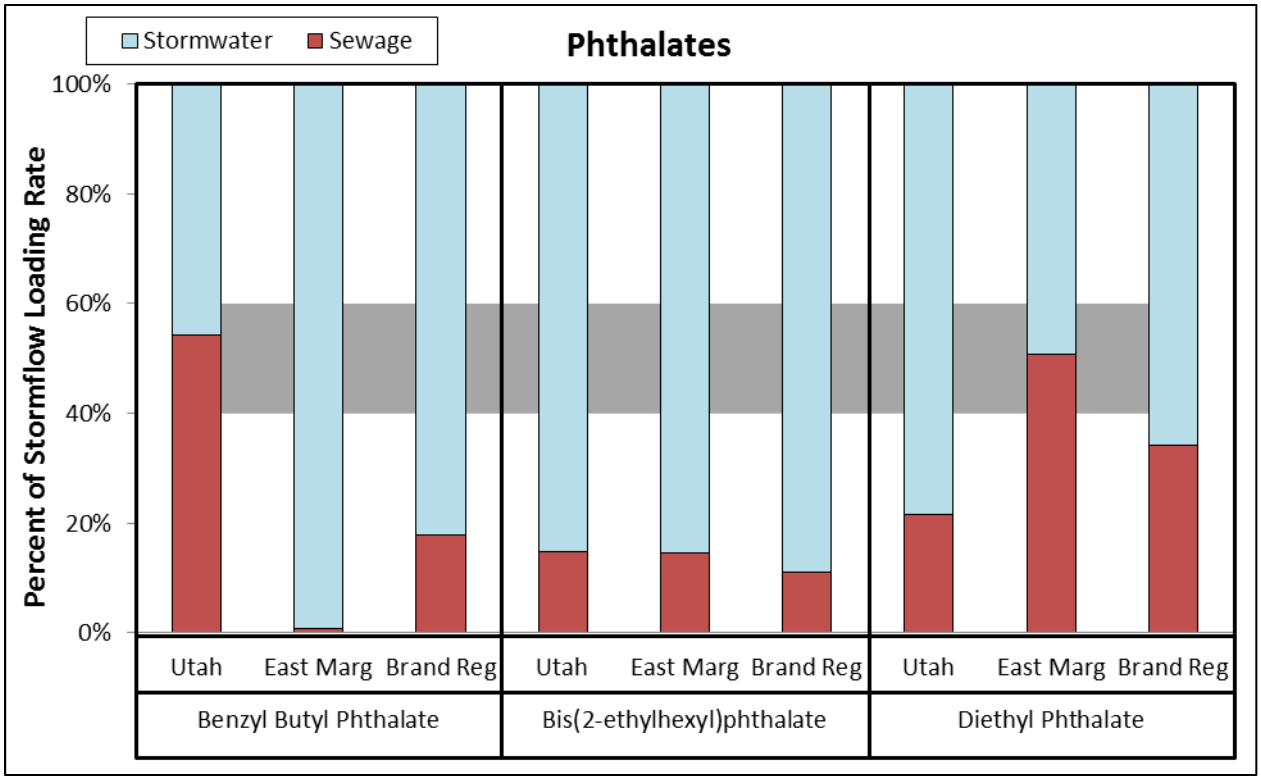

Figure 80. Relative Magnitude of Pathways (Sewage versus Stormwater) for Phthalates by Location.

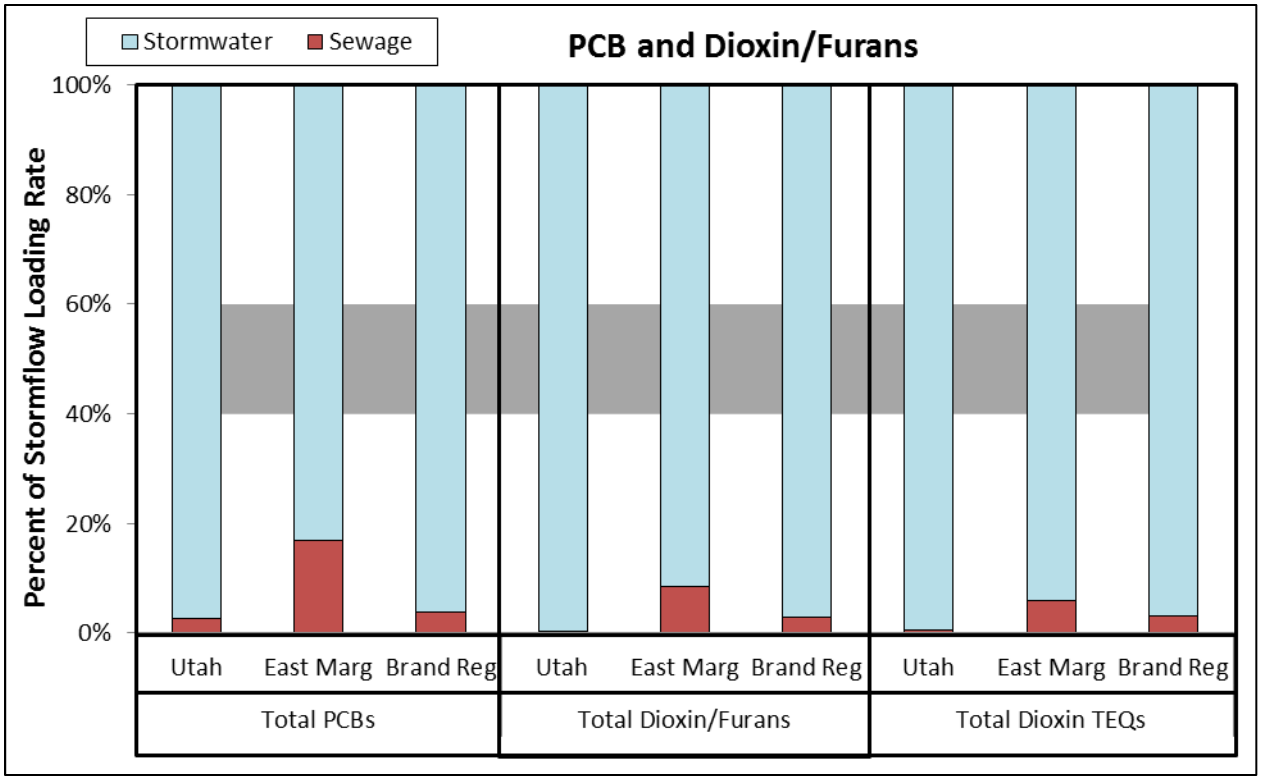

Figure 81. Relative Magnitude of Pathways (Sewage versus Stormwater) for PCBs and Dixoin/Furans by Location.

7.4 Uncertainty Assessment

The uncertainty of various components of the loading estimates was evaluated separately, although statistical methods were not used. The first section discusses whether rainfall (Section 7.4.1) conditions during the study year (7/19/2011–7/18/2012) were typical of recent years. Section 7.4.2 considers the variability in the loading rate estimates used to determine the relative magnitude of pathways, which was then used in Section 7.4.3 to evaluate the uncertainty in the identification of the primary pathway for each parameter. These later two analyses were only conducted for parameters with greater than 75% FOD at a given site.

7.4.1 Rainfall and Weather Uncertainty

The individual flow measurements were assumed to be accurate to the meter manufacturer's specifications; all flow meter installations were also independently field-verified. However, year to year variability in rainfall could be a potentially large source of uncertainty when extrapolating from this sampling period. To compare rainfall during the study year (2011–2012) to historical rainfall in the area, precipitation data from the Hamm Creek rain gauge were used. This gauge provided a more consistent historical record than the East Marginal rain gauge, which was periodically interrupted for construction and equipment repairs prior to the study period. Rainfall conditions during the study year are compared to rainfall conditions from 1999 to 2013 and illustrated below in Figure 83.

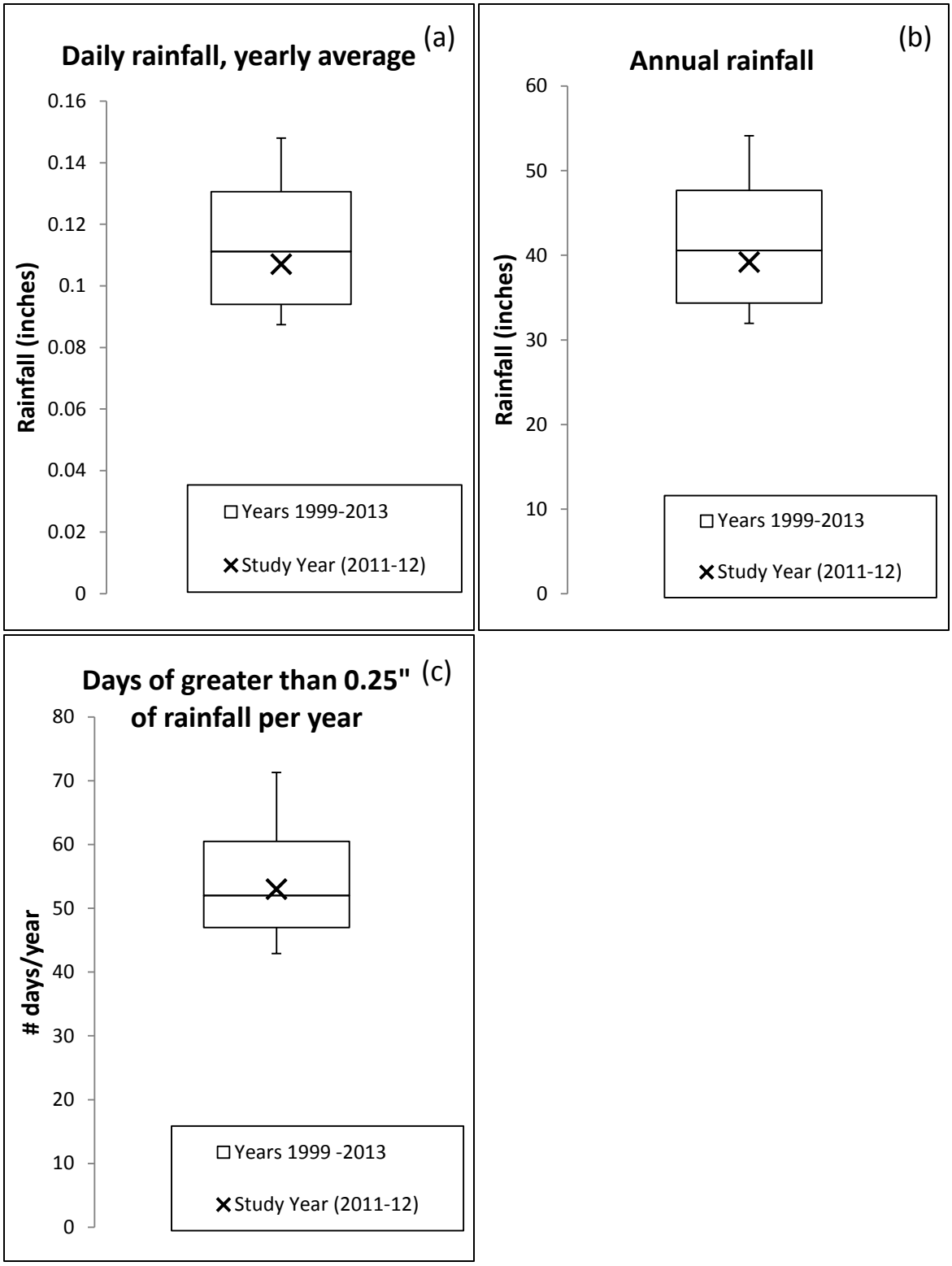

Figure 82. Box Plots of Hamm Creek Rain Gauge (a) Mean Daily Rainfall per Year, (b) Annual Rainfall, and (c) Number of Days with Greater than 0.25" Rainfall Compared to Study Year Data.

Figure 83 illustrates that mean daily rainfall and annual rainfall during the study year were quite similar to median conditions for the past 15 years. The past 15 years of rain gauge data were used to represent current/future conditions given uncertainties about the impact of climate change on rainfall patterns and intensities. During the study year, the number of days with rainfall over 0.25 inches was similar to the median. Overall, rainfall conditions during the study year appear representative of the average past 15 years of rainfall conditions near the Brandon Basin.

While differences in antecedent dry periods may be a source of variability in the storm loadings, it is not testable in the uncertainty assessment. Antecedent dry periods associated with stormflow sampling ranged from 0 to 125 hours during this study, with a mean of 21 hours for Brandon Regulator samples.

7.4.2 Uncertainty in Mean Loading Rates

To evaluate the uncertainty in mean loading rates, uncertainty ranges for sewage and stormwater loading rates were established based on standard deviations around the mean. Standard deviations were used in this calculation because more typical uncertainty bounds, such as the 25th and 75th percentiles did not always bracket the mean loading rates. That is, some arithmetic mean loading rates were higher than the 75th percentile loading rate due to the skewness and small data set. Relative variability was also established; calculated comparably to a relative standard deviation. Appendix F provides a detailed description of these calculations and tables summarizing the findings (Appendix F; Tables F-1 through F-6). This assessment provides a metric for the relative variability in sewage and stormwater loading rates between parameters, locations, and flow conditions.

Qualitatively, uncertainty is lowest for the sewage loading rate estimates as baseflow was directly sampled. Uncertainties for stormwater estimates are intrinsically higher, because they could only be derived through subtraction between the baseflow and stormflow sample loading rates. Thus, the mean estimate for the stormwater fraction is inherently less reliable and certain than the mean estimate for the sewage fraction.

Relative variability for conventional parameters was generally low compared to many metals and phthalates; the low and the high estimates were almost always within a factor of two of the mean estimate (Appendix F; Table F-2). For many metals, relative variability was higher at Brandon Regulator compared to Utah or East Marginal, especially for arsenic and chromium where one very high baseflow loading rate event at Brandon Regulator dramatically increased the overall uncertainty in the calculated mean loading rates (Appendix F; Table F-3). The relative range between the mean estimates, and low and high (using standard deviation) were smaller for organic chemicals because the variability around the sewage loading estimate was lower (Appendix F; Tables F-4, F-5 and F-6). Table 28 summarizes which parameters at each location had relatively higher uncertainty in the mean loading rates for sewage and stormwater. Overall, Brandon Regulator had more uncertainty in mean loading rates when compared to Utah and East Marginal sampling locations.

Table 28. Parameters with Higher Uncertainty in the Mean Loading Rate Estimates

Pathway	Parameter Group	Location		
		Utah	East Marginal	Brandon Regulator
Sewage Loading Rate	Conventionals	--	--	--
	Total Metals	Silver	--	Arsenic, Cadmium, Chromium, Lead, Nickel, Vanadium
	Dissolved Metals	Chromium	--	Arsenic, Cadmium, Chromium, Nickel, Vanadium
	Organics	--	--	Total Dioxin TEQs
Stormwater Loading Rate	Conventionals	--	DOC	--
	Total Metals	--	--	Chromium, Nickel, Silver, Mercury
	Dissolved Metals	--	--	Cadmium, Nickel
	Organics	Benzyl butyl phthalate	Benzyl butyl phthalate	Benzyl butyl phthalate

Note: Parameter included if relative variability >1.5 from Tables F-1 through F-6 in Appendix F. The relative variability is calculated similarly to a relative standard deviation (See Appendix F for details).

7.4.3 Uncertainty in Pathway Estimates

This section evaluates the uncertainty in the identification of the primary pathway for each parameter. The relative magnitude of each pathway (sewage versus stormwater) was calculated with five different scenarios using: (1) the mean estimate for both sewage and stormwater loading rates, (2) a high sewage estimate, (3) a low sewage estimate, (4) a high stormwater estimate, and (5) a low stormwater estimate. Table 29 shows how each scenario was calculated. Figures F-1 through F-32 in Appendix F graphically depicts the outcomes for these scenarios; that is, the relative magnitude of pathways for all parameters and locations under each scenario.

Table 29. Scenarios Used in the Uncertainty Assessment.

Scenario	Calculated from Sampling Results		Resulting Estimates	
	Baseflow Loading Rate (= A)	Stormflow Loading Rate (= B)	Sewage Loading Rate (= A)	Stormwater Loading Rate (= B – A)
1. Mean Estimate	Mean	Mean	Mean	Mean
2. High Sewage	Mean + St Dev	Mean	High	Biased low
3. Low Sewage	Mean – St Dev	Mean	Low	Biased high
4. High Stormwater	Mean	Mean + St Dev	Mean	High
5. Low Stormwater	Mean	Mean – St Dev	Mean	Low

St Dev – Standard Deviation
Note: "Biased low" is the result of subtracting a high baseflow loading estimate from the mean stormflow loading estimate. "Biased high" is the result of subtracting a low baseflow loading estimate from the mean stormflow loading estimate.

Stormwater was estimated to be the primary pathway during stormflows for most scenarios and parameters. Because of this, and the higher uncertainty in the stormwater estimates, the low stormwater scenario (Scenario 5 in Table 29) differed most dramatically from the mean estimate for almost all parameters and locations.

Table 30 summarizes the uncertainty in the primary pathway mean estimate for each parameter and location. Uncertainties were assigned as low, moderate or high based on the analysis. If all scenarios but the low stormwater resulted in the same primary pathway as the mean estimate, a low uncertainty was assigned and thus the mean estimate was determined to be a reasonable estimate of the primary pathway for that parameter. If two of the scenarios resulted in identifying the same primary pathway as the mean estimate, then moderate uncertainty was assigned. If most scenarios differed from the mean estimate or negative loading estimates were calculated for any scenario, a high uncertainty was assigned. Moderate or high uncertainties suggest less confidence in the primary pathway identified using the mean estimate.

For all conventional parameters, the uncertainty assessment supported the mean estimate of stormwater as the primary pathway at Utah. At East Marginal and Brandon Regulator, moderate uncertainty was found for TOC being primarily sourced from stormwater. For DOC, the mean estimate of an even mix of sewage and stormwater had the highest uncertainty of the conventional parameters at East Marginal and Brandon locations. For TSS, the mean estimate of stormwater as the primary pathway had low uncertainty at Brandon Regulator and moderate uncertainty at East Marginal.

Table 30. Results of Uncertainty Assessment of Primary Pathway Estimates.

Group	Analyte	Utah	East Marginal	Brandon Regulator
Conventionals	Total Organic Carbon			
	Dissolved Organic Carbon			
	Total Suspended Solids			
Total Metals	Arsenic			
	Cadmium			
	Chromium			
	Copper			
	Lead			
	Nickel			
	Silver			
	Vanadium			
	Zinc			
	Mercury			
Dissolved Metals	Arsenic			
	Cadmium	N/C	N/C	
	Chromium			
	Copper			
	Lead			
	Nickel			
	Silver	N/C	N/C	N/C
	Vanadium			
	Zinc			
PAHs	Phenanthrene		N/C	
	Fluoranthene		N/C	
	Total HPAHs			
Phthalates	Benzyl Butyl Phthalate			
	Bis(2-ethylhexyl)phthalate			
	Diethyl Phthalate			
PCBs and Dioxin/Furans	Total PCBs			
	Total Dioxin/Furans			
	Total Dioxin TEQs			

= low uncertainty; all scenarios same as mean estimate but low stormwater scenario

= moderate uncertainty; two scenarios same as mean estimate

= high uncertainty; most scenarios differ from mean estimate or negative loading estimates were calculated for a scenario

N/C = not calculated – relative magnitude of pathways was only estimated for parameters with greater than 75% frequency of detection at a given site.

For metals, the uncertainty assessment supported stormwater as the primary pathway at Utah and East Marginal (all showed low uncertainty), except for dissolved chromium at East Marginal, where the even mix mean estimate had moderate uncertainty. For many metals at these locations, all scenarios estimated stormwater as the primary pathway. At

Brandon Regulator, there was moderate or high uncertainty in the mean estimate for total and dissolved arsenic, cadmium and chromium and dissolved lead and vanadium due to highly variable sample loading rates within the same flow condition. This was particularly evident for total and dissolved arsenic and dissolved chromium where large negative loadings were theoretically generated for stormwater, as this fraction could only be estimated by subtraction of the already uncertain mean baseflow load. The remaining metals had low uncertainty suggesting the mean estimate of stormwater as the primary pathway was reasonable. Overall, the primary pathway for metals based on the mean estimate had less uncertainty at Utah and East Marginal compared to Brandon Regulator.

The uncertainty assessment indicates the mean estimate of stormwater as the primary pathway was reasonable for the PAHs evaluated, bis(2-ethylhexyl)phthalate, PCBs, dioxin/furans, and dioxin TEQs at all locations; all had low uncertainty. This was also true for benzyl butyl phthalate at East Marginal and Brandon Regulator, and diethyl phthalate at Utah. However, the primary pathway estimates had higher uncertainty for these latter two phthalates at the other locations.

7.4.4 Other Potential Sources of Uncertainty

The method chosen to estimate stormwater loading rates is one of several options that could have been used. Alternative methods could include probabilistic analysis of many base and stormflow loading combinations to generate a range of base and stormwater loading rates or subtracting the mean baseflow loading rates from each individual stormflow loading rate to generate a range of potential stormwater loading rates that vary by storm event. Dry and wet baseflow loading rates could have also been used separately in this analysis, instead of combining them to generate the overall mean baseflow loading rate. While alternative methods could have influenced conclusions, it was outside the scope of this project to evaluate all possible methodological alternatives. Future efforts may wish to use a variety of methods to evaluate the uncertainty in estimating sewage and stormwater loading rates based on these samples.

Additional sources of uncertainty that were not addressed in this assessment include the relatively small sample size, the exclusion of samples with non-detect concentrations from the loadings analysis, and the variability in flow and laboratory analysis of chemical concentrations.

8.0. CONCLUSIONS AND RECOMMENDATIONS

This investigation set out to estimate concentrations and loadings of chemicals within the Brandon Basin to better understand the primary pathways (i.e., stormwater, sewage and/or infiltration of groundwater) of contaminants to the combined sewer system. This basin is relatively small (244 acres) with predominately industrial and commercial land use, compared to other LDW combined sewer basins. This study required the measurement of both flow and contaminant concentrations during different combined sewer system conditions throughout the year. Continuous flow data and flow-weighted composite samples were collected at three locations in the Brandon Basin: Utah, East Marginal and Brandon Regulator. Samples were collected during periods of dry and wet baseflow and stormflow conditions. Samples were analyzed for conventional parameters, total and dissolved metals, PAHs, phthalates, PCBs and dioxin/furans. Discharges from CSOs were not sampled in this study; all samples were collected within the combined sewer system, and loading rate estimates apply only to the West Point Treatment Plant, not discharges to the LDW.

Mean flows during stormflow sampling ranged from 0.200 and 2.06 MGD at Brandon Regulator. During the 2009 to 2012 period, the minimum flow at Brandon Regulator during a CSO discharge event was 0.4 MGD, while the mean flow was 3 MGD. Because of the dynamic nature of flow in the basin, prior storms, and EBI flow capacity conditions (which is managed to minimize CSO discharge events), it is not possible to identify a threshold flow which triggers a CSO discharge event. The stormflow loading rates are only applicable to estimate the contaminant loading rates to West Point Treatment Plant from the Brandon Basin during mild to moderate storm events and are not representative of typical CSO discharge conditions.

The conclusions presented below are meant as estimates of conditions within this combined sewer basin. While sample periods appeared to accurately represent their respective flow condition, , the mean sample loading rates, due to the limited number of samples, do not necessarily characterize average conditions in the combined basin for a given flow condition (For details about this uncertainty, see Section 7.4).

8.1 Study Conclusions

The primary goals of this effort were to understand the relative chemical loadings from present-day sewage (domestic and industrial wastewater), groundwater infiltration, and stormwater inflow within the Brandon Basin combined sewer system, so that the primary pathway could be identified. Identifying the most significant pathways during storm events allows source control efforts prior to CSO control to better focus on reducing sources to the combined sewer system that, under some conditions, can discharge to the LDW and potentially re-contaminate sediments following cleanup actions.

This project developed five study design questions to guide the investigation and data analysis. These questions have been repeated below to focus the discussion and conclusion on pertinent issues discovered throughout the project and during data analysis.

1. **What are the chemical loadings within the Brandon Basin during dry season baseflow conditions (which represents the sewage component)?** and
2. **What are the chemical loadings within the Brandon Basin during wet season baseflow conditions (which represents both sewage and infiltration components)?**

   For many parameters, the sample with the minimum loading rate estimate at a given site was collected during dry baseflow conditions, but dry and wet baseflow loading rate estimates generally had overlapping ranges. These results provide a snapshot of baseflow loading rates in this basin, with the intention of estimating primary pathways for any source control needs prior to CSO control[11].

3. **What are the chemical loadings within the Brandon Basin during stormflow conditions (which represents the sewage and stormwater inflow components and low infiltration due to the hydrostatic pressure gradient)?**

   For almost all parameters, stormflow samples yielded the highest calculated loading rate estimates. For all chemicals with greater than 75% FOD, stormflow sample loading rate estimates were statistically different and higher than loading rates generated from combined dry and wet baseflow samples. These results provide a snapshot of stormflow loading rates within this basin[12].

   The differences in stormflow loading rate estimates between locations were heavily influenced by differences in flow. For example, Brandon Regulator always had greater loading rates because flows are greater due to the larger contributing basin area (244 acres versus 64 and 85 acres for the subbasins). Normalizing the sample loading rates by the contributing basin area decreased the influence of flow differences, and resulted in loading rates by acre that were much more similar between sites.

4. **What are the chemical loadings within the Brandon Basin from infiltration to the collection system pipes (which represents the wet season baseflow condition minus the sewage [dry season baseflow] component)?**

   A statistical difference in mean flow between dry and wet season baseflow samples was found at the Utah and East Marginal locations. This difference in mean flow during sampling did not translate to consistent differences in chemical loadings between dry and wet season baseflow samples. Thus, while there may be infiltration of groundwater or other non-sewage flows during the wet season, these loads are difficult to distinguish from the observed variation in sewage loading rates. For the small sample size available, any potential infiltration during wet season also did not statistically increase mean flow or contaminant loadings at Brandon Regulator compared to the dry season

[11] Dry and wet baseflow loading rate estimates during sampling events are presented in Section 6.
[12] Stormflow loading rate estimates are presented in Section 6, while statistical differences between baseflow and stormflow loading rate estimates are explored in Section 7.2.

(sewage) samples. However, there were some statistically significant loading differences for a few metals and phthalates within the Utah and East Marginal subbasins (See Section 7.1).

Flow conditions during dry and wet baseflow were heavily influenced by activities from dischargers within the Brandon Basin, further complicating comparisons between these conditions due to increased variability in chemical concentrations. Because mean loading rates generated from wet baseflow samples were not consistently greater than loading rates generated from dry baseflow samples, it was not appropriate to calculate infiltration loading rate estimates.

5. **What are the chemical loadings within the Brandon Basin from stormwater inflow (which represents the stormflow condition minus the sewage [baseflow] component)?**

   For this analysis, data for dry and wet baseflow loading rates were combined to increase sample size, and thus, statistical power. This approach is reasonable because there were few statistical differences in chemical loading rates between dry and wet baseflow samples, which suggest wet baseflow is still largely composed of sanitary and industrial sewage. For all chemicals with greater than 75% FOD, stormflow sample loading rates were statistically different and higher than loading rates generated from combined dry and wet baseflow samples. This suggests stormwater contributes a larger load than sewage for each parameter during stormflow conditions.

The primary pathway (sewage versus stormwater) to the combined sewer system during stormflow conditions was evaluated for all parameters with greater than 75% FOD at a given location. The mean hourly sewage load (dry and wet baseflow samples combined) was subtracted from the mean hourly stormflow load to generate mean hourly stormwater load estimates. The relative magnitudes of sewage and stormwater loading rates were then compared to evaluate the primary pathway during stormflow conditions within the Brandon Basin. Stormwater was estimated to be the primary pathway for almost all parameters. The exceptions were (1) total and dissolved arsenic and chromium at Brandon Regulator where sewage was estimated to be the primary pathway (heavily influenced by one baseflow sample as discussed in Sections 5.2 and 5.4); and (2) DOC, dissolved chromium and diethyl phthalate at East Marginal and DOC at Brandon Regulator where a more even mix between the pathways was estimated. While this analysis does not estimate loads to the LDW from the Brandon combined sewer basin, they could suggest primary pathways during CSO releases, especially for parameters estimated to be sourced primarily from stormwater at Brandon Regulator, as this pathway would be an even greater contributor during larger storms.

The primary pathway analysis summarized above represents estimates and cannot be statistically tested; however, an uncertainty assessment was conducted[13]. The uncertainty assessment bounded the mean estimates of pathway loading rates. In general, there was less uncertainty in estimating loading rates for the sewage fraction since baseflows were sampled directly. The stormwater loading rates were generated by subtracting baseflow

[13] Uncertainty assessment is presented in Sections 7.4.

(sewage fraction) from stormflow (combined sewage and stormwater), and were therefore influenced by the variability of both. Overall, there was greater uncertainty in mean loading rates at Brandon Regulator location when compared to results for Utah and East Marginal sampling locations. The greatest uncertainty in the primary pathway estimates was for DOC, total arsenic, and dissolved arsenic, cadmium, chromium, and vanadium at Brandon Regulator and DOC and diethyl phthalate at East Marginal and benzyl butyl phthalate at Utah. Moderate uncertainty was also found for TOC, TSS, a few metals and diethyl phthalate at either Brandon Regulator or East Marginal. For other chemicals, the uncertainty assessment suggested the mean estimate was reasonable for estimating the primary pathway to the basin during storm events

The findings of this study are intended to be used as a guide for source control needs in combined basins prior to CSO control. The loading rate estimates presented in Section 7.3 suggest whether sewage or stormwater is the primary pathway to the combined sewer system for a given contaminant during stormflow conditions. The results of the uncertainty assessment are important to consider in any decision-making based on this study. Discharges from CSOs were not sampled, and stormflow loading rate estimates from this study are not representative of CSO loading rates, because only relatively low intensity storms were sampled as part of this study. CSO discharges are typically generated during higher intensity storms than those sampled. For this reason, the loading rates in this study should not be used to estimate potential loadings to the LDW, only to consider potential pathways to the combined sewer system. Additionally, land use patterns in this basin differ from other combined sewer basins with overflows to the LDW, and thus, the findings from this study may differ for other combined sewer basins.

8.2 Recommendations

This project was considered a pilot effort to better understand the chemical inputs to the combined sewer system associated with sewage (domestic and industrial wastewater), stormwater, and to the extent possible, groundwater infiltration. This project was able to provide estimates of loading rates during dry baseflow, wet baseflow and stormflow samples for conventional parameters, metals, select PAHs and phthalates, total PCBs, total dioxin/furans and dioxin TEQs at three sampling locations in the Brandon Basin. The relative magnitude of each pathway (sewage versus stormwater) during stormflow was also estimated.

For some parameters, and especially at Brandon Regulator, loading estimates were highly variable due to wide-ranging concentrations and variable flow patterns. In particular, the high variability in baseflow loadings impeded the analysis of loading contributions from the infiltration pathway, and increased the uncertainty of loading rate estimates for sewage and stormwater. Continuous flow monitoring of all major subbasins within the combined sewer basin of interest would be a useful tool to differentiate changes in flow, concentrations, or resulting loading rates. A larger sample size across a range of storm event conditions would increase statistical power, and reduce the influence of a single sample event, which was found to skew the mean baseflow loading rate for some metals in this study.

In 2013, King County began a similar study in the Michigan combined sewer basin, a larger basin with more diverse land use, and is scheduled to be completed in 2016. Results from the Brandon basin will be compared to results from the Michigan basin to assess if primary pathways of contaminants to a combined sewer system during storm events under present-day conditions are consistent.

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