REDUCTIONS IN TURBIDITY AND SPECIFIC CONDUCTIVITY IN RUNOFF TREATED BY BIOSWALES ALONG I-294 IN NORTHERN COOK COUNTY, ILLINOIS

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ILLINOIS STATE GEOLOGICAL SURVEY
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EXECUTIVE SUMMARY

In a seven-year study, ISGS monitored and evaluated the quantity and quality of roadway runoff in the existing ditch system of I-294 in northern Cook County, IL, prior to construction and for five years after bioswale installation. This report details data from continuously monitored turbidity and specific conductivity using data loggers deployed at nine sites in four bioswales. We measured both turbidity and specific conductivity as proxies for surface-water pollutants of concern – total suspended solids and total dissolved solids. Chloride (from road salt) is the main dissolved solid of concern. We modeled those data as masses of total suspended solids and total dissolved solids using water sample chemistry and discharge data. We monitored two different types of bioswales to determine if design factors influenced bioswale performance: wet bioswales that detained runoff on land surface, and dry bioswales that were designed to infiltrate runoff.

All bioswales improved runoff quality, as determined by comparing input to output locations, although performance varied depending on site factors and specific aspects of bioswale design. Percent reductions in mean turbidity over the post-construction record ranged from about 35% to 76%. Turbidity tended to increase in spring and summer, with more intense precipitation, and decrease in the winter. Both wet and dry bioswales performed well at reducing turbidity, with wet bioswales performing slightly better over Years 2-5, but surface-water outlets from dry bioswales did not reduce turbidity. Percent reductions in turbidity concentrations were less than percent reductions of total suspended solids concentrations measured from flow-integrated composite water samples. Pre-construction turbidity data had much higher peaks and maximum readings than the post-construction data, which indicates the bioswales were effective at lowering peak turbidity.

Data analysis indicated that both dry and wet bioswales are effective at reducing specific conductivity in roadway runoff, and that the wet bioswale at site TB7B was the most efficient, likely due to infiltration. Specific conductivity tended to increase in the winter and spring with larger road salt applications and subsequent snowmelts. Percent reductions in mean specific conductivity over the post-construction period ranged from 23% to 97% by site. Post-construction specific conductivity values were generally lower than pre-construction at TB15B and TB19, showing that the dry bioswales offset any increase in total dissolved solids caused by additional roadway area. Percent reductions in specific conductivity concentrations were usually less than percent reductions of total dissolved solid concentrations measured from flow-integrated composite water samples.

Models were developed to calculate total suspended solids based on turbidity, and total dissolved solids based on specific conductivity. Mass loadings of modeled total suspended solids and total dissolved solids values were in many cases similar to those from total suspended solids and total dissolved solids measured from samples submitted for laboratory analysis. The best correlations between turbidity and total suspended solids were at TB15Bsw and TB7Bout. At TB15Bgw and TB19gw, there was not a significant correlation between total suspended solids and turbidity. Modeled total suspended solids loads were generally similar to total suspended solids loads calculated using measured water samples when considering the entire period of record. Although the specific conductivity-total dissolved solids regression had an almost perfect fit (R^2=0.99), modeled total dissolved solids mean percent reductions were higher than lab-measured mean percent reductions of total dissolved solids by 5% to 31%, likely due to the timing of sampling events and other related issues. The method shows promise as a less expensive and less labor-intensive alternative to collecting and analyzing water samples to determine total suspended solids and total dissolved solids loads.

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INTRODUCTION

Bioswales are a useful best management practice (BMP) to improve the quality and quantity of water coming off roadways before interacting with wetlands, forest preserves, downstream waterways, and other natural areas. Bioswales are wide, gently sloping, vegetated ditches that reduce the quantity and improve the quality of roadway runoff by slowing or infiltrating water and fostering contact of runoff with soils and vegetation (Figure 1). In 2007, the Illinois State Geological Survey (ISGS) was contracted by the Illinois State Toll Highway Authority (Illinois Tollway) to monitor the removal efficiency of planned bioswales to treat roadway runoff as part of the reconstruction of I-294 in northern Cook County, Illinois, USA. From February 2008 through August 2010, the ISGS monitored the quality and quantity of runoff from I-294 into the existing roadside ditch system in locations where bioswales were to be constructed. The objective of this monitoring was to develop an understanding of pre-construction conditions and compile data to later be compared to post-construction conditions. Baseline discharge and water-quality results from the pre-construction period were presented in Miner et al. (2012a and 2016). In 2010, the bioswales were constructed, and they were monitored by the ISGS through August 2015. The first three years of post-construction monitoring were presented in Miner et al. (2012b, 2013, 2014). Due to new methods developed during post-construction monitoring and the subsequent reanalysis of previously reported results, this report contains post-construction surface-water turbidity and specific conductivity (SpC) data and analysis from all monitoring years and supersedes all previous reports. Companion reports, detail other aspects of the larger study (Miner et al. 2016, Bryant et al. 2016, Carr et al. 2016, Plankell et al. 2016).

This report was prepared under contracts #ITHA RR-07-9918 and #ITHA 2015-01230 MINER, and is limited to activities regarding bioswale construction and monitoring along the I-294 corridor between Touhy Avenue, northeast of O’Hare International Airport, and Lake-Cook Road. It does not address other activities contained within the contracts.

PURPOSE AND SCOPE

The purpose and scope of the larger project are detailed in Miner et al. (2012a, 2016). In summary, the quantity and quality of runoff discharging from each bioswale were monitored, pre- and post-construction, and the removal efficiencies of the bioswales were determined by comparison of measured inputs and outputs. The specific purpose of this study was to identify the removal efficiency of bioswales at reducing the quantity and improving the quality of runoff. In this report, we assess the removal efficiency of bioswales in improving the quality of runoff by analyzing turbidity and SpC data as measured continuously by data loggers. Total suspended and dissolved solids are important to monitor due to the possible health effects on surface-water and groundwater downstream of these sites. High levels of TSS can cause water-clarity issues, which have an adverse effect on fish and other aquatic life (Voichick et al. 2016). High levels of TDS can cause increases in salinity and ionic composition, which can lead to shifts in biotic communities and limit biodiversity (Weber-Scannell et al.

2007). A comprehensive study of storm-water runoff in California suggested that for the purpose of assessing trends in runoff and removal efficiency of best management practices (BMPs), reductions in concentration and loads of TDS, chloride, and TSS can be estimated using SpC and turbidity as surrogate parameters (Kayhanian et al. 2006).

The scope of this report is to present data that focused on water-quality parameters collected with data loggers to evaluate bioswale processes. Continuous monitoring of turbidity and SpC was done to supplement collection of water samples for laboratory analysis (Miner et al. 2016) and provide more comprehensive data than can be provided by intermittent sampling alone. The second part of the scope is to develop models to provide estimates of TSS and TDS, and the masses of each constituent being transported in runoff.

METHODS

SITE DETAILS

The bioswales installed for this project include both “dry” and “wet” types. Dry bioswales have underdrains below a sand bed to facilitate infiltration (Figure 1); they are intended to improve the quality of runoff by removing suspended solids and their adsorbed metals via filtration. Ponding of water is negligible in dry bioswales, and vegetation density can be less than in wet bioswales due to the dry conditions in the soil zone. Wet bioswales do not have an underdrain, but retain surface water for longer periods due to their flat profile and the regular spacing of check dams. They are designed to slow and detain runoff, facilitate deposition of suspended solids in ponded segments, and increase interaction between runoff and biota.

Nine locations at four bioswales were monitored for this study. Details of the sites are provided in Tables 1 and 2 and locations are shown in Figures 2 through 6. Some monitoring locations spanned more than one contiguous bioswale, but adjoining sections were treated as being continuous, and the name used for the monitoring location was the bioswale in which the monitoring location was found (e.g. monitoring location TB9A included bioswales TB7C through TB9A, but was located in TB9A).

In addition to the inputs described in Tables 1 and 2, non-point source inputs also occur at all bioswales. These include precipitation that falls directly into the bioswale and runoff from the roadway embankment (foreslope) and from areas that drain toward the ditch from adjacent land. Non-point source inputs were not quantified.

All monitoring years discussed in this report began on August 16 and ended on August 15 of the following year. Year 1 began in August 2010, Year 2 began in August 2011, Year 3 began in August 2012, and so on.

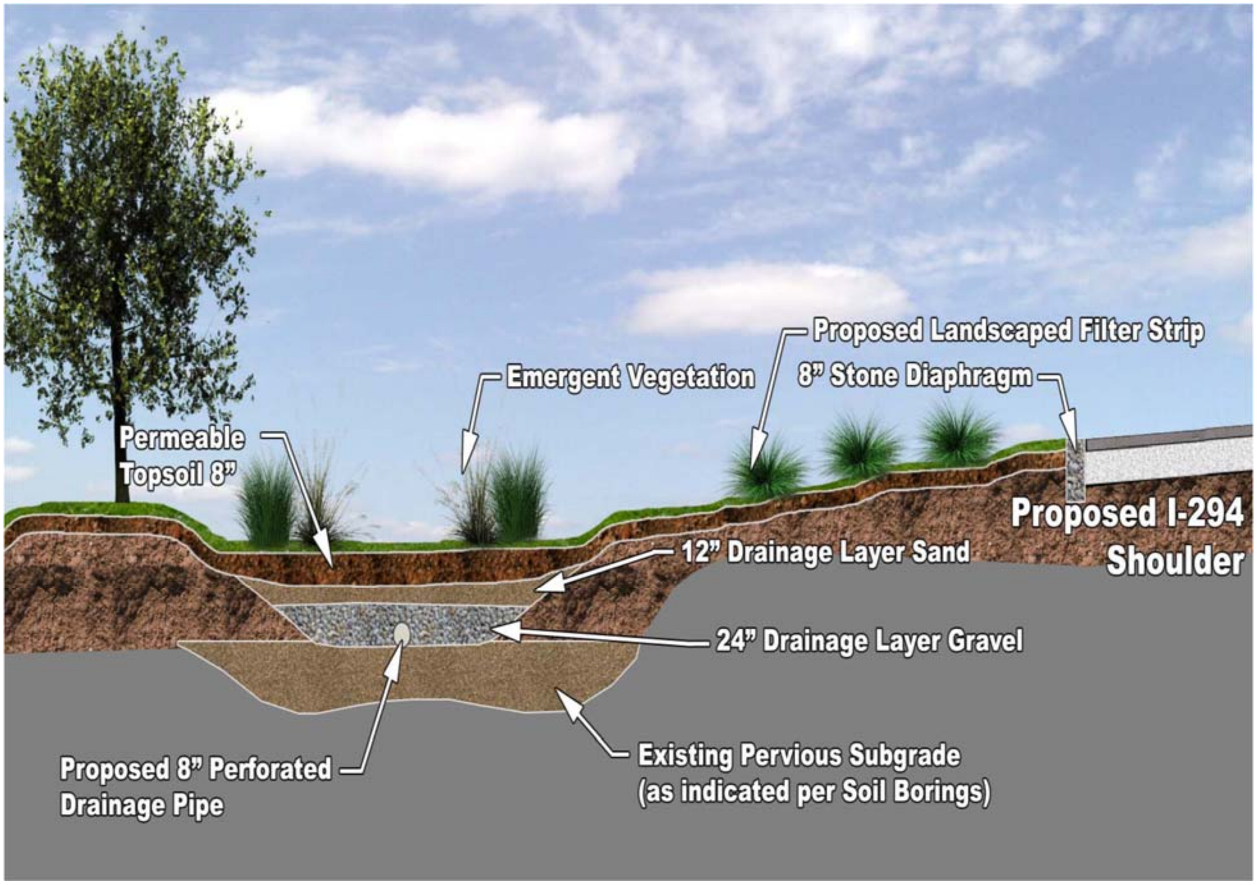

Figure 1. Schematic diagram of a dry bioswale. Dry bioswales installed for this project lacked a gravel layer. Wet bioswales are similar, but lack underdrains. Diagram was prepared by Huff and Huff, Incorporated and Transystems and is used with their permission.

Table 1. Names and details of the four bioswales discussed in this report.

Bioswale Name	Type	Details	Monitoring period (data loggers)
TB7B	Wet	-One point-source input carries water from an elevated section of roadway via a guttered system -One surface-water output	Post-construction only
TB9A	Wet	-Five point-source inputs carry water from an elevated section of roadway via a guttered system -One surface-water output	Post-construction only
TB15B	Dry	-Three major point-source inputs from drains in the median of I-294 -Two outputs (surface water and underdrain)	Pre- and post-construction
TB19	Dry	-Lacks point-source inputs -Two outputs (surface water and underdrain)	Pre- and post-construction

Table 2. Details of the nine monitoring locations discussed in this report.

Site Name	Type	Details	Time period of post-construction monitoring with data loggers
TB7Bin	Input	Point-source input; carries runoff directly from an elevated gutter section of the roadway to the bioswale	Turbidity: 3/01/12 – 8/15/15* SpC: 6/22/11 – 8/15/15*
TB7Bout	Output	Surface-water output	Turbidity: 7/12/11 – 8/15/15* SpC: 5/08/12 – 8/15/15*
TB9Ac2N	Input	One of multiple point-source inputs to the bioswale (“culvert 2 north”)	Turbidity: 10/03/13 – 8/15/15 SpC: 10/15/13 – 8/15/15
TB9A	Output	Surface-water output	Turbidity: 3/01/12 – 8/15/15 SpC: 6/22/11 – 8/15/15
TB15Bc1N	Input	One of multiple point-source inputs to the bioswale (“culvert 1 north”)	Turbidity: 10/02/13 – 8/15/15 SpC: 10/06/13 – 8/15/15
TB15Bsw	Output	Surface-water (“sw”) output	Turbidity: 3/01/12 – 8/15/15* SpC: 6/20/11 − 8/15/15*
TB15Bgw	Output	Exit point for underdrain/groundwater (“gw”)	Turbidity: 3/01/12 – 8/15/15* SpC: 8/26/11 − 8/15/15*
TB19sw	Output	Surface-water (“sw”) output	Turbidity: 2/29/12 – 8/15/15 SpC: 8/25/11 – 8/15/15
TB19gw	Output	Exit point for underdrain/groundwater (“gw”)	Turbidity: 3/01/12 – 8/15/15 SpC: 8/25/11 – 8/15/15

*monitoring continued after 8/15/15

LEVEL AND DISCHARGE

Water level was measured at all sites during all years and discharge was calculated as described in Bryant et al. (2016). Water levels were collected simultaneously with turbidity and SpC and were used to determine validity and quality of turbidity and SpC readings. Level and discharge were also used to calculate standardized concentrations of TSS and TDS (see method description later).

PRECIPITATION

Precipitation data were obtained from the Midwestern Regional Climate Center (MRCC) for the Chicago O’Hare Airport Weather Service Office (WSO) (Midwestern Regional Climate Center 2015). The O’Hare Airport WSO is about three miles south of the southernmost bioswale site.

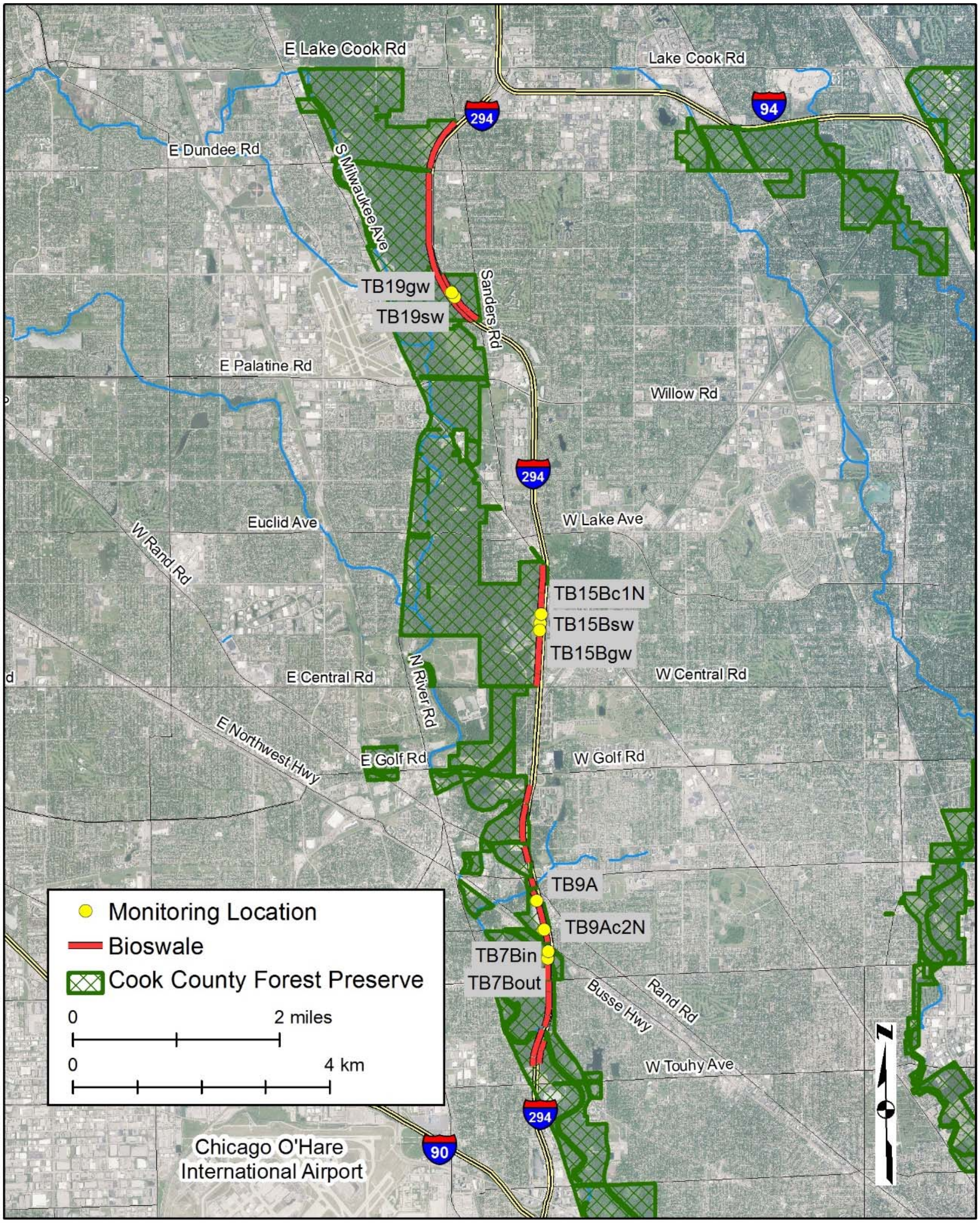

Figure 2. Location of bioswales and monitoring points discussed in this report.

Figure 3. Location of bioswale and monitoring points at TB7B.

Figure 4. Location of bioswales and monitoring points at TB9A.

Figure 5. Location of bioswales and monitoring points at TB15B.

Figure 6. Location of bioswales and monitoring points at TB19.

TURBIDITY

Post-construction turbidity data were collected at all nine locations and are shown in Table 2. Turbidity is an optical property of water attributed to suspended sediment content and other colored material in water (e.g. tannins, dissolved constituents, microorganisms). In this study, turbidity data were collected with Forest Technology Systems (FTS) DTS-12 sensors. The DTS-12 sensor emits light and detects the reflection of that light from suspended matter to measure turbidity. The detector in the DTS-12 is 90° to the incident light beam, and the light that the DTS-12 emits has a wavelength of 780 nm (Forest Technology Systems 2010). The technology of the DTS-12 sensors is considered compliant with the International Standards Organization (ISO) 7027 method in that it uses an infrared light source with a nephelometric design, but it does not use the wavelength specified in that method (860±30 nm) (International Organization for Standardization 1990). Different turbidity instruments that use different technologies and methods have different designated units (Anderson 2004). ISO 7027 designates that turbidity is reported in Formazin Nephelometric Units (FNUs), but in this report turbidity data are given in Nephelometric Turbidity Units (NTUs) as specified by the manufacturer, although 1 FNU is equivalent to 1 NTU in this circumstance.

The DTS-12 sensors measure turbidity between 0 and 1,600 NTU with an error of ±2% (0-399 NTU) to ±4% (400-1,600 NTU). Values greater than 1,600 NTU were sometimes recorded during very turbid events and are included in analyses in this report, but they are outside of the range of calibration of the instrument and may be less accurate.

The DTS-12 turbidity data loggers took readings every 15 minutes for the duration of monitoring. Because turbidity sensors operated during periods of no flow, and thus collected data that do not reflect actual turbidity conditions, data were filtered to include only turbidity readings collected when a valid discharge was recorded and water level was sufficiently high to cover the sensor. This eliminated times when there was no water, when water was stagnant, or when the sensor was covered in snow or ice. From this dataset, turbidity readings collected when the water level at the sensor was less than 0.10 ft. were also omitted. This ensured that the optical sensor on the DTS-12 unit was under water when readings were collected. Readings collected when the DTS-12 recorded temperatures less than 0°C were omitted as well, as this is the minimum temperature of the operating range of the instrument. Other times when the sensor was malfunctioning (e.g. broken wiper or faulty cable) were identified and removed manually. This method of data processing differs from the methods used in previous ISGS bioswale reports (i.e., Miner et al. 2012b, 2013, 2014), so turbidity averages and other summary statistics presented here supersede those reports.

Pre-construction turbidity data were collected at TB15B and TB19 using Hydrolab MS5 multi-parameter water-quality sondes (Miner et al. 2012a). The turbidity sensors on the MS5 sondes are similar to the DTS-12 sensors, except they use an 880 nm light source, which complies with the ISO 7027 method. The sondes took readings every hour throughout the duration that they were deployed. Although the turbidity sensors on the Hydrolab sondes can accurately read up to 1,000 NTU, the sensors were only calibrated between 0-100 NTU. Values were often outside this range, causing the values to not have the same accuracy. Level and discharge data were not available for pre-construction analyses, so turbidity data were filtered instead based on temperature and SpC collected with the same Hydrolab sonde in order to determine when sensors were dry or below 0°C. Comparison of pre- and post-construction data should therefore be viewed with caution.

SPECIFIC CONDUCTIVITY

Specific conductivity (SpC) is a measure of the electrical conductivity of water and is related to the amount and species of dissolved solids. It is temperature corrected to 25°C and expressed in microSiemens/centimeter (μS/cm). SpC of runoff was measured every hour in Years 1-3, and was recorded every 15 minutes starting in Year 3 using AquaTROLL 200 data loggers. The AquaTROLL (AT) loggers measure SpC between 5 and 100,000 μS/cm with an error of ± 0.5% of readings when the reading is less than 80,000 μS/cm. The loggers recorded water level and temperature in addition to SpC, and were calibrated according to the In-Situ AquaTROLL 200 manual (In-Situ, Inc. 2010). A majority of the readings were taken when flow was low (<0.1 cfs). The time span of this study was relatively long and has a very large data set.

The ATs operated continuously, including during periods of no flow, and thus collected data that do not reflect actual SpC conditions. SpC data were filtered in the same way as the turbidity data to include only SpC readings collected when a valid discharge was recorded and the water level was sufficiently high to cover the sensor. From this dataset, SpC readings were omitted when water levels at the sensor were less than 0.219 ft. for vertically installed ATs, or were less than 0.065 ft. for horizontally installed ATs. This ensured that the SpC sensor and temperature sensor on the AT were fully submerged when readings were collected. Other times when the sensor was malfunctioning or it was determined the composite sampler wasn’t recording discharge were identified and data were evaluated manually. This method of data processing differs from the methods used in previous ISGS bioswale reports (i.e., Miner et al. 2012b, 2013, 2014), and so SpC averages and other summary statistics presented here supersede those reports.

Pre-construction SpC data were collected at TB15B and TB19 using Hydrolab MS5 sondes (Miner et al. 2012a). The SpC sensors on the MS5 sondes are similar to the AT sensors, but slightly less accurate (±1% of reading). The sondes took readings every hour throughout the duration that they were deployed. Level and discharge data were not available for pre-construction analyses, so SpC data was filtered instead based on temperatures below 0°C collected with the same Hydrolab sondes.

WATER SAMPLES

Both grab samples and flow-integrated composite samples were collected at all monitoring locations following methods described in Miner et al. (2016). The composite water samples were collected using Isco Avalanche (6712-type) automated samplers, and so are referred to as “composite samples” throughout this report. These samples were submitted to the Illinois State Water Survey Public Service Laboratory for analysis for a number of constituents including TDS and TSS. Percent reductions of TSS and TDS were calculated from the composite samples and are presented in Miner et al. (2016). In this report, the laboratory data are compared to percent reductions calculated for data-logged turbidity and SpC in order to determine if removal efficiencies of bioswales can be monitored using data loggers alone. Water-quality parameters, including turbidity and SpC, were collected with Hydrolab MS5 sondes at the time of sample collection. Those data are used in this report to determine relationships between 1) turbidity and TSS and 2) SpC and TDS.

PERCENT REDUCTION DETERMINATIONS FOR TURBIDITY AND SPECIFIC CONDUCTIVITY

When using data loggers instead of water samples, percent reductions of parameters like turbidity and SpC can be calculated by comparing means at inputs and outputs. Data-logged concentration data are proportional to the volume of discharge represented by the measurement, so they are not directly parallel to composite sampling. Concentrations alone cannot be used to determine how much of a constituent is coming in or out of the bioswale, but are pertinent to water quality and aquatic life health standards. Furthermore, concentrations (along with discharge) were needed to calculate masses; this is discussed further below.

TB7B was the only bioswale with an input and an output that could be directly compared to determine removal efficiencies, because there were no other effectively monitored discrete inputs at the bioswales. Ideally, all bioswales would have their inputs and outputs measured, but other locations either had runoff inputs that were not point sources, such as roadway segments where runoff flowed diffusely off the shoulder into the ditches, or had too many inputs to monitor (three to five point sources each), which prevented comprehensive monitoring. We also attempted to monitor discrete inputs at TB15Bc1N and TB9Ac2N, but ultimately deemed the data unfit for direct comparison due to malfunctioning equipment or poor drainage design for installing monitoring devices (i.e. remnant construction sediment and extreme discharge rates). In all cases, outputs were compared to the input at TB7B, necessarily presuming similar input conditions at all bioswales. The loads of TSS and TDS to the roadways and the roadway hydrologic inputs per unit area are assumed to be similar.

TOTAL SUSPENDED SOLIDS CALCULATED FROM TURBIDITY

The turbidity data used to establish the models were collected with Hydrolab MS5 sondes, but FTS DTS-12 loggers were used for monitoring continuous turbidity in the bioswales. A United States Geological Survey (USGS) study found that Hydrolab and DTS-12 loggers both had less than 5% error when tested in a range of calibration solutions (Snazelle 2015), and a study from the Department of Environment and Conservation in Newfoundland also found that Hydrolab and DTS-12 data were similar (Department of Environment and Conservation 2011). In addition, since input and output data were collected in the same manner, there should be no change in percent difference from this method. This approach should therefore be sufficient for the purposes of this report, although some caution is warranted in considering these results due to the possibility of an offset in absolute turbidity between instruments.

The relationship between turbidity and suspended solids depends not only on concentration of sediment, but also particle size, shape, composition, and water color (Gippel 1989, Lewis 1996). The relationship is site-specific; an equation developed in one location generally cannot be used in another (Lewis 1996). For these reasons, we developed models relating TSS to turbidity for each of the bioswale locations. The models were based on laboratory-measured TSS and field-measured turbidity from the flow-integrated composite samples.

TOTAL DISSOLVED SOLIDS AND CHLORIDE CALCULATED FROM SPECIFIC CONDUCTIVITY

Specific conductivity (SpC) is strongly related to the amount of total dissolved solids (TDS) in water. TDS is also strongly related to the amount of chloride in water, especially from roadways treated with salt. Miner et al. (2016) details TDS and chloride masses at the bioswales. Regression relationships can be used to calculate concentrations of TDS and chloride from SpC (Granato and Smith 1999, Paul and Mayer 2001, Watson et al. 2002). These relationships then were used to calculate mass of TDS and chloride when multiplied by discharge. Data-logged SpC allows thorough data coverage for the whole time span of the project, and ensures data are collected between samplings. SpC data loggers are robust and reliable, allowing nearly continuous monitoring over the duration of the study.

The linear relationships between SpC and TDS, and SpC and chloride were compiled using all grab and composite samples from surface water in all bioswales, and the resulting equations were used to calculate TDS and chloride from data-logged SpC at each bioswale site. Equation 1 was used to calculate TDS from SpC, and equation 2 was used to calculate chloride from SpC.

$$\text{Equation 1:}\ \ \text{TDS (mg/L)} = 0.5814 * \text{SpC} - 57.13$$

$$\text{Equation 2:}\ \ \text{Chloride (mg/L)} = 0.3546 * \text{SpC} - 204.82$$

Given that both equations can generate negative values at very low readings, negative values were removed prior to statistical analysis. Using equation 2, whenever SpC exceeds 1,988 µS/cm, chloride levels are projected to be at or above 500 mg/L, which is the Illinois Pollution Control Board's (IPCB) General Use Water Quality Standard (Illinois Pollution Control Board, undated) for chloride in surface water.

MASS PERCENT REDUCTION DETERMINATIONS

Because flow volumes varied greatly between sites, comparing masses at TB7Bin to masses at outputs of other bioswales requires that a discharge-standardized concentration be calculated. To do this, concentrations of TSS and TDS were determined using the equations described above, and then each concentration was multiplied by the discharge (Q) over fifteen minutes to get the mass of TSS and TDS that went through the site during those fifteen minutes. The total sum of mass for all 15-minute periods in the period of interest was divided by the total discharge to yield a standardized concentration for the period, typically a year or the period of record, for comparison to other sites.

While using standardized concentration allows for comparison between sites with different discharges and durations of monitoring, other differences between sites likely affect the volume of discharge and mass generated per unit roadway area and require some caution in interpreting results. These differences include local slope and erosion, different conditions along the local roadway (e.g. loading rates of road salt, differences in the way the bioswale structures handle runoff, percent runoff generated from storm events), and differing unmeasured inputs and outputs. However, some sites are directly adjacent to each other and have similar designs, minimizing expected differences.

DATA AND RESULTS

PRECIPITATION

Daily, monthly, and 30-year average monthly precipitation data from the O'Hare Airport Weather Service Office (WSO) are shown in Figure 7. The average annual precipitation over the five-year monitoring period was 36.77 inches, which is just over the 30-year average of 36.27 inches. Year 1, Year 3, and Year 4 had above average precipitation (24%, 11%, and 6% above average, respectively), while Year 2 and Year 5 had below average precipitation (16% and 26% below average, respectively). Year 4 had the largest number of storm events, with three days when rainfall exceeded two inches. Year 3 had two days when rainfall exceeded two inches; Year 5 had only one; and in Year 2, daily rainfall never exceeded two inches. The amount and intensity of rainfall has an effect on how turbid runoff is and can affect the performance of bioswales, as will be discussed later.

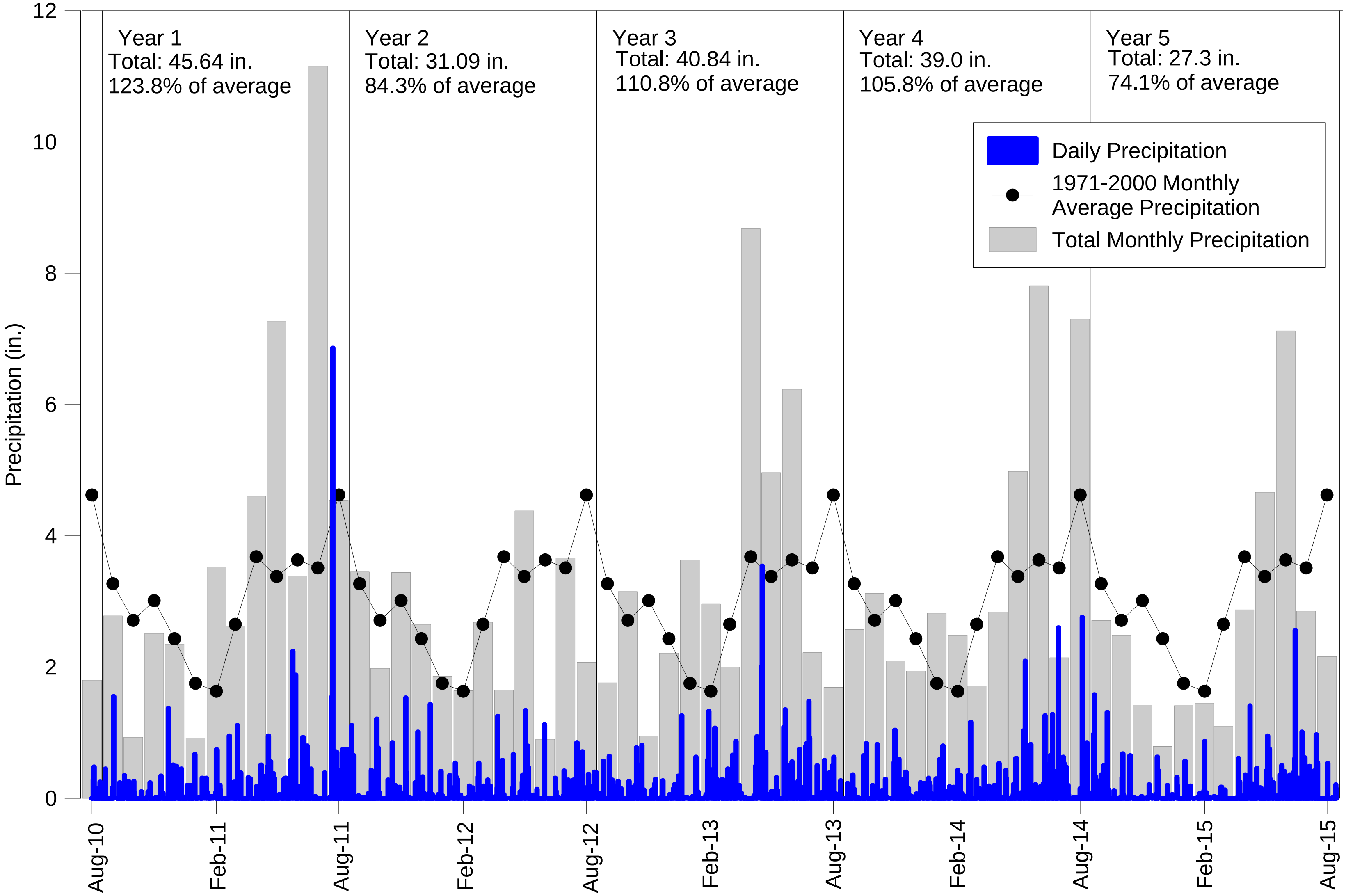

Figure 7. Precipitation recorded at O'Hare Airport Weather Service Office (WSO).

REDUCTIONS IN TURBIDITY AFTER BIOSWALE INSTALLATION

Overview and Aggregate Performance of All Bioswales

Throughout the duration of bioswale monitoring, turbidity readings were recorded every 15 minutes regardless of the amount of flow over the sensor, and therefore the majority of readings were taken when flow was low (<0.1 cfs). Turbidity during these conditions is much lower than it is during the relatively infrequent storm events, resulting in a skewed distribution of turbidity values for sites that flow regularly, which differs from other flow-integrated techniques like composite sampling. We summarized turbidity over relatively long time scales (minimum of one year) using both median and mean turbidity. Means are more affected by outliers, which include the high turbidity values from storm events. These peak turbidity values are important to consider when examining bioswale performance, and so mean turbidity is the statistic referred to in this report to summarize the dataset and calculate reductions.

Overall results show that bioswales are effective at lowering the turbidity of runoff. Mean turbidity reductions relative to the only monitored input location, TB7Bin, ranged from 35% to 76% at all outputs except the surface-water exits from the dry bioswales, which generally showed increases in turbidity, likely due to erosion of the poorly vegetated bioswale surfaces during high flows. Individual sites are discussed below.

Summary statistics for turbidity are presented in Table 3, with further details in Appendix A. Reductions in mean annual turbidity compared to reductions in TSS measured from water samples are in Table 4. Figures 8-11 show all valid post-construction turbidity data that were collected. The performance of dry bioswales was determined by calculating the discharge proportional mean by adding TSS from both outlets and dividing by the total discharge from both outlets. These calculations are shown in Appendix B, and results are included in Table 4.

TB7B Results

As previously discussed, the only site with a directly measurable single input and a single output is TB7B, which is a wet bioswale. Runoff at TB7Bin is piped directly from an elevated section of I-294 from a guttered runoff collection system. The runoff has no contact with soil prior to entering the bioswale, and so it is representative of runoff directly from the tollway. Discharge at the input is nearly continuous, but after periods without precipitation, it can occasionally dry completely or have flow too low to be measured by the turbidity sensor. TB7Bout only flows during significant precipitation events, meaning the turbidity dataset at TB7Bout is much smaller than at TB7Bin (see Table 3); high flows with high turbidity have a greater effect on weighing the annual mean at TB7Bout than at TB7Bin.

Data collected over the entire monitoring period had a mean turbidity of 111 NTU at TB7Bin and 56 NTU at TB7Bout. This indicates a 50% reduction in mean turbidity, which is less than the 77% reduction in TSS calculated from composite samples

Table 3. Summary of all turbidity data collected through the duration of monitoring. All values are in NTUs.

	Number of Readings	Minimum	Median	Mean	Max	Percent Reduction (mean) vs. TB7Bin
TB7Bin						
Year 2*	369	0.9	51.9	85.9	819.1	
Year 3	560	10.8	59.1	117.0	1,301.4	
Year 4	2,149	0.9	33.9	100.5	1,909.2	
Year 5	856	0.3	22.0	145.6	2,063.4	
Years 2-5	**3,934**	**0.3**	**38.4**	**111.3**	**2,063.4**	
TB7Bout						
Year 1	583	6.0	32.2	60.6	771.9	ND[1]
Year 2	1,059	0.7	21.6	34.2	680.1	60.3
Year 3	144	0.8	31.4	52.4	472.1	55.2
Year 4	712	4.3	29.0	94.5	2,322.4	5.9
Year 5	407	6.5	18.7	39.6	1,647.0	72.8
Years 1-5	**2,905**	**0.7**	**24.2**	**55.9**	**2,322.4**	**49.7**
TB9A						
Year 2*	1,750	0.1	5.7	13.3	501.1	84.5
Year 3	3,382	0.1	10.1	33.2	1,867.0	71.6
Year 4	2,644	0.1	13.3	36.4	1,154.5	63.8
Year 5	3,209	0.1	9.2	17.5	531.3	87.9
Years 2-5	**10,985**	**0.1**	**9.7**	**26.2**	**1,867.0**	**76.4**
TB15Bgw						
Year 2*	4,150	0.6	19.7	47.6	727.7	44.6
Year 3	5,837	0.4	14.2	40.9	1,474.6	65.0
Year 4	12,184	0.1	6.1	21.7	612.5	78.4
Year 5	4,914	0.1	12.0	43.6	1,111.9	70.0
Years 2-5	**27,085**	**0.1**	**10.4**	**33.8**	**1,474.6**	**69.6**
TB15Bsw						
Year 2*	18	240.3	1,901.8	1,622.4	2,558.4	-1,788.0
Year 3	18	14.4	31.6	61.1	504.8	47.8
Year 4	60	2.1	47.0	120.6	730.2	-20.0
Year 5	69	5.5	46.3	165.8	1,068.0	-13.9
Years 2-5	**165**	**2.1**	**48.6**	**296.9**	**2,558.4**	**-166.8**
TB19gw						
Year 2*	2,901	0.7	42.5	89.2	994.9	-3.8
Year 3	2,094	0.2	30.5	65.5	688.8	44.0
Year 4	4,332	0.7	46.7	75.5	713.0	24.9
Year 5	3,966	0.7	36.1	51.5	536.4	64.7
Years 2-5	**13,293**	**0.2**	**39.1**	**69.7**	**994.9**	**37.3**
TB19sw						
Year 2*	42	52.6	82.5	124.5	543.4	-44.9
Year 3	14	64.5	156.5	146.6	217.0	-25.3
Year 4	126	0.1	226.7	202.0	918.9	-101.0
Year 5	199	1.0	1.6	28.5	265.0	80.4
Years 2-5	**381**	**0.1**	**55.2**	**101.6**	**918.9**	**8.7**
TB15B						
Pre-construction	4,340	2.1	19.6	105.5	2,946.0	
TB19						
Pre-construction	2,375	2.1	29.1	76.5	2,506.0	

[1] no data

*At TB9, TB15B, TB19, and TB7Bin, Year 2 was only monitored with data-loggers for part of the year (March through August).

Shades of green indicate percent reductions >0, shades of yellow indicate percent increases 1 to 25%, and shades of red indicate percent increases >25%.

Table 4. Comparison of percent reductions of mean turbidity to percent reductions of TSS measured from composite samples.

	Mean Turbidity (NTU)	**Percent Reduction of Mean Turbidity vs. TB7Bin***	**Percent Reduction of TSS from Composite Samples****
TB7Bin			
Year 2	85.9		
Year 3	117.0		
Year 4	100.5		
Year 5	145.6		
Years 2-5	**111.3**		
TB7Bout			
Year 1	60.6	ND[1]	-107.8
Year 2	34.2	60.3	73.8
Year 3	52.4	55.2	53.3
Year 4	94.5	5.9	83.3
Year 5	39.6	72.8	83.5
Years 2-5	**55.9**	**49.7**	**76.8**
TB9A			
Year 2	13.3	84.5	81.6
Year 3	33.2	71.6	19.8
Year 4	36.4	63.8	89.9
Year 5	17.5	87.9	56.8
Years 2-5	**26.2**	**76.4**	**68.3**
TB15Bgw			
Year 2	47.6	44.6	86.4
Year 3	40.9	65.0	66.6
Year 4	21.7	78.4	93.5
Year 5	43.6	70.0	80.4
Years 2-5	**33.8**	**69.6**	**85.2**
TB15Bsw			
Year 2	1,622.4	-1,788.0	-615.4
Year 3	61.1	47.8	-104.9
Year 4	120.6	-20.0	31.7
Year 5	165.8	-13.9	-49.4
Years 2-5	**296.9**	**-166.8**	**-39.6**
TB15Bsw+TB15Bgw			
Year 2	58.0	32.5	79.5
Year 3	42.8	63.4	50.0
Year 4	27.1	73.0	90.1
Year 5	51.4	64.7	72.1
Years 2-5	**50.5**	**54.6**	**77.8**
TB19gw			
Year 2	89.2	-3.8	78.0
Year 3	65.5	44.0	71.4
Year 4	75.5	24.9	74.1
Year 5	51.5	64.7	84.7
Years 2-5	**69.7**	**37.3**	**76.4**
TB19sw			
Year 2	124.5	-44.9	-40.7
Year 3	146.6	-25.3	-35.6
Year 4	202.0	-101.0	42.3
Year 5	28.5	80.4	-4.7
Years 2-5	**101.6**	**8.7**	**8.7**
TB19sw+TB19gw			
Year 2	89.7	-4.3	75.0
Year 3	74.6	36.2	59.3
Year 4	95.1	5.4	69.2
Year 5	50.5	65.3	80.9
Years 2-5	**72.9**	**34.5**	**69.8**
TB15B			
Pre-construction	105.5		
TB19			
Pre-construction	76.5		

[1] no data

*Percent reduction calculations use mass for TB7B and standardized concentrations for all others.

**Water sample data presented in Miner et al. 2016.

Shades of green indicate percent reductions >0, shades of yellow indicate percent increases 1 to 25%, and shades of red indicate percent increases >25%.

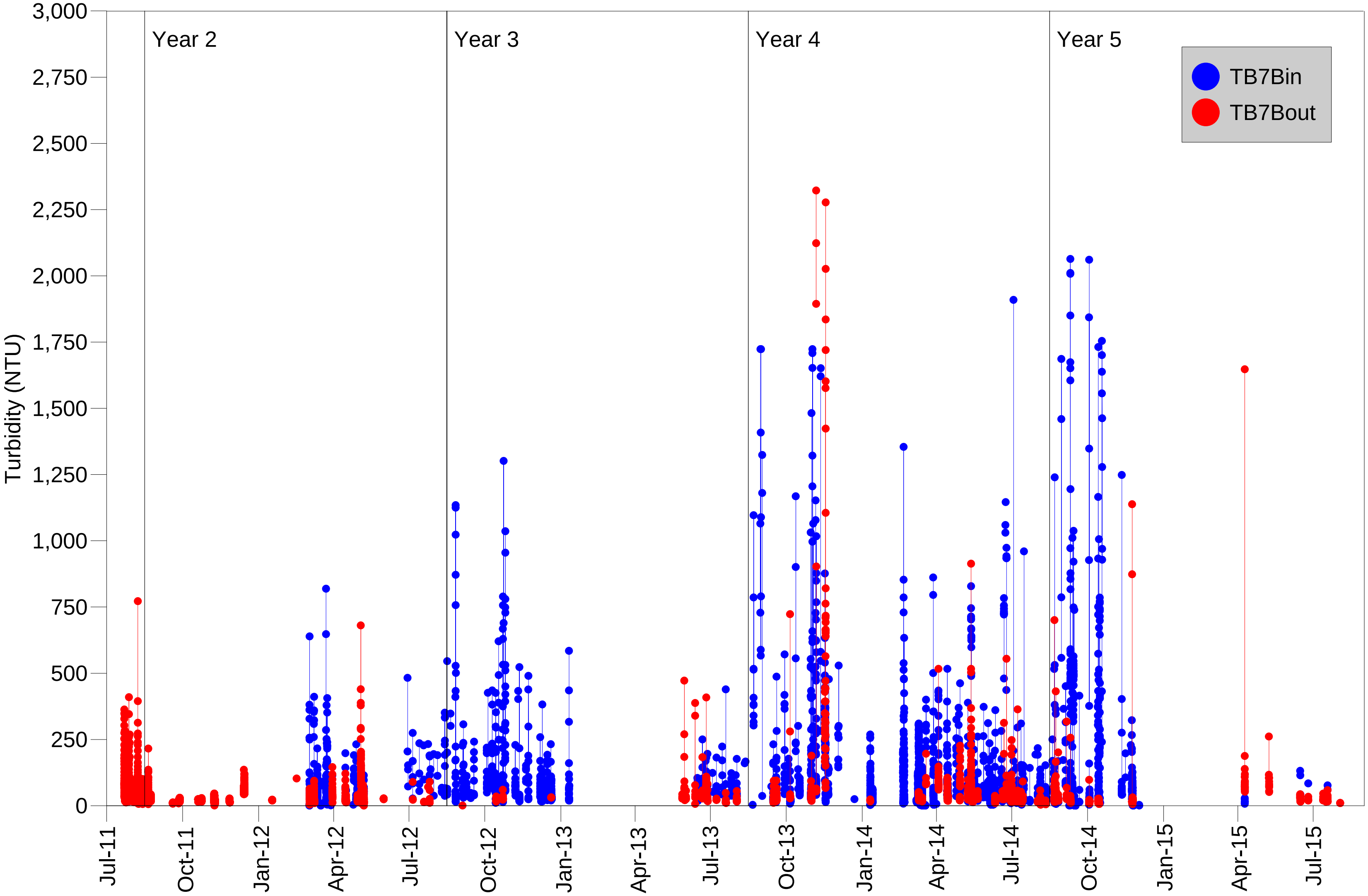

Figure 8. All valid turbidity data collected at TB7B.

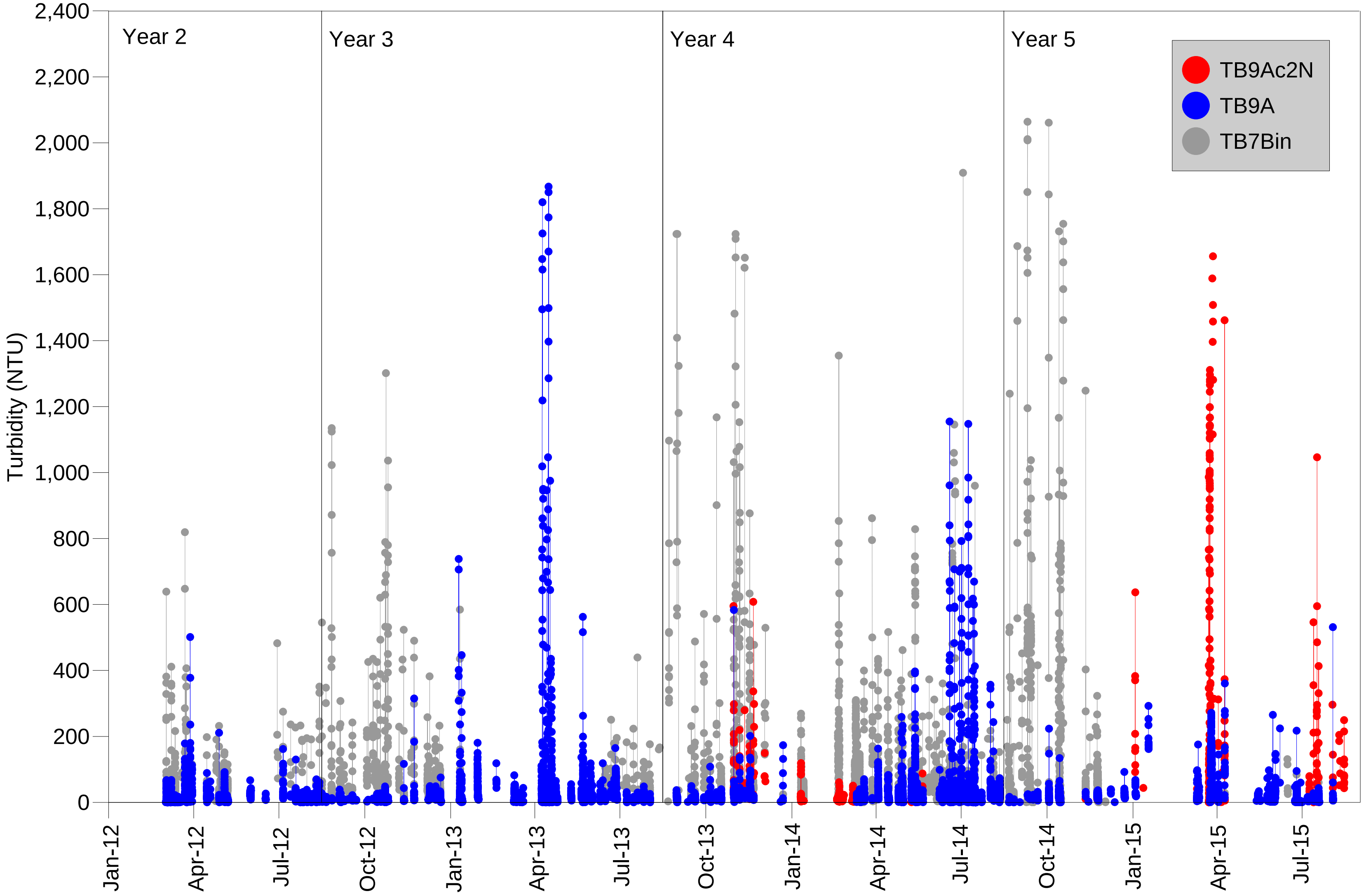

Figure 9. All valid turbidity data collected at TB9A. Turbidity data from TB7Bin also shown for comparison.

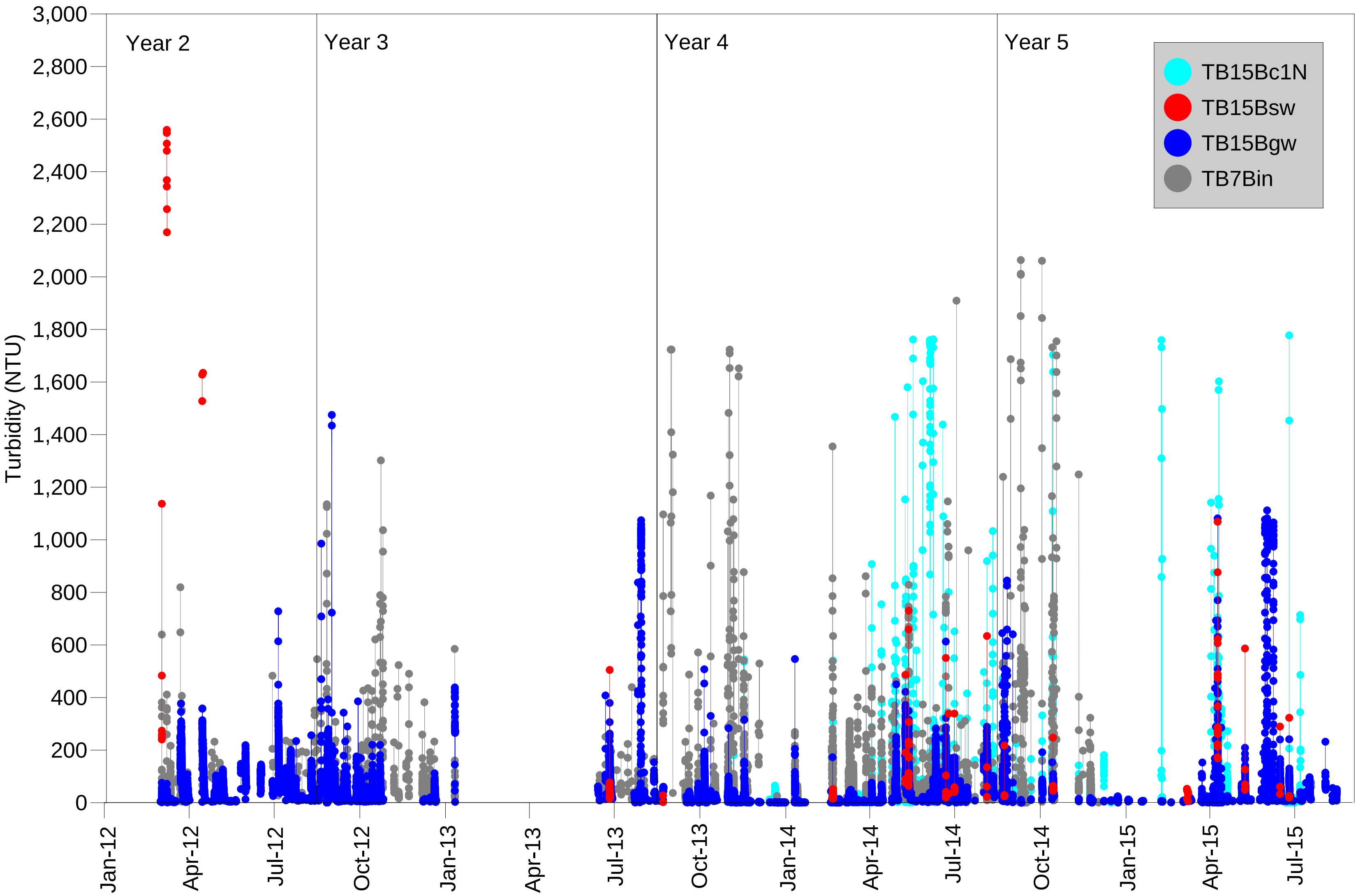

Figure 10. All valid turbidity data collected at TB15B. Turbidity data from TB7Bin also shown for comparison.

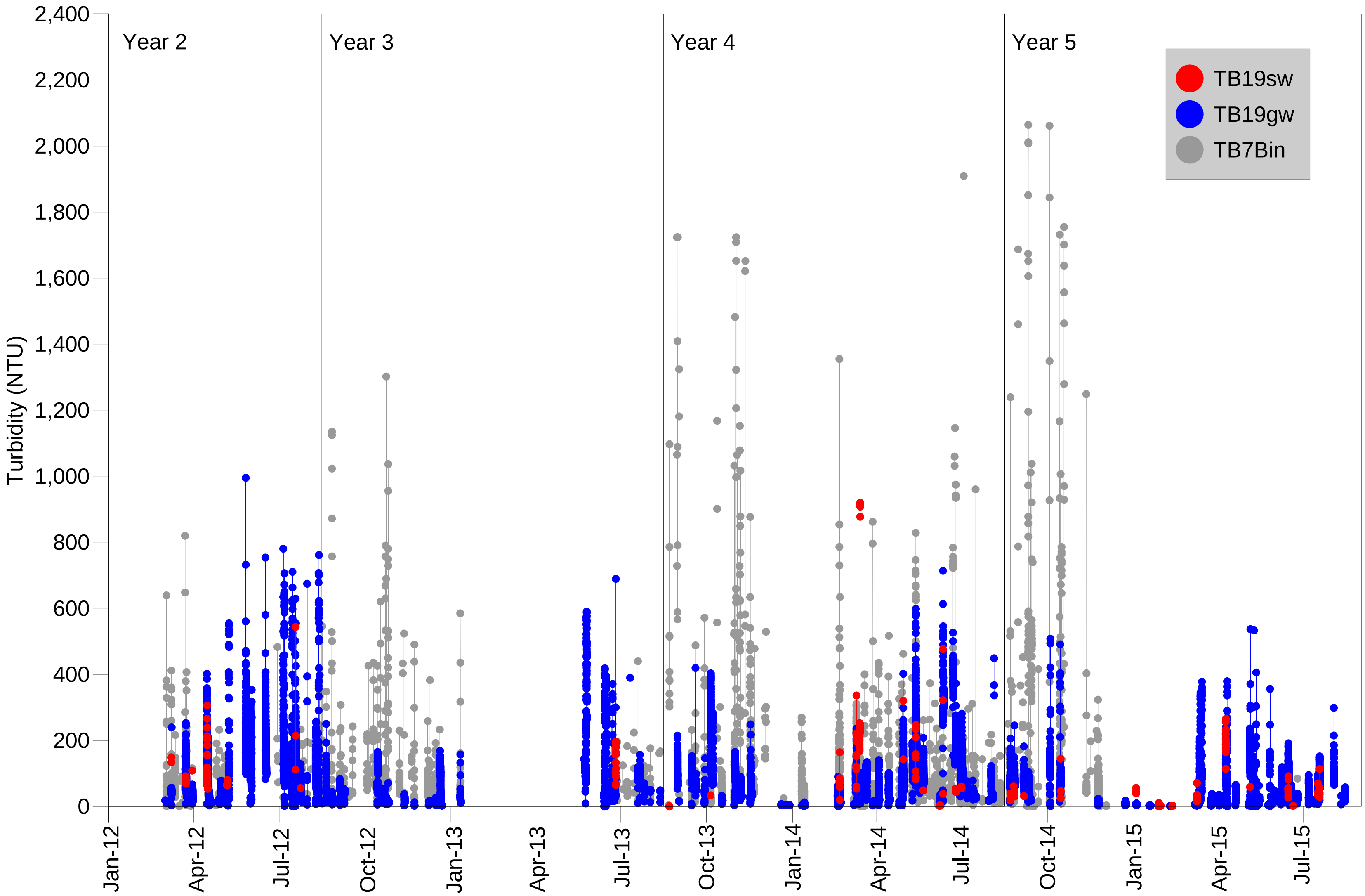

Figure 11. All valid turbidity data collected at TB19. Turbidity data from TB7Bin also shown for comparison.

collected at the same sites. This difference in reduction was due to the inability of the data loggers to collect valid measurements when water level and associated turbidity were very low, even as the Isco devices continued to sample this low-turbidity runoff. Miner et al. (2016) reports a 45% reduction in TSS, which includes composite samples from Year 1 when there was no turbidity logger installed, which were not included in this analysis. Individual monitoring years showed reductions in mean turbidity every year, ranging between 6% and 73%. TB7B had relatively long-term ponding, good vegetation cover, and stored significant inflows prior to any discharge, often delaying any discharge for two hours or more after an initial precipitation event. All of these factors helped to facilitate deposition of sediment in the bioswale and reductions in turbidity and TSS.

The reduction of only 6% in Year 4 is due in part to low mean turbidity at the input (101 NTU) as well as relatively high turbidity at the output (95 NTU) in that year. Year 4 had larger storm events (defined as days when rainfall exceeded two inches) than any other year, and the turbidity values increasing the mean in Year 4 are from two such events (Figure 8). During events such as these, it was possible that sediment was eroded from the roadway embankment and washed directly into the bioswale, or that sediment deposited in the bioswale was remobilized and transported to the output.

TB9A Results

TB9A is a wet bioswale with five main point-source inputs. Similar to TB7B, runoff input to TB9A was carried from an elevated section of roadway through a guttered system, so it does not have contact with soil prior to entering the bioswale. TB9A was the longest bioswale studied, at approximately 2,300 feet long, and has large areas of backslope that receive direct precipitation and are potentially more likely to have a dilution effect on the results.

TB9A, the monitoring point at the surface-water output for the bioswale, had the lowest mean turbidity of any output (26 NTU) and the highest percent reduction relative to TB7Bin (76%). The percent reduction is similar to the 68% percent reduction in TSS calculated from composite water samples. Miner et al. (2016) reports a 64% reduction in TSS, which includes samples from Year 1 and part of Year 2 when there was no turbidity logger installed. The site showed reductions in mean turbidity every year ranging from 64% to 88%. The high reduction of turbidity is likely because the bioswale is long, it contained nine individual segments separated by check dams, and it had long-term ponding in several segments. Vegetation in the bioswale was dense, and flow at TB9A was generally slow, which likely reduced sediment in suspension and lowered turbidity. TB9A also had long-term low-flow discharges, possibly due to groundwater inputs, which may have skewed the mean lower.

TB9Ac2N is one of the culverts which inputs runoff to TB9A. It was monitored with a turbidity data logger starting in October 2013. Because of the limited duration of deployment and frequent malfunction of the equipment, turbidity data are presented in Figure 9 and Appendix A, but were not used for any further analyses in this report.

TB15B Results

TB15B is a dry bioswale where the primary mechanism for reducing turbidity is infiltration of runoff. TB15Bgw, the underdrain exit for the bioswale, flows for weeks or months at a time, rarely drying out, but has very low turbidity other than during precipitation events. TB15Bsw is the surface-water outlet for the bioswale, and runoff only occurs there during heavy precipitation events. TB15Bgw had by far the largest number of readings collected by the turbidity data logger of any site, meaning the site was flowing at a measurable level more often than any other site. TB15Bsw had the fewest readings, indicating it had the fewest measurable flows.

TB15Bgw showed the second highest percent reduction in mean turbidity relative to TB7Bin (70%) of any monitored location. This is similar to the 85% percent reduction of TSS calculated from composite samples. Miner et al. (2016) reports an 81% reduction in TSS, which includes samples from part of Year 2 when there was no turbidity logger installed. These results are unsurprising considering that infiltration was the primary treatment mechanism at TB15B, and most of the water at TB15Bgw was coming from the underdrain. There were percent reductions in mean turbidity every year at TB15Bgw ranging from 45% to 78%. The slightly lower percent reduction of turbidity compared to TSS likely is due to the inability of the data loggers to collect valid measurements when water levels and associated turbidity were very low, even as the Isco devices continued to sample this low-turbidity runoff. TB15Bgw also had long-term low-flow discharges, possibly due to groundwater inputs, which may have skewed the mean lower.

TB15Bsw showed an overall increase in mean turbidity of 167% relative to TB7Bin. There was also an increase in composite sample TSS at TB15Bsw relative to TB7Bin (40%). Miner et al. (2016) reports a 122% increase in TSS, which includes samples from Year 1 and part of Year 2 when there was no turbidity logger installed. The large increase in turbidity is mostly because TB15Bsw only flowed during storm events when turbidity was high, and therefore few low-flow, low-turbidity measurements were recorded. Over the period of record, TB15Bsw had only 165 valid turbidity readings, whereas TB7Bin had 3,934, most of which were during regular, low-flow conditions. TB15B also lacked substantial vegetation due to slow growth and colonization through the first few years of monitoring, which also contributed to the lack of a reduction in turbidity. The turbidity and TSS percent mean increases are also not the same (-167% and -40%, respectively), due to the differences in how the data were collected. The Isco was able to capture more of the low-flow and low-TSS waters that would come through the bioswale sample at TB15Bsw, whereas the flow level had to be higher for the turbidity sensor to capture the data. Higher flows caused by heavier rain events, while relatively infrequent and likely short in duration, had higher mean turbidity due to more erosion within the bioswale and along the roadway embankment.

The overall increase in turbidity at TB15Bsw was strongly influenced by Year 2, where the site produced a mean of 1,622 NTU and showed an increase of 1,788% over TB7Bin. One event with very high turbidity (>2,000 NTU) strongly influenced the Year 2 average at TB15Bsw partly due to the limited number of readings. Rainfall in Year 2 was 16% less than average, and during dry periods, more sediment accumulates on the roadway, causing higher peak turbidity when it does eventually runoff. In addition, as mentioned above, TB15B lacked substantial vegetation in the first few years of monitoring, so when heavy precipitation did come there would be more erosion in the bioswale. If Year 2 were not included in the overall mean, the percent increase relative to TB7Bin would be only 21%, much closer to the TSS-based results.

The overall removal efficiency of dry bioswales for reducing TSS and turbidity are best determined by combining the effects at the surface-water and groundwater exits and comparing them to the input. This was calculated by multiplying mean turbidity at both TB15Bsw and TB15Bgw by their respective discharge volumes, adding those products together, and then dividing by the sum of the discharge volumes (Appendix B). The combined performance of both outlets at TB15B relative to TB7Bin showed a 55% reduction in turbidity over Years 2-5. This result is similar to the reduction calculated for TB15Bgw alone, and is unsurprising since the volume of discharge at the groundwater exit makes up nearly 94% of the total volume discharged from the bioswale. The combined performance of sw and gw percent reduction of TSS in composite samples was 78% for Years 2 through 5 (Miner et al. 2016 reports 71% for Years 1-5 period). This difference in performance is for the same reason mentioned for TB15Bgw: due to the inability of the data loggers to collect valid measurements when water level and associated turbidity were very low, even as the Isco devices continued to sample this low-turbidity runoff.

Turbidity at one of the culverts that provides runoff input to TB15B was also monitored to check whether input values were similar to TB7Bin. The culvert (TB15Bc1N) usually had a thick silt deposit in the bottom, which was likely legacy from construction projects and not related to roadway runoff. Ponding also occurred at the outlet of the culvert, which caused high turbidity values not associated with runoff that could not be identified definitively and removed from the dataset. For these reasons, turbidity data from TB15Bc1N are presented in Figure 10 and Appendix A, but were not used for any further analyses in this report.

TB19 Results

TB19 is a dry bioswale with a surface-water outlet and an underdrain outlet. It is the only bioswale studied that had no major point-source inlets. Instead, roadway runoff flowed diffusely into the bioswale over the road shoulder and foreslope.

TB19gw showed a reduction in mean turbidity of 37% relative to TB7Bin, which was the smallest reduction of any outlet besides the surface-water outlets at the dry bioswales (TB15Bsw and TB19sw). Over the period of investigation, it consistently had a smaller percent reduction in comparison to TB15Bgw, and about half of the amount of data collected (13,293 readings at TB19gw, 27,085 readings at TB15Bgw). It is unclear as to why a smaller reduction occurred here, because the turbidity loggers at both TB15B and TB19 were installed in a similar way and appeared to capture data in the same way and at the same times of year. The water at TB19gw, like at TB15Bgw, was sometimes darker in color possibly due to a high content of tannins or iron staining. This can cause an increase in turbidity unrelated to amount of sediment. Given that the reduction in composite sample TSS at TB19gw was 76% (Miner et al. 2016; Table 4), substantially higher than the 37% reduction in mean turbidity, it is possible that additional tannins or other non-sediment components may have increased turbidity. In addition, this 76% reduction is similar to the reductions seen at TB15Bgw in turbidity and TSS, pointing again to the outlying nature of TB19gw. More investigation would need to take place to identify why these differences exist.

TB19sw, like TB15Bsw, showed an increase in mean turbidity in three out of four post-construction monitoring years. However, the mean for the period of record showed a small (9%) reduction in mean turbidity. This latter result was heavily influenced by the turbidity data from Year 5, which were much lower than any of the preceding years, likely due in part to more turbidity readings recorded at the site in that year, as well as a possible increase in vegetation cover in the bioswale. Analysis of composite sample TSS showed the same result (9% reduction). Though it is intuitive that TB19sw and TB15Bsw would both show increases in turbidity, TB19sw flowed more often than TB15Bsw; the site had 381 turbidity readings over the period of record compared to just 165 at TB15Bsw. The foreslope and backslope at TB19 are steeper than the slopes at TB15B, which would cause more flows and less infiltration in comparison. In addition, TB19sw only has diffuse inputs, whereas TB15Bsw has direct inputs, possibly causing higher flow rates and more erosion. The more frequent flow and higher number of readings collected at lower flows at TB19sw likely reduced the mean turbidity and contributed to the slight overall reduction. In addition, the presence of diffuse inputs, instead of point-source, lowered the flow velocity that would have caused erosion.

Similar to TB15B, the reductions in turbidity at TB19sw and TB19gw were added together (Appendix B) to evaluate the total removal efficiency the TB19 bioswale had on reducing turbidity relative to TB7Bin. The combined performance of both outlets relative to TB7Bin showed a 35% reduction in turbidity over Years 2-5. The results were similar to the reductions calculated for TB19gw, which is unsurprising since the volume of discharge at the groundwater exit makes up 90% of the total volume for the bioswale. The combined performance of surface-water and groundwater percent reduction of TSS in composite samples was 70% for Years 2-5 (Miner et al. 2016 reports 68% for the complete time period). As with TB19gw, this difference in performance is possibly due to the presence of additional tannins or other non-sediment components, which may have increased turbidity.

Comparing Wet and Dry Bioswales

Surface-water outputs at wet bioswales and underdrain outputs at dry bioswales both showed substantial reductions in turbidity in most cases. The highest and third highest percent reductions in mean turbidity over the period of record (77% and 50%) were observed at surface-water outputs of wet bioswales (TB9A and TB7Bout, respectively). The second highest and fourth highest percent reductions (70% and 37%) were at underdrain outputs of dry bioswales (TB15Bgw and TB19gw, respectively). The total removal efficiency of the groundwater and surface-water exits together at TB15B was a

55% reduction, and at TB19 it was a 35% reduction. Both wet and dry bioswales, therefore, performed well at reducing turbidity, with wet bioswales performing slightly better over Years 2-5. However, as previously mentioned, infiltrated water that exited dry bioswales through the groundwater pipes was often dark in color, which increases turbidity values without the addition of sediment. The performance of the dry bioswales, therefore, could be slightly under-estimated by the turbidity data loggers; this is suggested by the discrepancy between turbidity reductions and TSS reductions at TB15Bgw and TB19gw (Table 4). Reductions of TSS measured from composite samples indicate that dry bioswales performed slightly better at reducing sediment in runoff over Years 1-5 (Miner et al. 2016). Although turbidity data loggers may underestimate sediment removals due to detecting tannins and therefore over-report turbidity, the convenience and lower cost of using data loggers rather than expensive composite sampling may outweigh the modest reductions in accuracy.

While the groundwater outputs at the dry bioswales showed large reductions in turbidity, the surface-water outputs at dry bioswales generally showed increases in turbidity, or low mean percent reductions. Two surface-water outputs at dry bioswales were monitored (TB19sw and TB15Bsw), and data from individual monitoring years for both indicate that these types of sites do not reduce turbidity relative to inputs in most years. At TB15B, vegetative cover was noted to be sparse in some areas within the bioswale and foreslope areas, and the turbidity at TB15Bsw was likely elevated due to erosion in these areas. It is also important to reemphasize that higher flows caused by heavier rain events, while relatively infrequent, had higher mean turbidity due to more erosion within the bioswale and along the roadway embankment. Therefore, the lack of discharge at the surface-water outputs had negligible effects on overall performance of the bioswales. However, measures to increase infiltration or decrease surface-water discharge, such as adding check dams, reducing slope gradients, and/or improving plant stabilization and growth, would likely improve dry bioswale performance.

Bioswale Performance Over Time

Dry bioswales performed slightly better at reducing turbidity at the groundwater outputs in the last two years of monitoring (Table 3). This could be due to the dry bioswales becoming more vegetated over time and stabilizing the soil within the bioswale, thus causing less erosion and movement of sediment. Continued improvement over time in the dry bioswales is possible. There was no clear improvement over time at wet bioswales or at the surface-water outputs of dry bioswales, although no data were collected in Year 1. TB9A and TB15Bgw had comparable reductions in turbidity each year, but other sites showed no pattern. Turbidity of runoff is dependent on many factors such as the rate and intensity of precipitation, antecedent moisture conditions, total flow volume, flow velocity, and the extent of vegetative cover on the surrounding slopes and within the bioswales. More analysis would be needed, incorporating all of these variables, to assess whether changes in percent reductions between years could be attributed to bioswale performance or other factors.

Pre-construction vs. Post-construction Turbidity

Turbidity data were collected at the locations of TB15B and TB19 before the bioswales were constructed (Figures 12 and 13). To evaluate the effects of the bioswales on lowering turbidity, pre-construction mean turbidity was compared to post-construction mean turbidity of the combined groundwater exit and surface-water exit of the dry bioswales (Appendix B). Mean turbidity at TB15B decreased from 106 NTU before bioswale construction to 51 NTU after construction, a 52% reduction. At TB19, mean turbidity decreased from 77 NTU before construction to 73 NTU post-construction – a 5% reduction. The small change in the mean at TB19 is largely because much more data were collected during the post-construction time period, including much more data during low flows. The pre-construction data from both sites had much higher peaks and maximum readings than the post-construction data, which indicates the bioswales were effective at lowering peak turbidity, even though the decrease in mean may not adequately reflect bioswale effects. Pre-construction data from water samples presented in Miner et al. (2016) also conclude that after construction there were improvements in the reduction of sediment at both TB15B (89%) and TB19 (99%).

Most of the post-construction turbidity data at the dry bioswales was collected at the bioswales' groundwater exits, and this infiltrated water likely has higher levels of tannins than the surface water monitored in the pre-construction ditches. The tannins make the water dark in color and increase turbidity values, and so the reduction of sediment at the sites from pre- to post-construction may have been greater than suggested by the mean turbidity values.

Pre- and post-construction turbidity data were collected using different types of instruments with different technologies, calibration ranges, and logging intervals, so comparisons between the data are not necessarily definitive. Pre-construction datasets also lacked level and discharge data that was used with post-construction datasets to assess the validity and quality of turbidity data, which may mean the pre-construction dataset is not as reliable.

Percent Reductions of Turbidity vs. Percent Reductions of TSS

Over the entire period of record, percent reductions in mean annual turbidity generally were similar to percent reductions in TSS measured from composite water samples, though some individual years showed large variations (Table 4). The sites with the most similar overall reductions were TB7Bout, TB9A, TB15Bgw, and TB19sw.

In general, percent reductions of mean turbidity were smaller than percent reductions of TSS calculated from water samples. This is likely because the turbidity data loggers took readings every 15 minutes regardless of the amount of flow at the site, and the majority of readings in the resulting datasets were therefore recorded during low-flow, low-turbidity conditions, not during precipitation events. This affected the annual means of the turbidity datasets to be slightly lower than they might have been if the loggers had taken measurements exclusively during runoff events. The Isco autosamplers were programmed to collect samples based on amount of flow at the site rather than on a

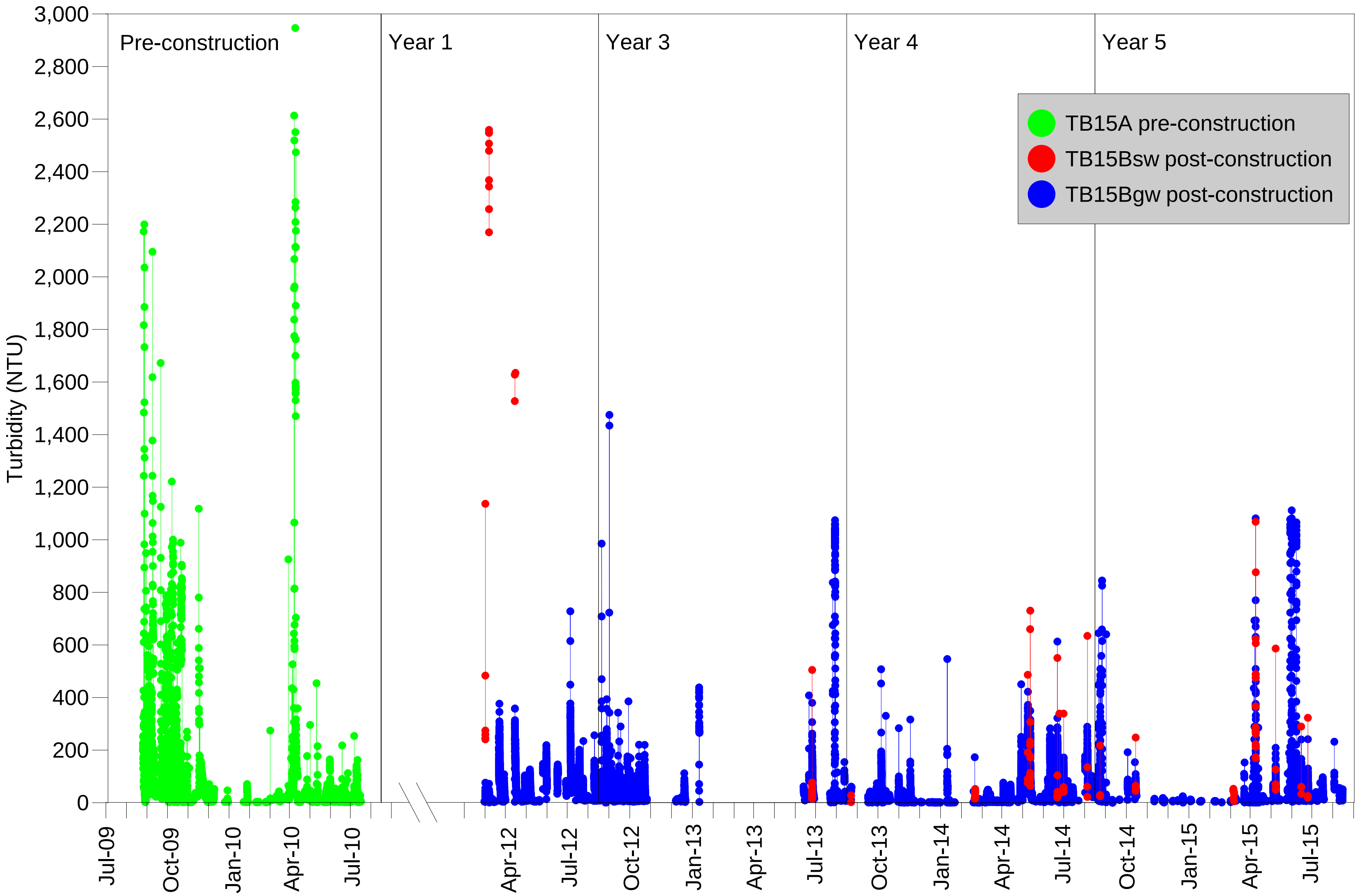

Figure 12. All valid pre- and post-construction turbidity data collected at TB15.

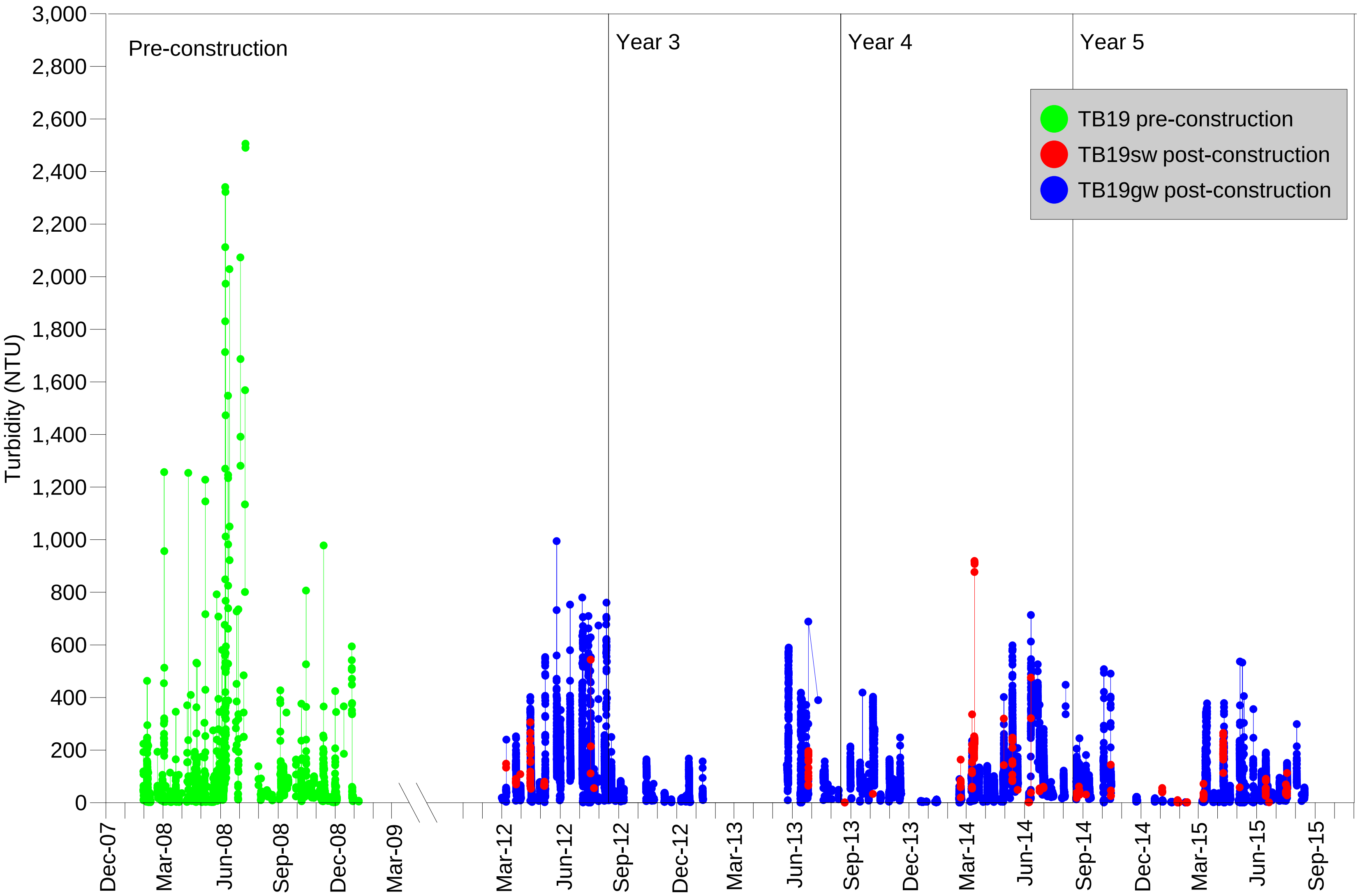

Figure 13. All valid pre- and post-construction turbidity data collected at TB19.

regular time interval, and so TSS totals reflect storm conditions and low flows in proportion to their occurrences. This is likely responsible for some of the discrepancy between the TSS reductions and the mean turbidity reductions. Additionally, as previously discussed, turbidity at some sites was likely affected by tannins in the water, which can increase turbidity values without the addition of sediment. The turbidity data loggers therefore likely underestimated the reduction of sediment and performance of the bioswales.

Overall, the similarity between turbidity reductions and TSS reductions is promising and suggests that for studies on reductions of TSS on long time scales, turbidity data loggers could be used as a less expensive and less labor-intensive alternative to collecting and analyzing water samples. On-site issues affecting accuracy and comparability include site-specific issues like duration of flow, percent of time that water flows through the bioswale, whether the flow is high enough to measure with each instrument type, measurement intervals on both instrument types, and others.

TOTAL SUSPENDED SOLIDS CALCULATED FROM TURBIDITY

Models to Calculate TSS from Turbidity

We developed relationships of turbidity to TSS for each of the studied locations (Figures 14-20, Table 5). Linear models were selected in all cases for consistency. Other studies found that most suspended sediment-turbidity relationships were linear, and in most cases, a singular linear fit performed nearly as well or better than other methods (Lewis 1996, Lewis 2002).

Table 5. Site-specific equations to calculate TSS (mg/L) from turbidity (NTU).

Site	Equation	R^2	n
TB7Bin	$y = 1.57x + 8.62$	0.69	40
TB7Bout	$y = 1.08x - 14.15$	0.90	22
TB9A	$y = 0.59x + 15.67$	0.44	35
TB15Bsw	$y = 0.63x + 14.11$	0.92	16
TB19sw	$y = 0.47x + 34.51$	0.51	13
TB15Bgw	No clear relationship		27
TB19gw	No clear relationship		25

The best correlations between turbidity and TSS were at TB15Bsw and TB7Bout. TB7Bin had a fair linear fit ($R^2 = 0.69$), but had more variability at higher turbidity values. TB9A had a poor fit and more scatter. All of the models could likely be improved from more data points collected during conditions that produce higher turbidity and TSS values.

At TB15Bgw and TB19gw, there was no clear correlation between TSS and turbidity (Figures 19 and 20). We were unable to calculate TSS from turbidity at these sites, although relationships can be seen. The lack of relationships at these sites is likely because the water from the underdrains was often dark colored due to the presence of tannins and/or other dissolved constituents, which can increase turbidity values without the addition of sediment. In addition, there is a limited range of values at the low end of the scale. Both sites showed indications of a positive linear trend, but more data points were needed to have confidence in a model.

The linear fit for TB7Bout had a negative y-intercept, and so TSS could not be calculated from turbidity values less than 13.1 NTU (Figure 15). The effects of this omission are expected to be negligible over the annual time scales used in this report. Alternative relationships would alleviate this effect, but they affect higher values adversely.

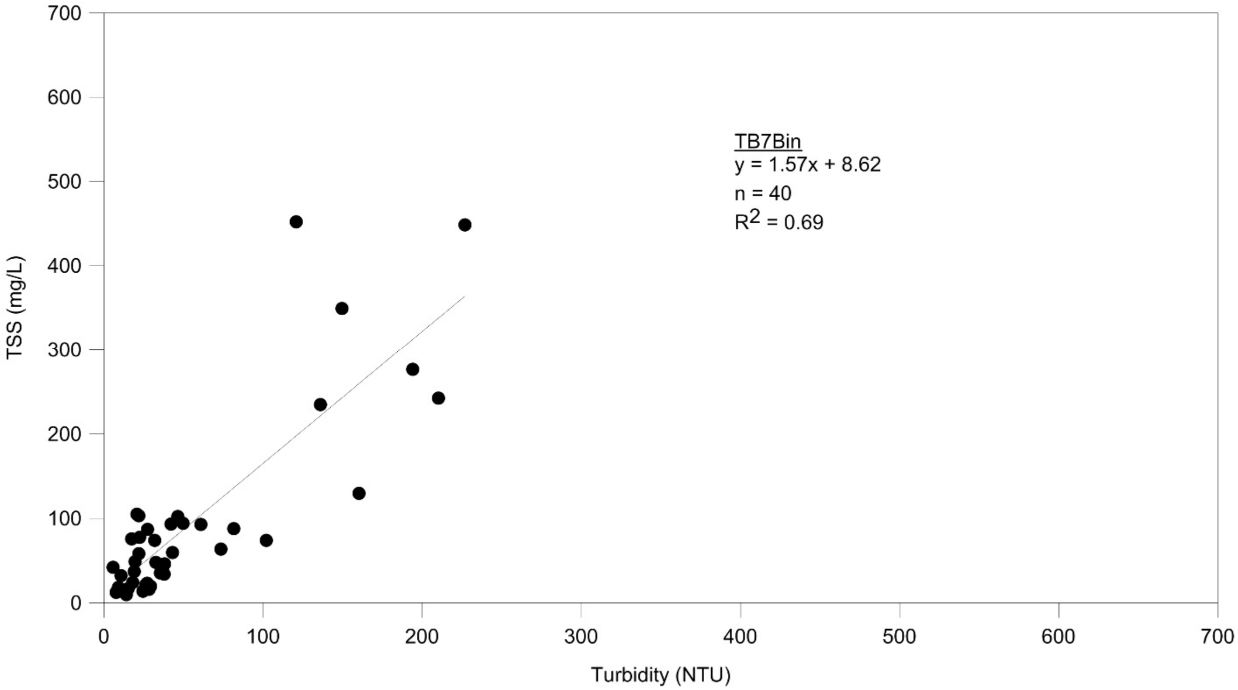

Figure 14. Turbidity vs. TSS at TB7Bin.

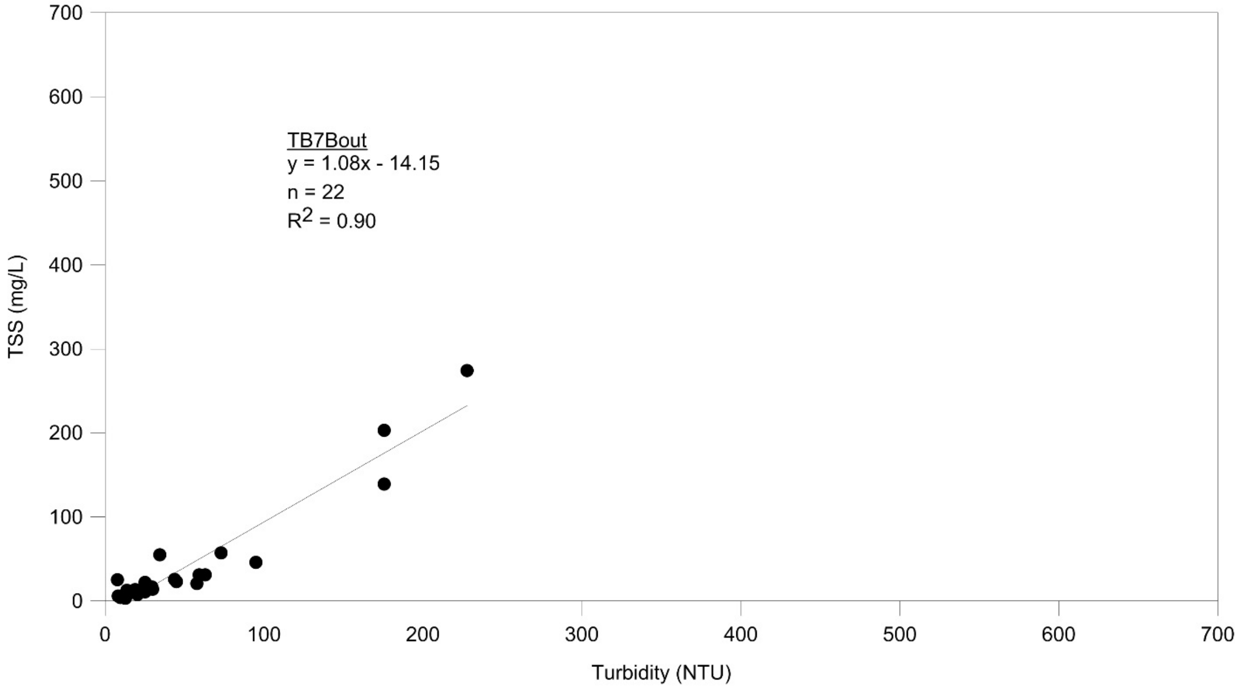

Figure 15. Turbidity vs. TSS at TB7Bout.

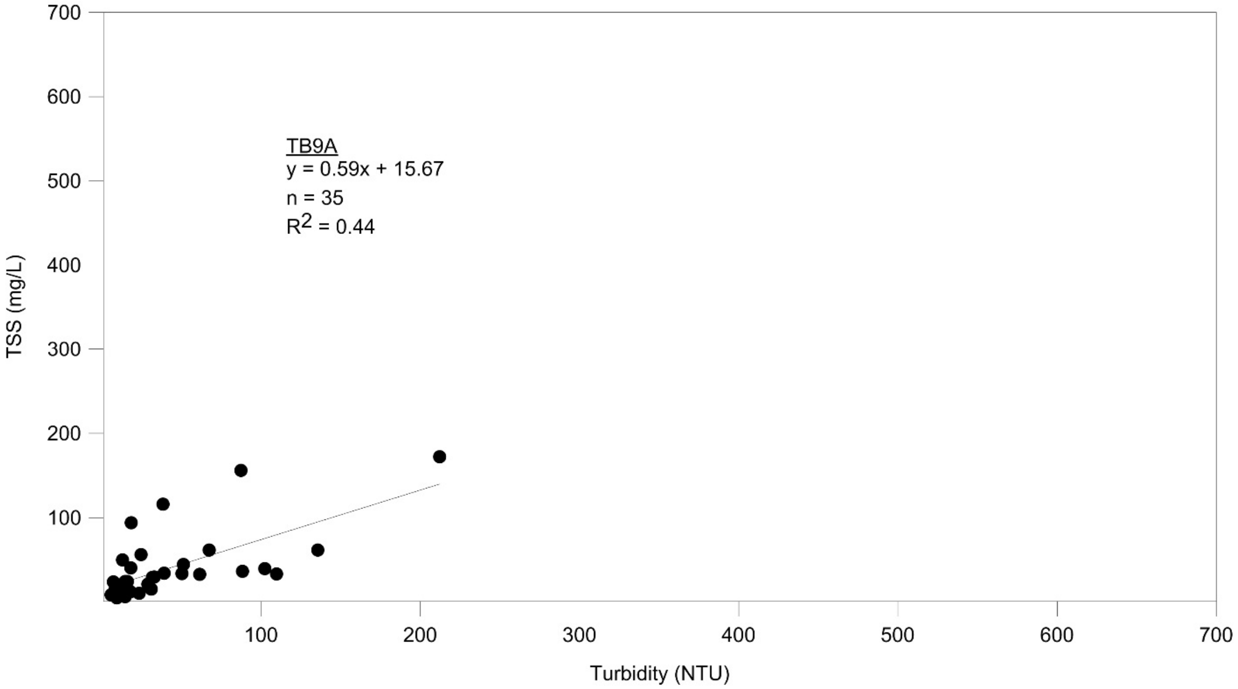

Figure 16. Turbidity vs. TSS at TB9A.

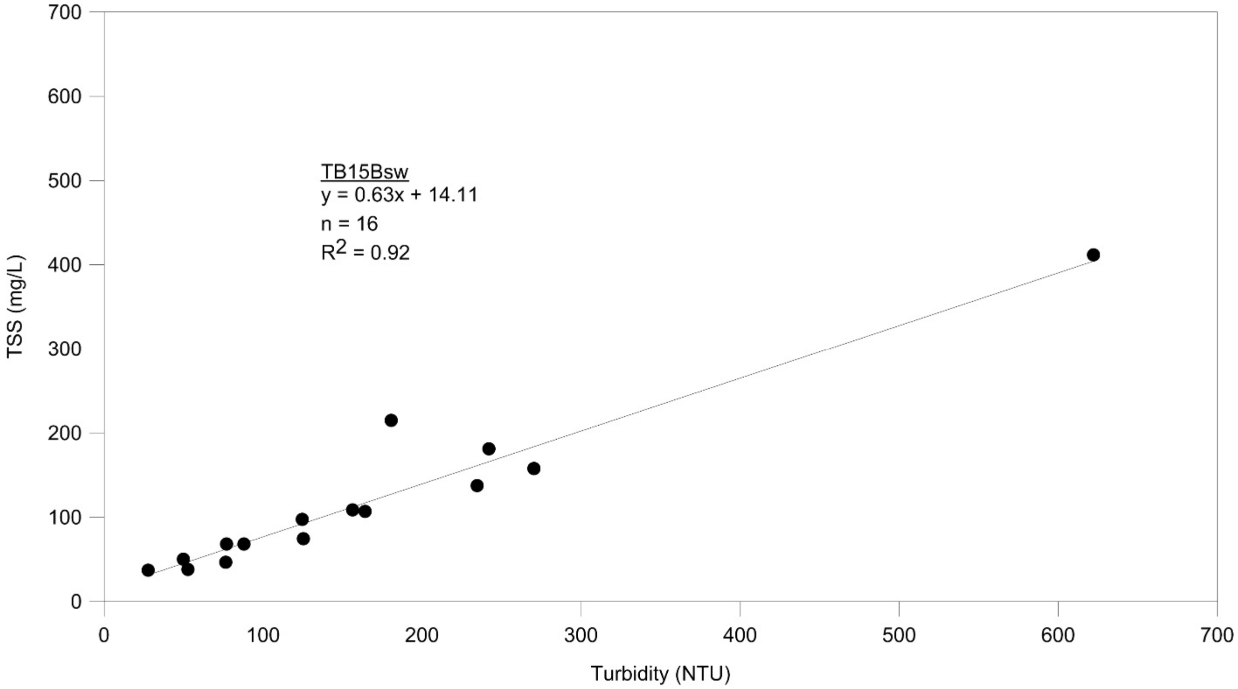

Figure 17. Turbidity vs. TSS at TB15Bsw.

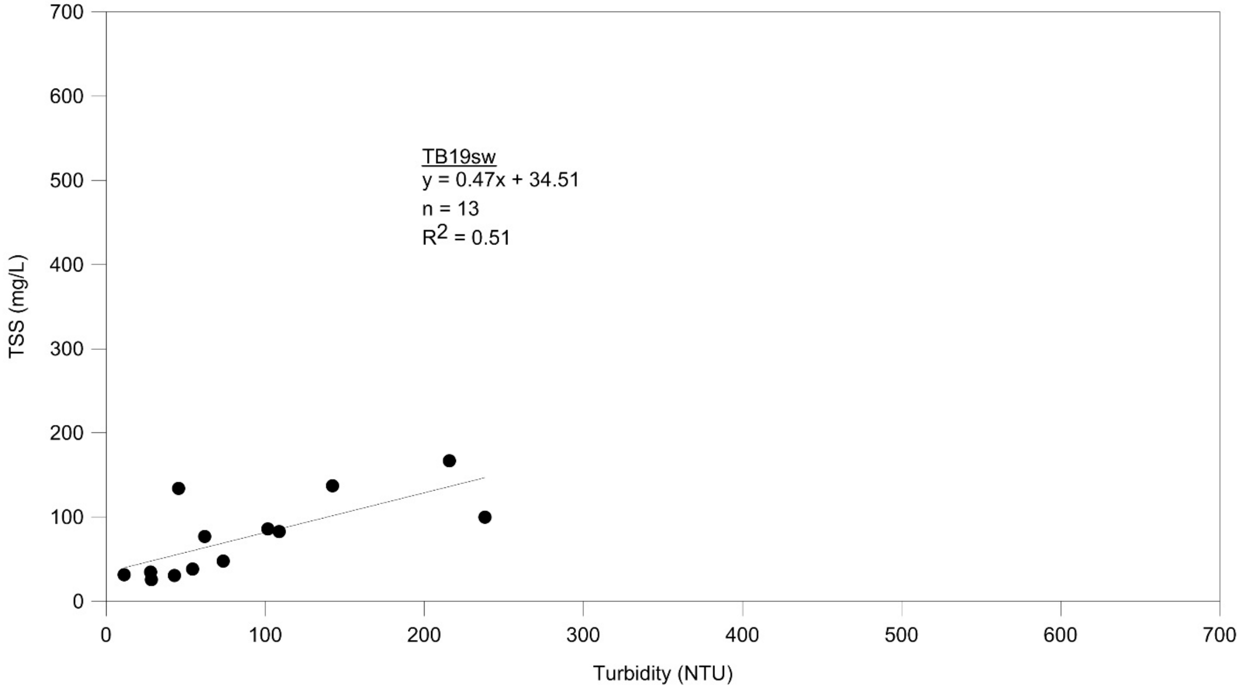

Figure 18. Turbidity vs. TSS at TB19sw.

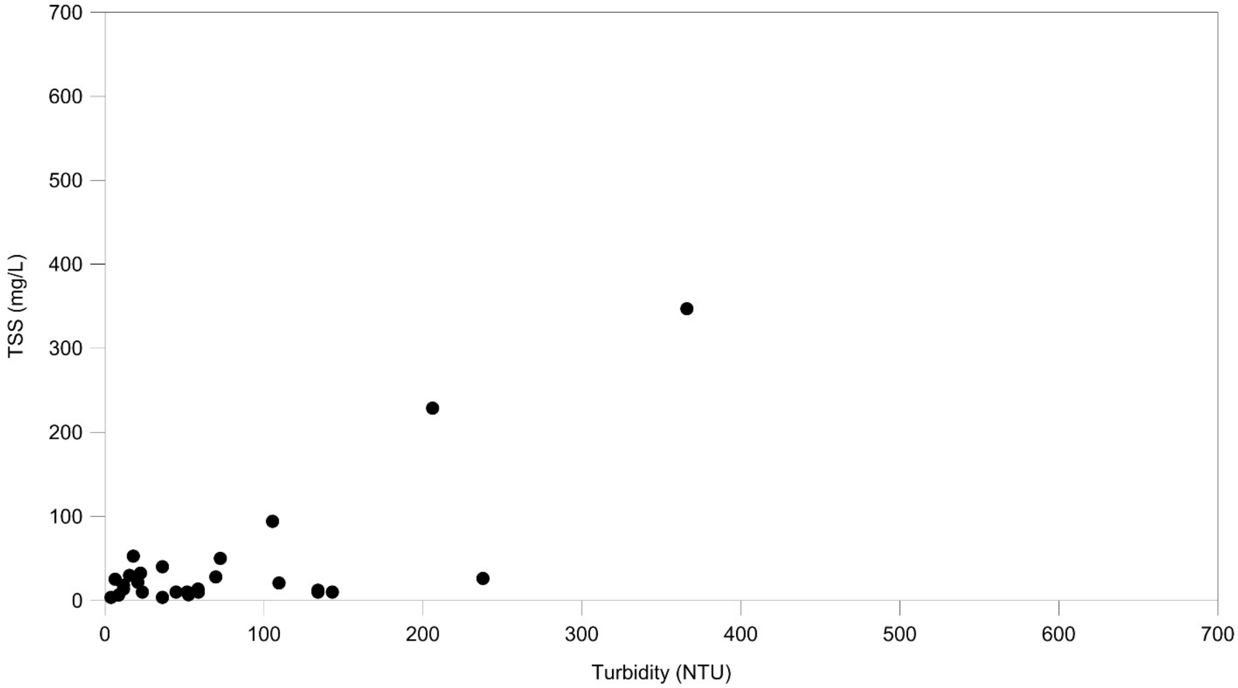

Figure 19. Turbidity vs. TSS at TB15Bgw.

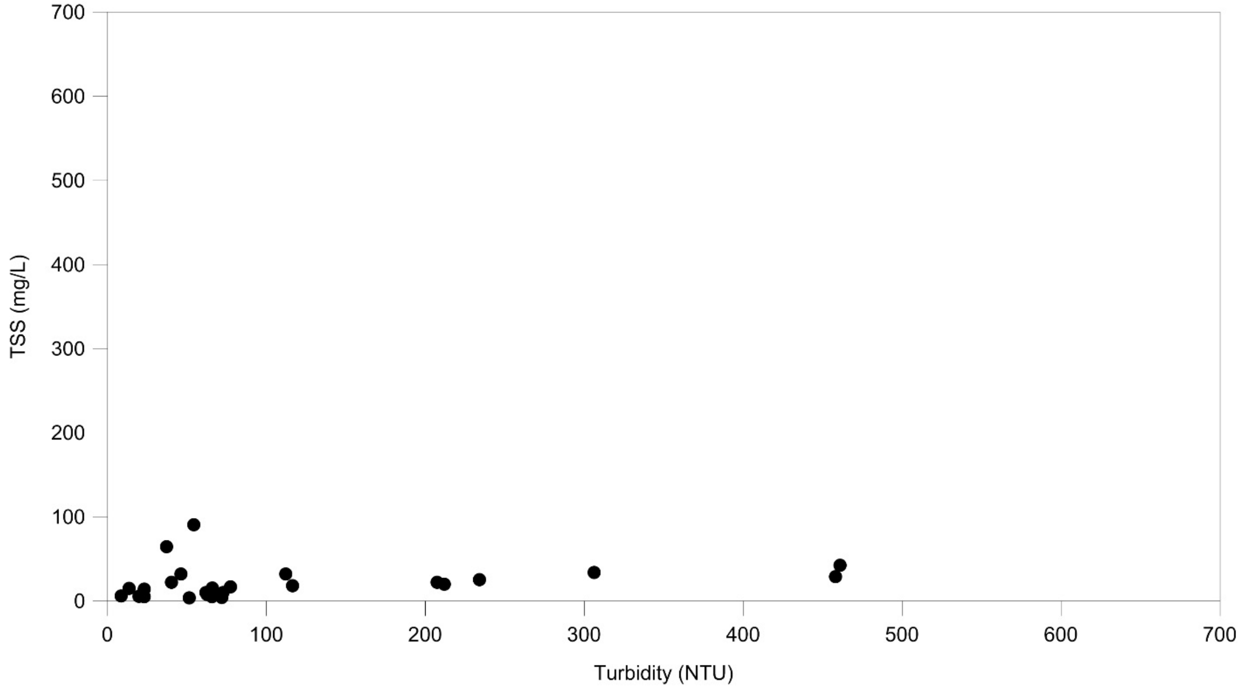

Figure 20. Turbidity vs. TSS at TB19gw.

Modeled vs. Measured Masses and Reductions

The TSS-turbidity models in Table 5 were used to calculate a TSS value for every turbidity reading from the data loggers, and then masses of TSS and standardized concentrations were calculated using the methods described previously in this report. The results are presented in Table 6. For comparison, the masses calculated from the composite water samples and presented in Miner et al. (2016) are also in Table 6. No turbidity-derived TSS is available for Year 1 because the turbidity loggers were not installed until Year 2.

Loads of TSS calculated from lab-measured samples were compared to loads from the modeled TSS values (Table 6, columns 2 and 3). In some cases (e.g. TB19sw Year 4, TB7Bin Year 5, TB7Bout Year 2), the numbers agreed very closely, and even when there were discrepancies in individual years, the overall Years 2-5 total loads were similar for all sites except TB15Bsw. The percent reductions calculated using modeled TSS values and measured TSS values are also very similar in most cases except at TB15Bsw (Table 6, columns 6 and 7). This affirms that continuously measuring turbidity and using models to determine TSS may be a valid method for determining sediment loads. Variations in modeled TSS are likely due to site-specific differences and differences due to the methods.

At all sites except TB7Bout, the Year 2 modeled TSS loads were substantially less than the Year 2 measured TSS loads. This is likely because the data loggers were only deployed from March through August of Year 2, while water samples were taken through the entire year. Other discrepancies between measured and calculated TSS values can mostly be attributed to error introduced from the equations used to calculate TSS from turbidity. Better fitting equations developed from more data points could help address this problem. At TB15Bsw, the larger discrepancy is likely because runoff events at the site are short in duration and so the turbidity logger, which takes a measurement every 15 minutes, may only record one or two data points, but the flow-composite sampler may take multiple samples, thus resulting in a much higher TSS load calculated from samples than from modeled data.

REDUCTIONS IN SPECIFIC CONDUCTIVITY AFTER BIOSWALE INSTALLATION

Overview and Aggregate Performance of All Studied Bioswales

Specific conductivity (SpC) is a measure of the electrical conductivity of water and is related to the amount and species of total dissolved solids (TDS). A majority (55%) of the TDS that runs off the road comes when discharge is less than 0.1 cfs (Higley et al. 2014). Though large flows can carry large masses of TDS, both the concentration of TDS and the frequency of these large flows are typically low, so most of the TDS in the bioswales is recorded during the very frequent, very-low flows that often consist of base flow from roadway drains or from groundwater, which can be high in TDS in the vicinity of the roadway (Carr et al. 2016). The lowest-flow events often had water levels too low

Table 6. Masses and standardized concentrations of TSS from samples measured in the lab and TSS modeled from turbidity values.

	Lab: Total TSS load (kg)	Model: Total TSS load (kg)	Lab: Standardized concentration (mg/L)	Model: Standardized concentration (mg/L)	Lab: TSS percent reduction vs. TB7Bin**	Model: TSS percent reduction vs. TB7Bin**
TB7Bin						
Year 2*	316.0	126.8	80.3	62.2		
Year 3	319.0	252.1	65.5	51.7		
Year 4	846.0	1,261.9	165.0	245.8		
Year 5	448.0	421.2	91.5	86.2		
Years 2 - 5	**1,929.0**	**2,062.0**	**102.4**	**121.7**		
TB7Bout						
Year 1		145.9				
Year 2*	82.8	95.8			73.8	24.4
Year 3	149.0	41.3			53.3	83.6
Year 4	141.0	278.2			83.3	78.0
Year 5	73.8	54.2			83.5	87.1
Years 2 - 5	**446.6**	**615.4**			**76.8**	**70.2**
TB9A						
Year 2*	467.0	259.8	14.8	30.1	81.6	51.6
Year 3	2,290.0	1,884.5	52.5	43.3	19.8	16.2
Year 4	547.0	1,408.9	16.7	42.8	89.9	82.6
Year 5	1,140.0	441.0	39.5	15.3	56.8	82.3
Years 2 - 5	**4,444.0**	**3,994.2**	**32.5**	**35.1**	**68.3**	**71.2**
TB15Bsw						
Year 2*	81.9	24.2	571.3	442.6	-611.4	-611.6
Year 3	266.0	23.8	134.2	12.0	-104.9	76.8
Year 4	144.0	101.6	112.8	79.6	31.7	67.6
Year 5	118.0	80.2	136.6	92.8	-49.3	-7.7
Years 2 - 5	**609.9**	**229.8**	**143.0**	**55.0**	**-39.6**	**54.8**
TB19sw						
Year 2*	24.7	9.4	112.9	114.0	-40.6	-83.3
Year 3	164.0	62.2	88.8	33.7	-35.8	34.8
Year 4	210.0	207.3	95.2	94.0	42.3	61.8
Year 5	37.4	107.1	95.7	274.5	-4.6	-218.4
Years 2 - 5	**436.1**	**386.0**	**93.6**	**85.3**	**8.6**	**29.9**

*At TB9, TB15B, TB19, and TB7Bin, Year 2 was only monitored with dataloggers for part of the year (March through August). Samples were collected through the entire year.

**Percent reduction calculations use mass for TB7B and standardized concentrations for all others. Shades of green indicate percent reductions >0, shades of yellow indicate percent increases 1 to 25%, and shades of red indicate percent increases >25%.

to be recorded by the AquaTROLLs (ATs), possibly lowering mean levels, since these flows presumably have higher SpC values.

Summary statistics for SpC organized by site can be found in Table 7 and Appendix D. Figures 21 through 24 show all valid post-construction SpC data that were collected.

TB7B Results

As previously discussed, the only site with both a directly measureable single input and single output was TB7B, which is a wet bioswale (Fig. 21). Data collected over the entire monitoring period had a mean SpC of 13,874 µS/cm at TB7Bin and 2,774 µS/cm at TB7Bout (Table 7). This indicates an 80% reduction in mean SpC, which is similar to the 90% reduction in TDS calculated from composite samples collected at TB7B. Miner et al. (2016) reports a 90% reduction which includes samples from Year 1 at TB7Bout when there was no AT logger installed (Table 8). Individual monitoring years showed major reductions every year, ranging between 84% and 98%. We anticipate that the very high reductions in SpC were related to the infiltration capacity of TB7B. TB7B had frequent low flows that infiltrated well, lowering the overall mean SpC at TB7Bout.

TB7Bin had the highest overall post-construction SpC maxima of all of the bioswales at 81,231 µS/cm, which is higher than the SpC of seawater (54,000 µS/cm). At TB7Bin, during the winter, SpC values were commonly above 20,000 SpC, but would fall below that value in the spring and summer as heavier rain events occurred, and runoff was diluted. Data were missing for much of winter in Year 2, which was reflected in its reduced mean SpC of 8,366 µS/cm. The logger had to be removed so the bioswale could be repaired in late November 2011, and then was not replaced until early January 2012, followed by subsequent freezes in January and February 2012 that limited wintertime data collection.

TB9A Results

TB9A is a wet bioswale (Fig. 22). TB9A had the second highest mean SpC of the outputs at 10,655 µS/cm and the lowest percent reduction relative to TB7Bin (23%) (Table 7). The percent reduction is about half of the reduction in TDS calculated from composite water samples (48%) (Miner et al. 2016) (Table 8). The site showed reductions in mean SpC every year ranging from 15% to 33%. TB9A had the second highest overall maxima of SpC at 37,488 µS/cm, which occurred in Year 4, when wintertime temperatures were often freezing and potentially more roadway deicing occurred. Overall, TB9A reduced SpC less effectively than all other bioswales, possibly due to high conductivity inputs from groundwater, or from the creek north of the site backing up into the bioswale. In addition, the bioswale elevation was similar to the water table at TB9A, as evidenced by the surface of Belleau Lake, causing the infiltration gradient to be less than it would be at TB7B. Miner et al. (2016) mentions that groundwater likely discharges to the bioswale at the north end of the site near where the surface-water outlet AT is installed. In general, the placement of the AT

Table 7. Summary of all SpC data collected through the duration of monitoring. All values are in µS/cm.

	Number of Readings	Minimum	Median	Mean	Max	Percent Reduction (mean) vs. TB7Bin
TB7Bin						
Year 1*	1,084	100.2	9,759.1	8,939.5	15,087.4	
Year 2	2,559	77.7	7,855.6	8,365.7	47,805.6	
Year 3	2,462	518.1	11,000.8	13,276.8	66,161.3	
Year 4	2,468	29.2	33,358.2	24,851.5	49,703.7	
Year 5	8,528	12.3	12,812.1	13,149.1	81,230.8	
Years 1-5	**17,101**	**12.3**	**10,655.0**	**13,873.8**	**81,230.8**	
TB7Bout						
Year 2*	4	119.2	156.4	157.3	197.0	98.1
Year 3	110	48.7	436.3	909.2	5,851.0	93.2
Year 4	1,404	62.8	1,910.5	3,905.4	23,973.0	84.3
Year 5	1,025	23.2	814.3	1,434.3	10,420.2	89.1
Years 2-5	**2,543**	**23.2**	**1,107.8**	**2,773.9**	**23,973.0**	**80.0**
TB9A						
Year 1*	260	237.5	6,480.1	6,658.5	12,125.4	25.5
Year 2	2,041	87.6	7,897.2	7,120.7	20,994.6	14.9
Year 3	636	179.0	8,206.6	9,286.0	24,404.3	30.1
Year 4	2,071	208.4	16,640.0	17,139.4	37,487.5	31.0
Year 5	2,282	1,370.8	7,240.9	8,768.3	20,891.3	33.3
Years 1-5	**7,290**	**87.6**	**8,988.3**	**10,655.1**	**37,487.5**	**23.2**
TB15Bgw						
Year 2	3,701	468.5	4,158.0	4,894.0	10,809.8	41.5
Year 3	4,331	396.7	2,827.7	4,294.0	17,456.1	67.7
Year 4	12,955	3.3	5,582.5	6,987.7	21,710.6	71.9
Year 5	10,003	222.5	4,823.2	6,147.5	25,260.0	53.2
Years 2-5	**30,990**	**3.3**	**4,557.6**	**6,090.0**	**25,260.0**	**56.1**
TB15Bsw						
Year 1*	7	26.2	81.2	102.0	295.5	98.9
Year 2	0	ND[1]	ND	ND	ND	ND
Year 3	14	75.1	268.0	261.2	535.5	98.0
Year 4	48	11.3	128.8	313.0	1,067.3	98.7
Year 5	35	35.7	284.9	696.2	2,719.0	94.7
Years 1-5	**104**	**11.3**	**147.8**	**420.8**	**2,719.0**	**97.0**
TB19gw						
Year 2	1,692	66.6	1,789.9	2,053.7	10,229.7	75.5
Year 3	3,325	268.4	2,425.9	4,102.0	32,443.2	69.1
Year 4	7,850	26.3	2,343.5	4,505.0	16,273.6	81.9
Year 5	8,655	494.7	2,995.5	4,346.4	15,328.3	66.9
Years 2-5	**21,522**	**26.3**	**2,548.0**	**4,186.2**	**32,443.2**	**69.8**
TB19sw						
Year 2	12	45.4	1,612.6	2,864.3	14,810.1	65.8
Year 3	17	143.1	271.4	1,341.1	16,580.8	89.9
Year 4	84	52.2	362.7	3,004.4	24,456.5	87.9
Year 5	28	29.1	139.4	208.6	635.0	98.4
Years 2-5	**141**	**29.1**	**288.5**	**2,236.7**	**24,456.5**	**83.9**
TB15A						
Pre-construction	6,000	32.7	4,745.5	7,143.0	28,641.0	
TB19						
Pre-construction	3,688	88.5	8,559.0	10,068.4	66,192.0	

* At TB7Bin, TB9A, and TB15Bsw, Year 1 was only monitored with data loggers for part of the year (June through August). And at TB7Bout, Year 2 was only monitored for part of the year (May through August).

[1] no data

Shades of green indicate percent reductions >0, shades of yellow indicate percent increases 1 to 25%, and shades of red indicate percent increases >25%.

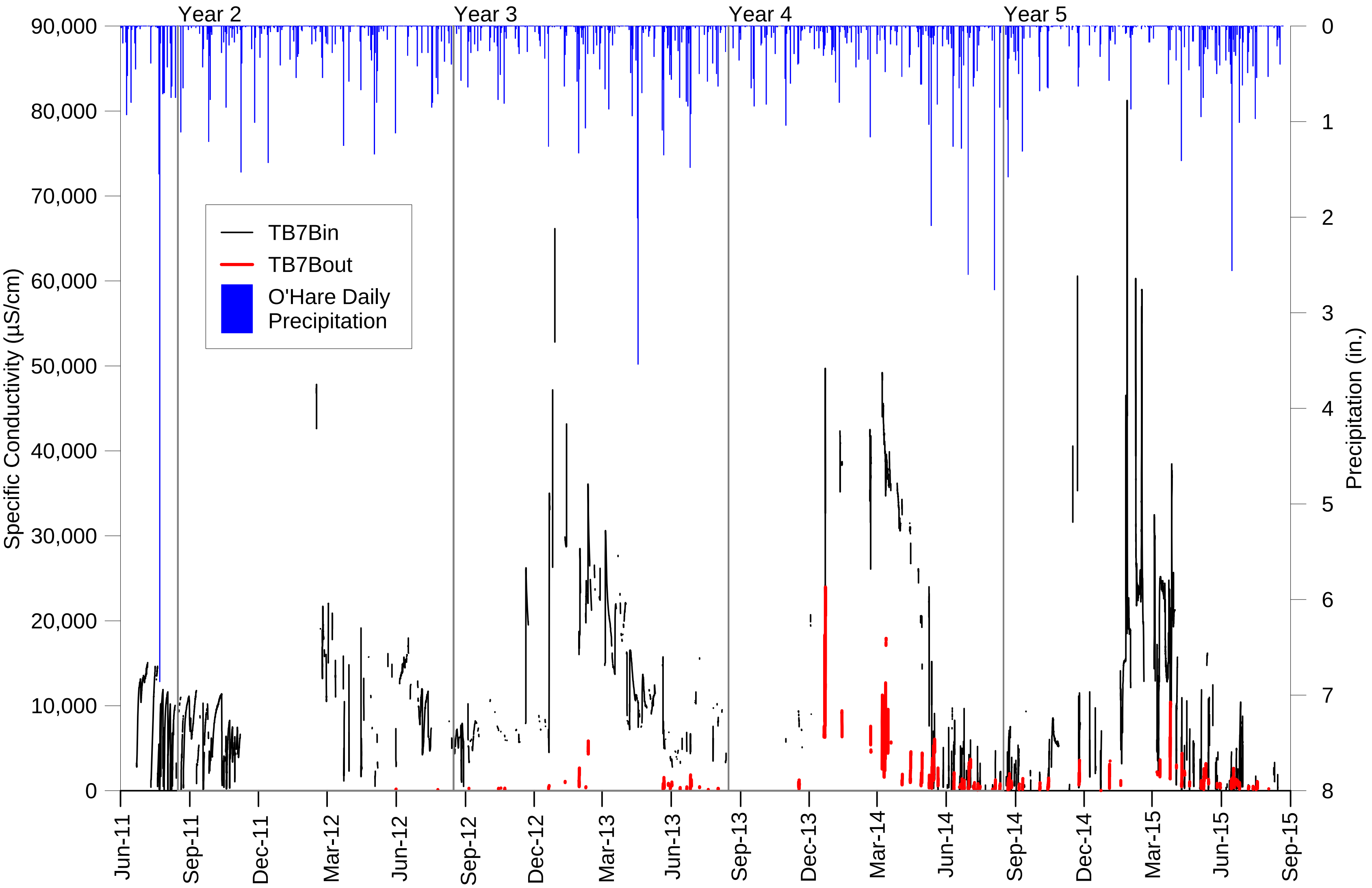

Figure 21. SpC of runoff at TB7Bin and TB7Bout, and precipitation recorded at O'Hare WSO.

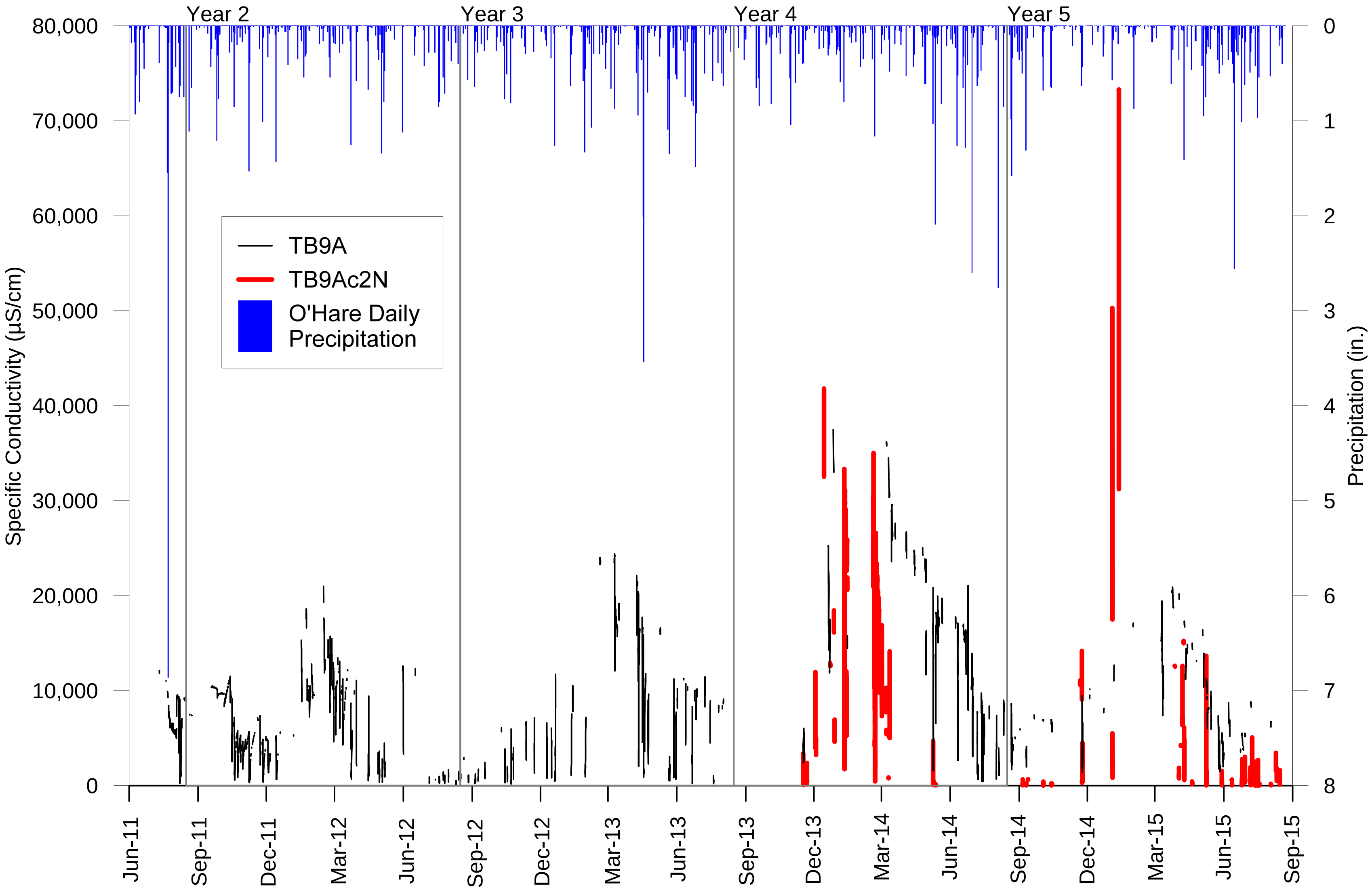

Figure 22. SpC of runoff at TB9A and TB9Ac2N, and precipitation recorded at O'Hare WSO.

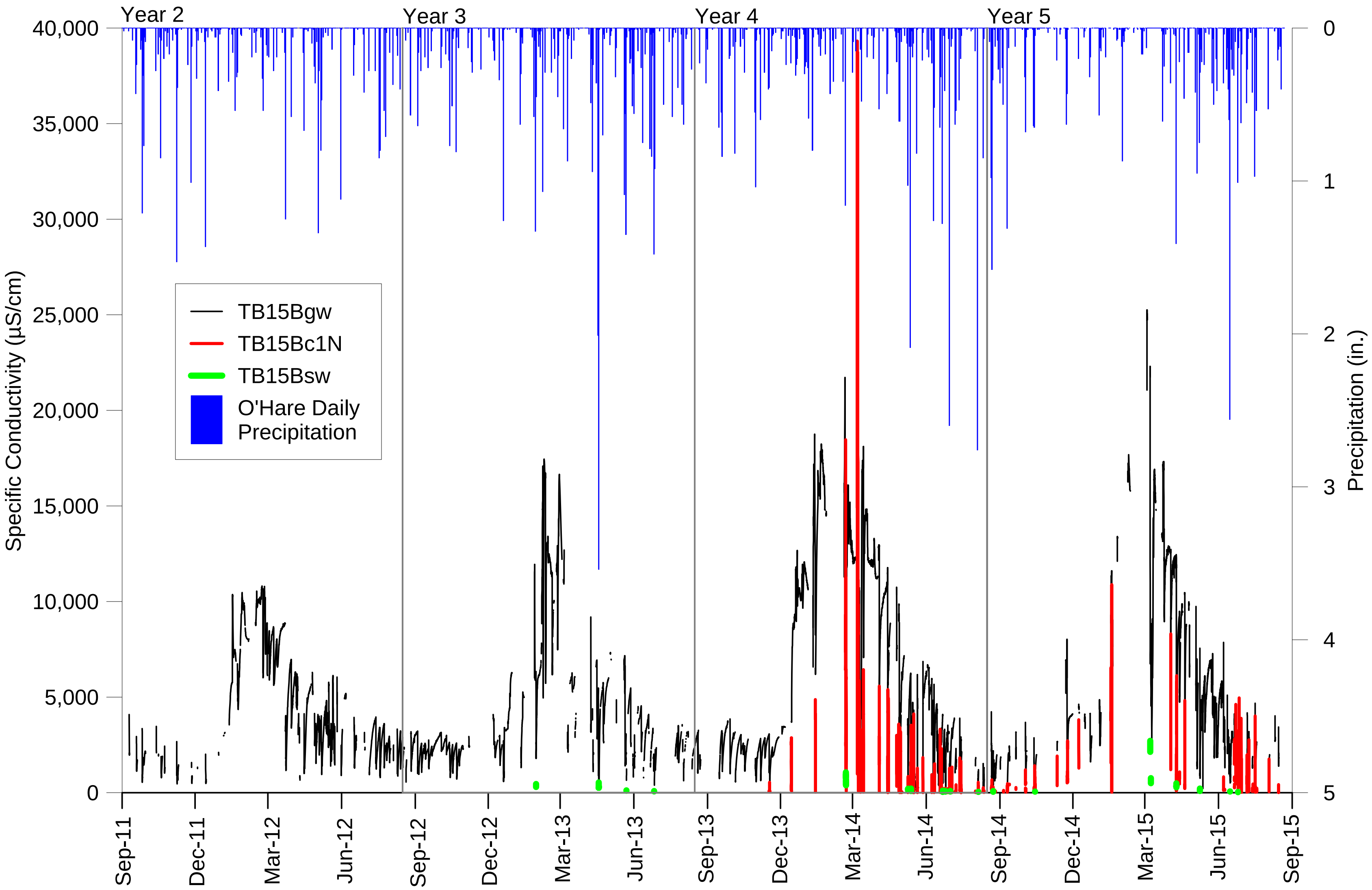

Figure 23. SpC of runoff at TB15Bsw, TB15Bgw, and TB15Bc1N, and precipitation recorded at O'Hare WSO.

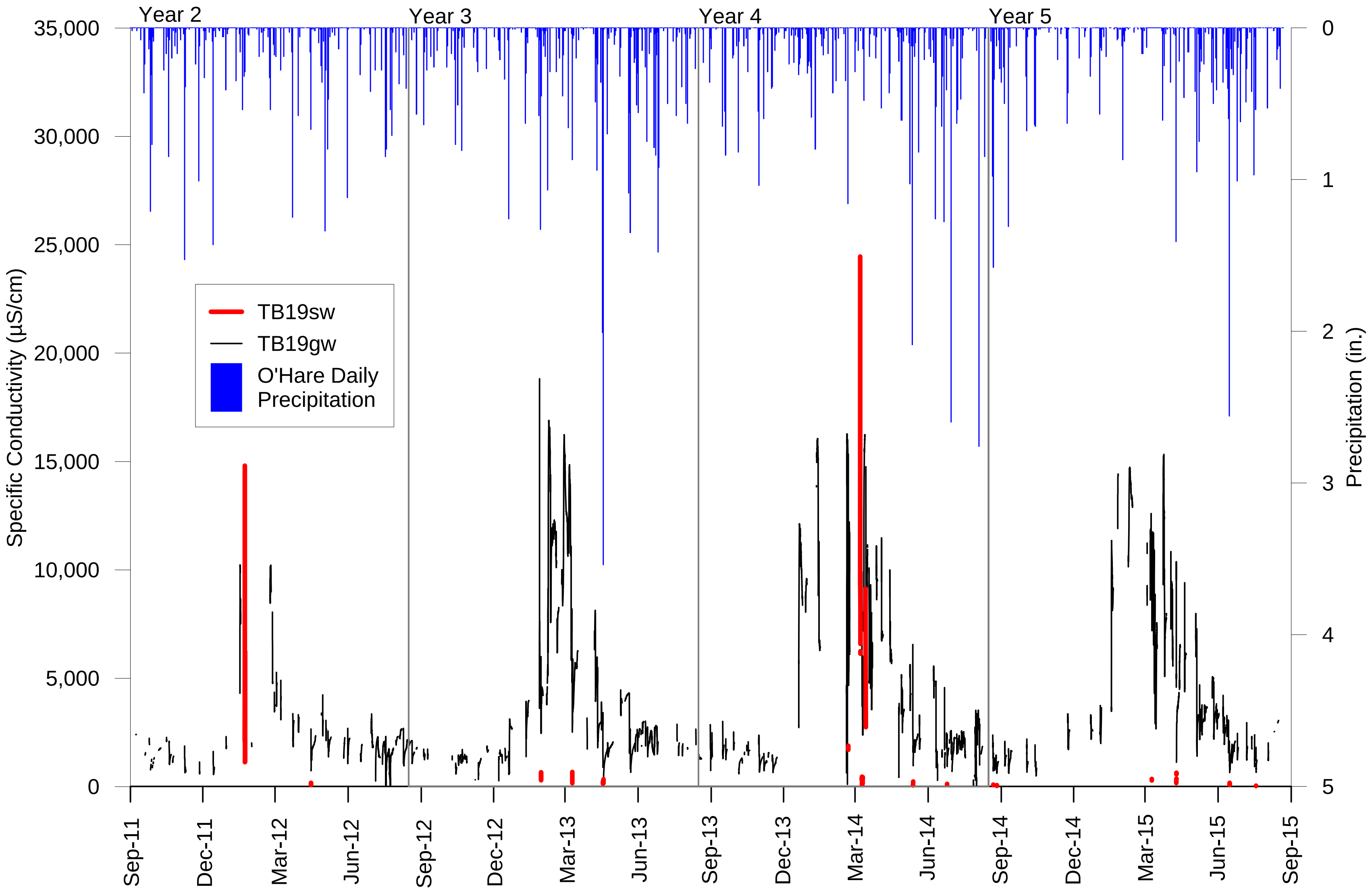

Figure 24. SpC of runoff at TB19sw and TB19gw, and precipitation recorded at O'Hare WSO.

Table 8. Comparison of percent reductions of mean SpC to percent reductions of TDS measured from composite samples.

	Mean Specific Conductivity (µS/cm)	Percent Reduction of Mean Specific Conductivity vs. TB7Bin*	Percent Reduction of TDS from composite water samples**
TB7Bin			
Year 1	8,939.5		
Year 2	8,365.7		
Year 3	13,276.8		
Year 4	24,851.5		
Year 5	13,149.1		
Years 1-5	**13,873.8**		
TB7Bout			
Year 2*	157.3	98.1	83.9
Year 3	909.2	93.2	96.3
Year 4	3,905.4	84.3	78.0
Year 5	1,434.3	89.1	91.0
Years 2-5	**2,773.9**	**80.0**	**89.9**
TB9A			
Year 1	6,658.5	25.5	64.3
Year 2	7,120.7	14.9	45.8
Year 3	9,286.0	30.1	75.7
Year 4	17,139.4	31.0	23.8
Year 5	8,768.3	33.3	31.5
Years 1-5	**10,655.1**	**23.2**	**47.6**
TB15Bgw			
Year 2	4,894.0	41.5	17.3
Year 3	4,294.0	67.7	66.9
Year 4	6,987.7	71.9	11.9
Year 5	6,147.5	53.2	20.2
Years 2-5	**6,090.0**	**56.1**	**24.9**
TB15Bsw			
Year 1	102.0	98.9	95.8
Year 2	ND[1]	ND	78.0
Year 3	261.2	98.0	97.0
Year 4	313.0	98.7	90.2
Year 5	696.2	94.7	63.4
Years 1-5	**420.8**	**97.0**	**89.0**
TB15Bsw+TB15Bgw			
Year 2	4,845.7	**42.1**	**17.9**
Year 3	3,906.4	**70.6**	**69.8**
Year 4	6,623.8	**73.3**	**16.2**
Year 5	5,800.3	**55.9**	**22.9**
Years 2-5	**5,754.6**	**52.5**	**29.8**
TB19gw			
Year 2	2,053.7	75.5	49.8
Year 3	4,102.0	69.1	44.5
Year 4	4,505.0	81.9	13.9
Year 5	4,346.4	66.9	42.2
Years 2-5	**4,186.2**	**69.8**	**24.5**
TB19sw			
Year 2	2,864.3	65.8	94.1
Year 3	1,341.1	89.9	96.3
Year 4	3,004.4	87.9	77.5
Year 5	208.6	98.4	92.5
Years 2-5	**2,236.7**	**83.9**	**85.1**
TB19sw+TB19gw			
Year 2	2,074.7	**75.2**	51.0
Year 3	3,790.2	**71.5**	50.4
Year 4	4,272.7	**82.8**	23.7
Year 5	4,171.3	**68.3**	44.3
Years 2-5	**3,997.9**	**66.5**	**30.4**
TB15A			
Pre-construction	7,143.0		
TB19			
Pre-construction	10,068.4		

*Percent reduction calculations use mass for TB7B and standardized concentrations for all others.

**Water sample data presented in Miner et al. 2016.

[1] no data

Shades of green indicate percent reductions >0, shades of yellow indicate percent increases 1 to 25%, and shades of red indicate percent increases >25%.

sensor at TB9A is likely measuring the base flow or groundwater at the site and not the precipitation events that come through the bioswale.

TB9Ac2N is one of the five culverts that supply runoff to TB9A. Three of the culverts supply water between TB9Ac2N and the output at TB9A. TB9Ac2N was monitored with an AT starting in October 2013 (two months into Year 4). It was monitored because its input was constructed similarly to TB7Bin with the direct input from a guttered system from the roadway. TB9Ac2n did have a similar overall mean (12,713 µS/cm) and maximum (73,293 µS/cm) as TB7Bin (13,874 and 81,231 µS/cm, respectively), but because of the limited duration of deployment of the equipment, SpC data are presented in Figure 22 and Appendix D, but were not used for any further analyses in this report.

TB15B Results

TB15B is a dry bioswale where the primary mechanism for improving the quality of runoff is infiltration (Fig. 23). TB15Bgw, the underdrain exit for the bioswale, flows for weeks to months at a time, rarely going dry. TB15Bgw had by far the largest number of readings collected by the AT of any site (30,990); meaning water at the site was flowing more often than at any other site.

TB15Bgw showed the second lowest percent reduction in mean SpC relative to TB7Bin (56%) of any monitored location. There were percent reductions in mean SpC every year at TB15Bgw ranging from 42% to 72%. This is more than double the 25% percent reduction of TDS calculated from composite samples (Miner et al. 2016) (Table 8). TDS mean percent reductions are lower than SpC due to the differences in monitoring methods. TB15Bgw SpC reduction is low relative to other sites due to the high-SpC groundwater that surrounds the underdrain (Carr et al. 2016). Seasonally, SpC values at TB15Bgw exceeded 15,000 µS/cm in the winter and fell below 5,000 µS/cm in the summer or during periods of high precipitation, and had an overall maximum of 25,260 µS/cm, which occurred in Year 5.

TB15Bsw had the fewest readings (104), indicating flowing water occurred the least often here. When TB15Bsw was compared to TB7Bin, there was a 97% reduction for the period of record, with annual reductions ranging from 95-99%. This is similar to the 91% percent reduction of TDS calculated from composite samples (Miner et al. 2016 reports an 89% reduction which includes samples from Year 1 at TB15Bgw when there was no AT logger installed) (Table 8). TB15Bsw had the lowest mean SpC (421 µS/cm) when compared to TB7Bin (13,874 µS/cm) and TB15Bsw (6,090 µS/cm), because flow only occurred during heavy precipitation when dilution of TDS occurred.

The total removal efficiency of dry bioswales was assessed by combining the results measured at the surface-water and groundwater exits relative to the input. This was calculated by multiplying mean SpC at TB15Bsw and TB15Bgw by their respective discharge volumes, adding those products together, and then dividing by the sum of the discharge volumes (Table 8 and Appendix E). The combined performance of both outlets relative to TB7Bin showed a 53% reduction in SpC over Years 2-5. This result is similar to the reduction calculated for TB15Bgw alone, since the volume of discharge at the groundwater exit made up nearly 94% of the total volume for the bioswale. The combined performance of surface-water and groundwater percent reduction of TDS in composite samples was 30% for years 2 through 5 (Table 8). As at TB15Bgw, this difference in performance is due to differences in monitoring methods.

TB15Bc1N is a surface-water input that receives water directly from the adjacent roadway and was being monitored to see if the inputs to TB15B were similar to TB7B, but the overall mean and maxima were not similar. The culvert (TB15Bc1N) usually had a thick silt deposit in the bottom, which was likely left over from construction projects and not related to roadway runoff. Ponding also occurred at the location of the AT monitoring runoff at TB15Bc1N, which caused SpC values not associated with runoff to be recorded that could not definitively be identified and removed from the dataset. For these reasons, SpC data from TB15Bc1N are presented in Figure 23 and Appendix D, but were not used for any further analyses in this report.

TB19 Results

As discussed above, TB19 is a dry bioswale with a surface-water outlet and an underdrain outlet. It is the only bioswale studied that has no major point-source inlets. Instead, roadway runoff flowed diffusely into the bioswale over the road shoulder and foreslope. The bioswale at TB19 consists of two outlets: surface water (sw) and an underdrain (gw) (Fig. 24).

At TB19gw, the mean SpC reduction was 70% overall, and the mean annual reductions ranged from 67-82% when compared to TB7Bin. This is almost three times the 25% reduction of TDS calculated from composite samples (Miner et al. 2016) (Table 8). TDS mean percent reductions are lower than SpC due to the differences in methods used in monitoring. As with TB15Bgw, this site may receive some high-TDS groundwater that surrounds the underdrain pipe, but not as much as TB15B because the predicted groundwater flow direction at TB19 is northwestward, away from the site. This allows the underdrain to reflect actual bioswale performance. TB19gw had consistent peak wintertime values at or above 10,000 µS/cm, with the highest peak occurring in Year 3 at 32,443 µS/cm.

TB19sw had an overall 84% mean reduction for the period of record, with annual reductions of 66-98% when compared to TB7Bin. Similar to TB15Bsw, readings only occurred during runoff events that diluted TDS. The mean percent reduction was also similar to the percent reduction of TDS calculated from composite samples (85%). This dry bioswale was also efficient at infiltration, which can be seen by the infrequent events at TB19sw, although it also had some large peaks in Years 2, 3, and 4 after winter storm events when any road salt still sitting on the surface of the bioswale would have entered the bioswale as the snow was melting.

As was discussed for TB15B, the reductions from TB19sw and TB19gw were added together (Table 8 and Appendix E) to determine the overall removal efficiency the bioswale had on reducing SpC relative to TB7Bin. The combined performance of both outlets relative to TB7Bin showed a 67% reduction in SpC over Years 2-5. The results were similar to the reductions calculated for TB19gw, since the volume of discharge at the groundwater exit makes up 90% of the total volume for the bioswale. The combined performance of sw and gw percent reduction of TDS in composite samples was 30% for years 2 through 5 (Table 8). As at TB19gw, this difference in performance is due to differences in monitoring methods.

Comparing Wet and Dry Bioswales

Surface-water outputs at both wet and dry bioswales showed significant reductions in SpC. The highest percent reduction in mean SpC (when compared to TB7Bin) was observed at the surface water output of a wet bioswale: TB7Bout (80%) (Table 7). TB7B works well at infiltrating low-flow, high-TDS events. The dry bioswales (TB15B and TB19) had a combined above average performance (surface-water plus groundwater) of 53% and 67%, respectively. The underdrain at TB15B likely received high-TDS groundwater flowing from under the roadway towards the bioswale, masking its overall removal efficiency at treating runoff. TB19 also likely received some groundwater input, but not as much as TB15B due to the anticipated groundwater flow direction being westward, oblique to the bioswale; otherwise their differences in performance may be attributed to site design or data collection methods. As stated before, TB9A, a wet bioswale, was the lowest performing bioswale, reducing SpC by 23% when compared to TB7Bin, because it did not infiltrate runoff and likely received some groundwater input. This suggests that infiltration and interactions with groundwater are important factors in reducing the amount of SpC in a bioswale. Both wet and dry bioswales, however, performed well at reducing SpC.

Mean percent reductions of TDS measured from composite samples also indicated that the wet bioswale at TB7Bout performed effectively with a 90% reduction for the entire post-construction period (Table 8), probably due to its ability to infiltrate low-flow, high-TDS runoff. The other wet bioswale, TB9A, had the second highest TDS reduction of composite samples at 48%, and the two dry bioswales (TB15B and TB19) were the lowest performing with mean percent reductions of TDS from composite samples of 30% for both sites. TB9A and the dry bioswales did not perform as similarly to the SpC data due to differences in the methods of SpC and TDS data collection. At TB9A, the AT SpC showed a lower performance than the composite sample TDS by about half. We attribute this to the Isco retrieving more of its samples during high-flow, low-TDS events, and then filling the sampling container before low-flow, high-TDS events flowed past, whereas the AT logger had more of its verified readings during low-flow, high-TDS events. The dry bioswales (TB15B and TB19) also did not perform similarly to the SpC data due to differences in SpC and TDS data collection. This is attributed to the same premise as the TB9A data collection.

Bioswale Performance Over Time

Over the five years of the study, both wet and dry bioswales were effective at reducing SpC. TB7B, a wet bioswale, performed slightly better in Years 2 and 3 (98% and 93%) than in Years 4 and 5 (84% and 89%), but over the entire time period had the highest performance (Table 8). Infiltration may have reduced over time due to sediment building up in the bioswale. The other wet bioswale, TB9A, had a slight increase in performance over time, from 26% to 33%. The dry bioswale (TB15B and TB19) trends are not obvious; they had slight decreases in performance in Year 5, but otherwise showed decreases. For TB15B, the largest mean percent reduction in SpC occurred in Years 3 and 4 (71% and 73%), with less reduction in Years 2 and 5 (42% and 56%). For TB19, SpC reduction slightly decreased over time, from 75% to 68%, but the best year for SpC reduction was in Year 4 with an 83% reduction.

The SpC of runoff is dependent on many factors such as (1) the amount of salt application to the roadways in comparison to other years, due to a harsher or milder winter, (2) above or below average precipitation, or the rate and intensity of precipitation (remobilized dissolved solids from soils), (3) the baseline SpC flowing into the bioswales from adjacent groundwater, which is related to groundwater levels, (4) the total flow volume of the bioswale, and (5) the amount of infiltration, especially of low flows. Overall, more analysis would need to be incorporated for all of these variables to evaluate whether changes in percent reductions between years could be attributed to bioswale performance or other factors.

Pre-construction vs. Post-construction Specific Conductivity

Data-logged SpC data were collected at the locations of TB15A and TB19 before the bioswales were constructed. Pre- and post-construction SpC data were collected with different types of instruments with different sensitivities and ranges, so comparisons between the data are not necessarily definitive, although SpC sensors are generally reliable and comparable among manufacturers. We also lacked the level and discharge data collected in post-construction years used to determine validity of the SpC data, which may mean the pre-construction dataset may contain measurements that do not represent actual flows. Mean SpC at TB15A was 7,143 μS/cm and 10,068 μS/cm at TB19 (Table 7). Maxima were 28,641 and 66,192 μS/cm, respectively.

General comparisons show that mean pre-construction SpC at both sites was higher than mean post-construction SpC at the combined surface-water and groundwater outputs of the bioswales once they were constructed (Figure 25 and 26). The pre-construction data at TB19 had much higher peaks and maximum readings than the post-construction data, which indicates the bioswales were effective at lowering peak SpC as well. This suggests that the construction of the dry bioswales caused a reduction in the SpC of runoff as measured at the output both sites, perhaps due to increased infiltration, dilution, or other bioswale functions.

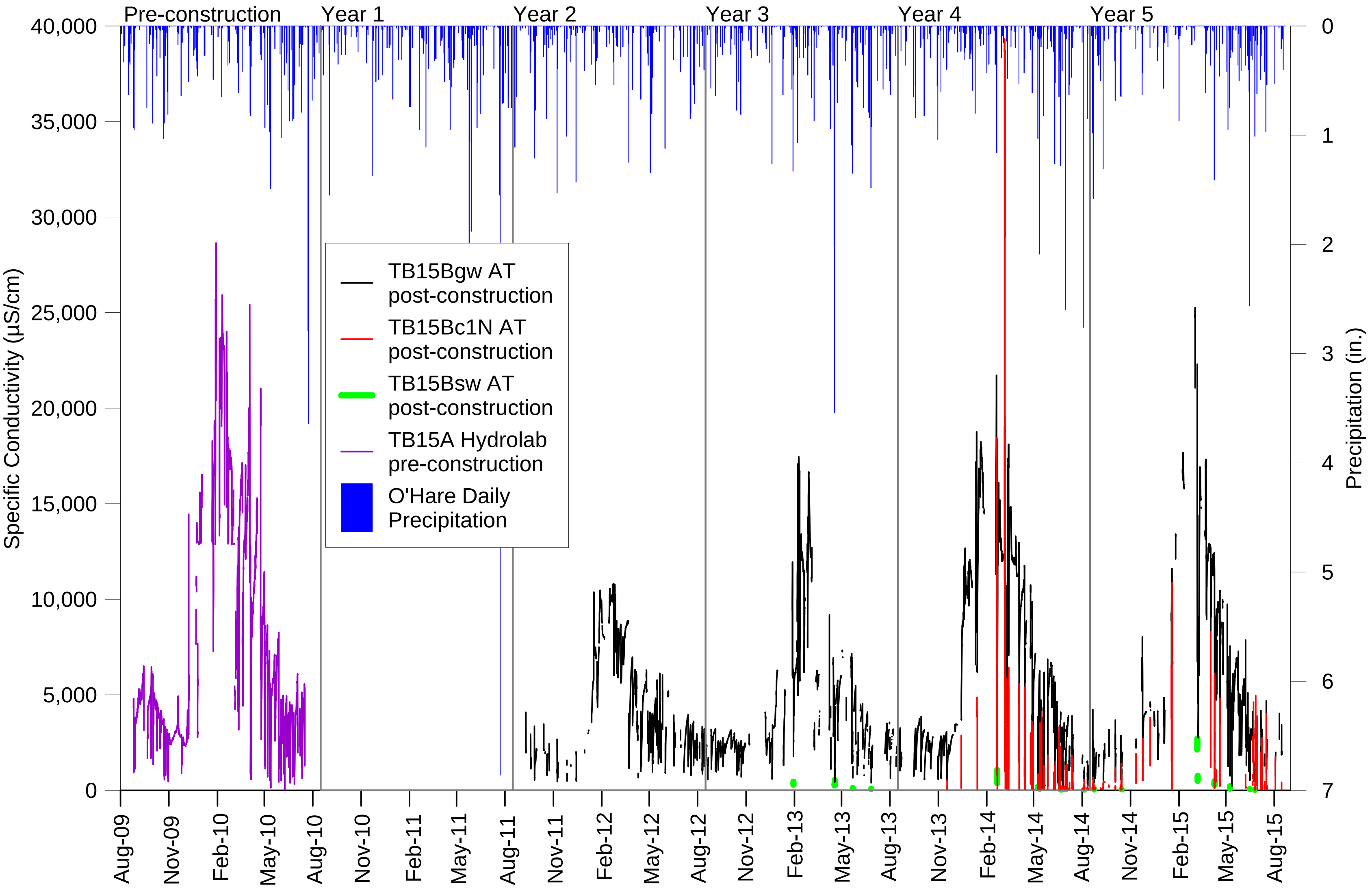

Figure 25. All valid pre- and post-construction SpC data collected at TB15.

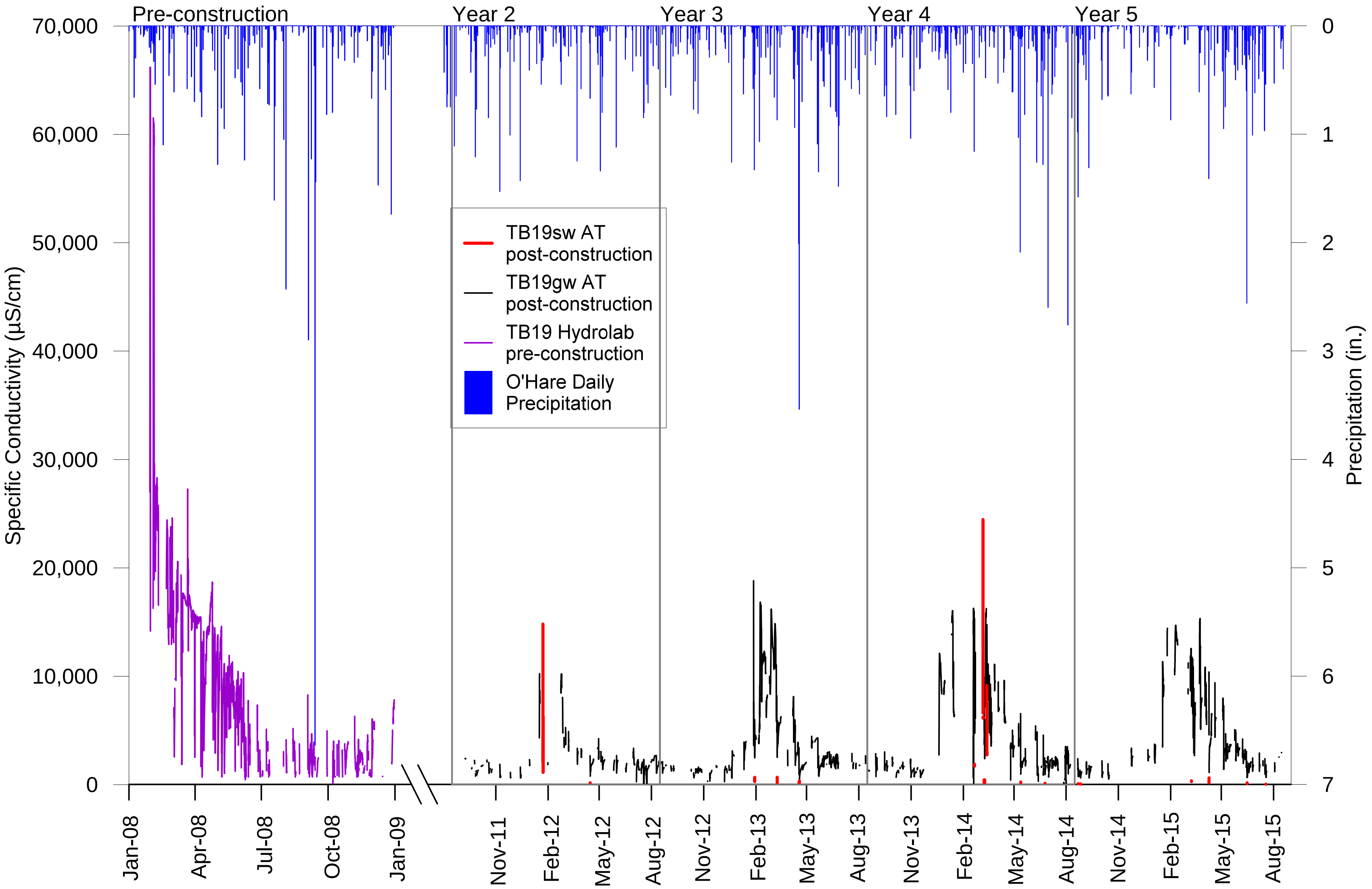

Figure 26. All valid pre- and post-construction SpC data collected at TB19.

Percent Reductions of Specific Conductivity vs. Percent Reductions of TDS

Over the period of record, percent reductions in mean annual SpC (AT data-logged) varied when compared to percent reductions in TDS from composite water samples at TB7B (Table 8). The site with the most similar overall reductions was TB7Bout, with similarity in all years. At TB9A, percent reductions in lab-measured TDS were larger than percent reductions in AT-measured mean SpC, and at TB15B combined (sw+gw) and TB19 combined, SpC reductions were greater than TDS.

The differences in TDS measured from composite samples versus SpC measured by ATs can be accounted for by the difference in monitoring methods. Lab-derived TDS at TB9A was lower than SpC because the Isco sampler measured flow that was too low for the AT to measure. Surface water in the bioswale at TB9A would flow for long periods of time, triggering water sampling by the Isco, but these waters were likely lower in TDS due to the overflow of Farmer's Creek (located at the terminus of the bioswale) into the bioswale. At TB15B and TB19, where the percent mean SpC reduction was higher than the mean percent TDS reduction, it is likely that, although both gw pipes and TB7Bin have almost constant low flows, the flow at the groundwater sites had much longer durations or slightly higher levels, which may have caused the Isco to preferentially sample the higher-TDS groundwater.

Overall, the similarity between SpC reductions and TDS reductions is promising and suggests that for studies on reductions of TDS on long time scales, SpC data loggers could be used as a less expensive and less labor-intensive alternative to collecting and analyzing water samples. Installation locations need to be considered carefully to decrease the amount of error involved due to any site variations.

TOTAL DISSOLVED SOLIDS AND CHLORIDE CALCULATED FROM SPECIFIC CONDUCTIVITY

Models to Calculate Total Dissolved Solids/Chloride from Specific Conductivity

Specific conductivity is strongly related to TDS and chloride, and using SpC to calculate TDS and chloride is useful for determining masses and concentrations of dissolved solids in runoff. We developed relationships of SpC to TDS and SpC to chloride by combining all samples collected from the nine bioswale locations (Equations 1 and 2, Figures 27 and 28). As previously discussed, equations were based on laboratory-measured TDS and field-measured SpC from the flow-composite samples and grab samples (i.e. all surface-water samples).

For all sites, the SpC-TDS relationship was used to calculate a TDS value for every valid SpC reading from each AT. The calculated TDS values were multiplied by discharge measured over the monitored period (presented in Bryant et al. [2016]) to calculate both total mass and standardized concentrations of TDS. The SpC-chloride relationship (Eq. 2, Figure 28) was also used to calculate a chloride value for every valid

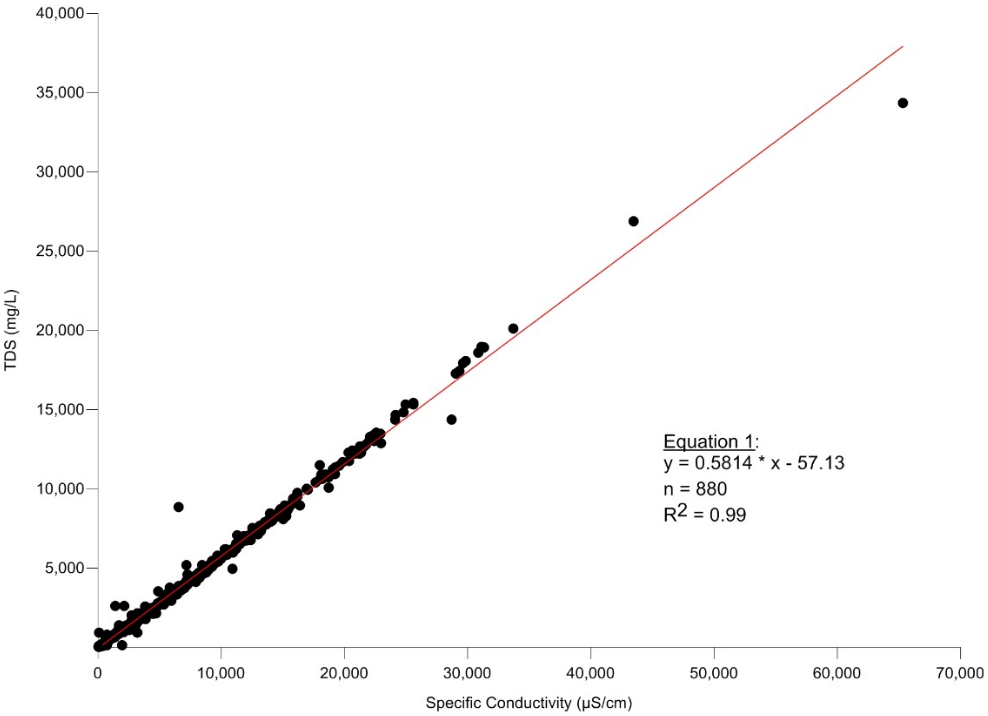

Figure 27. SpC vs. TDS with a linear equation relationship for all surface-water samples.

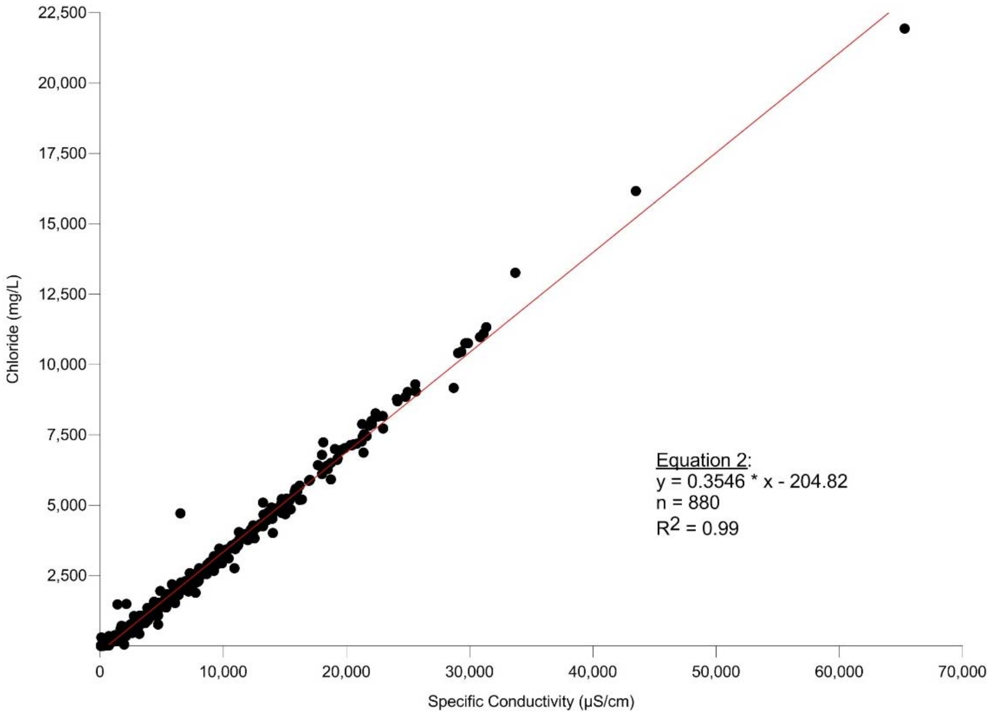

Figure 28. SpC vs. chloride with a linear relationship for all surface-water samples.

SpC reading from the AT at TB7Bin, with total mass and standard concentration determined similar to TDS above (Fig. 29).

Modeled vs. Measured Masses and Reductions

Linear models for TDS and chloride were selected in all cases for consistency and were based on other studies, which found that most SpC-TDS models were linear (Granato and Smith 1999, Paul and Mayer 2008, Watson et al. 2002). The linear R^2 value, 0.99, was also as good or better than other nonlinear relationships (e.g. power, polynomial, etc.). If the SpC-TDS relationship resulted in any negative values of TDS, those values were removed from the overall calculated means or other statistics. For comparison, the masses calculated from the composite water samples and presented in Miner et al. (2016) are also in Table 9. As was done with the SpC data, output locations at all four bioswales were compared to TB7Bin.

Comparisons of the percent reductions calculated using modeled TDS loads and measured TDS loads were close in some cases (TB7Bout, TB9A, TB15Bsw, TB19sw), but not in others (TB15Bgw, TB19gw) (Table 9). Measured percent reductions of TDS for TB15Bgw and TB19gw were about half of those using modeled TDS, suggesting the undercounting of TDS due to high-TDS, low-level flows that were captured by the Isco autosampler, but not by the data-logged data. This is similar to what was seen in the SpC data presented earlier. Low-level base flows were filtered out from AT data but sampled by the Isco, so total load measured by the Iscos were higher. These results are promising and suggest that, after developing a SpC-TDS equation, future studies could be conducted using SpC data loggers instead of autosamplers for TDS. However, some site-specific changes to logger deployment are warranted to capture more low-flow events.

The discrepancies between measured and modeled TDS loads likely can be attributed to error introduced from the way the SpC data is filtered to only include values when levels were greater than 0.065 or 0.147 feet (dependent on vertical or horizontal installation). Composite water samples were taken at every site, whenever the bioswale was flowing, so the samples included times where discharge was lower than the SpC data loggers would measure accurately, when TDS is typically higher because it is not as diluted by runoff. When precipitation events are sufficiently large, the Isco will fill and shut off, missing any other high-TDS, lower-flow discharge that might occur in the rest of a two-week period before field staff collect the sample and restart the Isco; this error additionally caused modeled percent reductions of TDS to be higher than lab-measured reductions of TDS. Other problems that may have occurred when comparing modeled and measured TDS and chloride values include: the SpC data loggers drifting out of calibration, or Isco sampling hoses freezing in the winter thus preventing the collection of samples (Fig. 29).

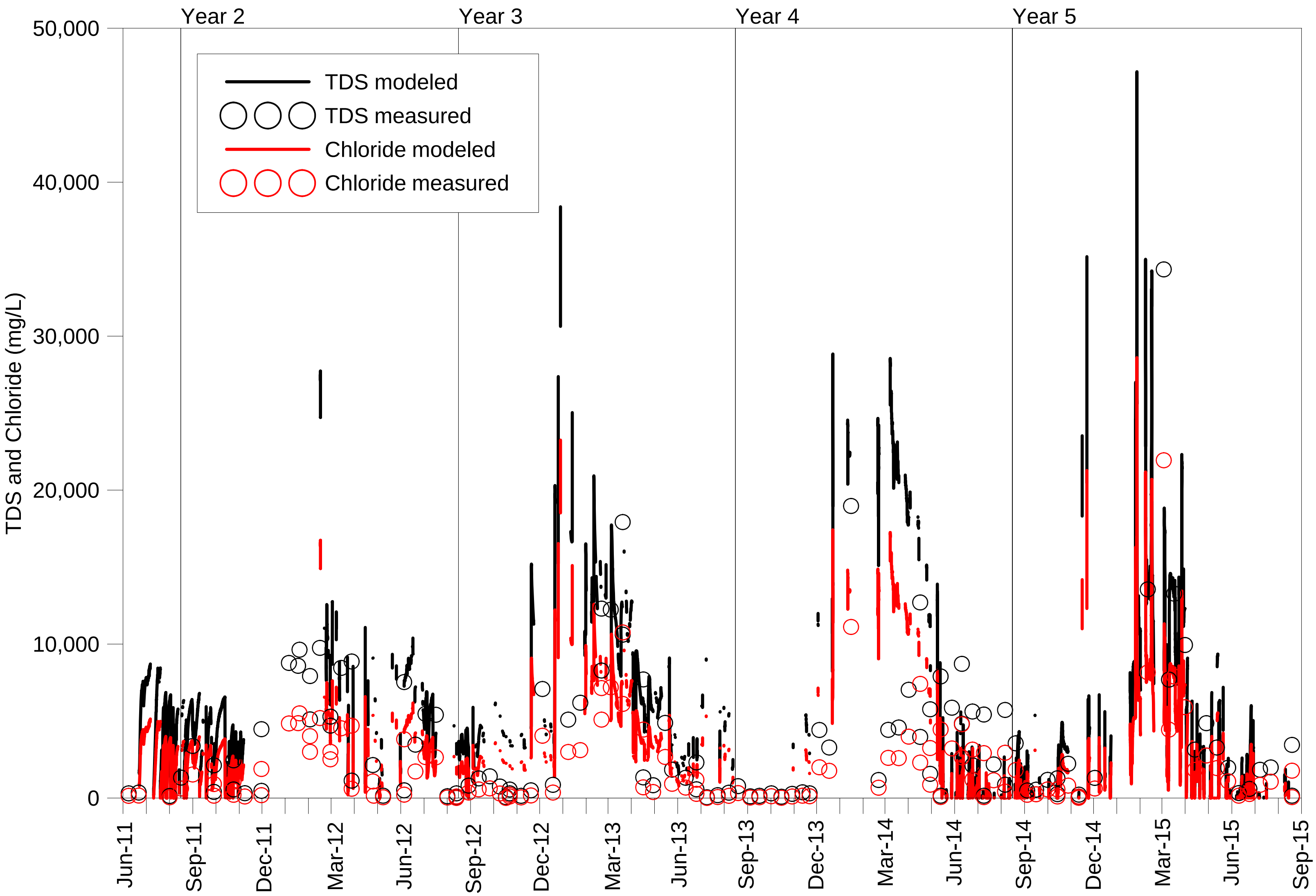

Figure 29. Modeled and measured TDS and chloride concentrations for TB7Bin.

Table 9. Masses and standardized concentrations of TDS from composite samples and TDS modeled from SpC values.

	Lab: Total TDS load (kg)	Model: Total TDS load (kg)	Lab: Standardized concentration (mg/L)	Model: Standardized concentration (mg/L)	Lab: TDS percent reduction vs. TB7Bin**	Model: TDS percent reduction vs. TB7Bin**
TB7Bin						
Year 1*	8,720.0	1,431.3	1,583.8	929.1		
Year 2	9,640.0	5,229.5	2,448.9	1,328.5		
Year 3	25,800.0	9,523.0	5,297.2	1,955.2		
Year 4	18,100.0	56,093.5	3,531.5	10,944.3		
Year 5^	16,600.0	6,812.4	3,388.6	1,390.6		
Years 1 - 5	**78,860.0**	**79,089.7**	**3,240.4**	**3,882.3**		
TB7Bout						
Year 2*	1,550.0	0.3			83.9	100.0
Year 3	956.0	114.6			96.3	98.8
Year 4	3,980.0	2,605.8			78.0	95.4
Year 5	1,490.0	984.6			91.0	85.5
Years 2 - 5	**7,976.0**	**3,705.3**			**89.9**	**95.3**
TB9A						
Year 1*	10,500.0	4,743.8	565.8	804.1	64.3	13.4
Year 2	42,000.0	21,214.9	1,327.7	670.7	45.8	49.5
Year 3	56,100.0	26,078.3	1,286.5	599.8	75.7	69.3
Year 4	88,400.0	129,284.2	2,691.2	3,926.9	23.8	64.1
Year 5	67,000.0	82,294.6	2,319.7	2,862.4	31.5	-105.8
Years 1 - 5	**264,000.0**	**263,615.8**	**1,697.4**	**1,847.5**	**47.6**	**52.4**
TB15Bgw						
Year 2	29,100.0	7,025.6	2,025.2	488.9	17.3	63.2
Year 3	32,700.0	7,846.3	1,752.3	420.5	66.9	78.5
Year 4	68,900.0	48,953.7	3,111.5	2,210.7	11.9	79.8
Year 5	34,400.0	30,317.4	2,705.6	2,384.5	20.2	-71.5
Years 1 - 5	**165,100.0**	**94,143.0**	**2,431.9**	**1,386.7**	**24.9**	**64.3**
TB15Bsw						
Year 1*	86.3	0.8	67.0	0.6	95.8	99.9
Year 2	77.3	ND[1]	539.2	ND	78.0	ND
Year 3	311.0	38.9	156.9	19.6	97.0	99.0
Year 4	444.0	76.0	347.7	59.5	90.2	99.5
Year 5	1,070.0	96.1	1,238.9	111.3	63.4	92.0
Years 1 - 5	**1,988.6**	**211.8**	**358.0**	**49.6**	**89.0**	**98.7**
TB19gw						
Year 2	10,100.0	2,065.8	1,228.5	251.3	49.8	81.1
Year 3	42,600.0	10,374.9	2,938.3	715.6	44.5	63.4
Year 4	36,600.0	29,288.9	3,041.2	2,433.7	13.9	77.8
Year 5	17,300.0	14,816.4	1,958.2	1,677.0	42.2	-20.6
Years 2 - 5	**106,600.0**	**56,546.0**	**2,445.6**	**1,297.2**	**24.5**	**66.6**
TB19sw						
Year 2	31.4	56.5	143.4	258.0	94.1	80.6
Year 3	366.0	32.3	198.2	17.5	96.3	99.1
Year 4	1,750.0	725.1	793.3	328.7	77.5	97.0
Year 5	99.6	16.7	254.9	42.7	92.5	96.9
Years 2 - 5	**2,247.0**	**830.6**	**482.0**	**178.2**	**85.1**	**95.4**

*At TB7Bin, TB9A, and TB15Bsw, Year 1 was only monitored with dataloggers for part of the year (June through August). And at TB7Bout, Year 2 was only monitored for part of the year (May through August). Samples were collected through the entire year.

**Percent reduction calculations use mass for TB7B and standardized concentrations for all others.

^Loads of TDS in Year 5 at TB7Bin were affected by the lack of winter discharge measurments due to a malfunctioning Isco. Loads are much lower than expected.

[1] no data

Shades of green indicate percent reductions >0, shades of yellow indicate percent increases 1 to 25%, and shades of red indicate percent increases >25%.

CONCLUSIONS

Turbidity data collected over four years at seven different bioswale sites showed that both dry and wet bioswales reduced turbidity in roadway runoff. Turbidity tended to increase in spring and summer, with more intense precipitation, and decrease in the winter. Mean turbidity reductions relative to TB7Bin ranged from 35% to 76% at all outputs except the surface-water exits from the dry bioswales. At wet bioswales, the primary mechanisms for reducing turbidity were ponding and retention of surface-water for long periods of time. At dry bioswales, infiltration was the primary mechanism for reducing turbidity. Percent reductions in turbidity often closely matched percent reductions of TSS measured from flow-integrated composite water samples. Both wet and dry bioswales, therefore, performed well at reducing turbidity, with wet bioswales performing slightly better over Years 2-5. Surface-water exits did not show a reduction in turbidity due to sparse vegetative cover and erosion within the bioswale, however flow at these exits was infrequent, so these results were negligible when considering the overall removal efficiency of the bioswales.

Dry bioswales performed slightly better at reducing turbidity at the groundwater outputs in the last two years of monitoring than in the first two years, suggesting improvements due to vegetation establishment. There was no clear improvement over time at wet bioswales or at the surface-water outputs of dry bioswales. Mean turbidity at TB15B decreased from 106 NTU before bioswale construction to 51 NTU after construction. At TB19, mean turbidity decreased from 77 NTU before construction to 73 NTU post-construction. The pre-construction turbidity data had much higher peaks and maximum readings than the post-construction data, indicating the bioswales were effective at lowering peak turbidity. In general, percent reductions of mean turbidity were less than percent reductions of TSS calculated from water samples. This is likely because the turbidity data loggers took readings every 15 minutes regardless of the amount of flow at the site, and the majority of readings in the resulting datasets were therefore recorded during low-flow conditions and not solely during precipitation events that would have influenced the annual turbidity means.

We found that site-specific data could be used to model measurements of TSS from turbidity data loggers. The best correlations between turbidity and TSS were at TB15Bsw and TB7Bout. At TB15Bgw and TB19gw, there was no clear correlation between TSS and turbidity although relationships were noted. Modeled TSS loads were generally similar to TSS loads calculated using measured water samples when considering the entire period of record, though there were frequent discrepancies in individual years. In future studies, turbidity loggers could replace water sampling as a less expensive and less labor-intensive method of monitoring TSS concentrations and loads for long-duration monitoring, although site-specific conditions need to be considered.

Mean SpC reductions relative to TB7Bin ranged from 23% to 97% at all outputs. At wet bioswales, the primary mechanisms for reducing SpC were dilution during precipitation events, attenuation, infiltration, interaction with plants and other biota, or adsorption.

TB9A, however, did not do as well as the other wet bioswale, TB7B, at reducing SpC, because the site likely did not support infiltration but instead had groundwater input, and due to differences in monitoring methods. At dry bioswales, infiltration along with the attendant attenuation and dilution were the primary mechanisms for reducing SpC at surface-water outputs. Groundwater interactions, adsorption, or differences in sampling and logger placement are likely the primary causes for reducing SpC in groundwater outlet pipes. Percent reductions of TDS concentrations measured from flow-integrated composite water samples did not match percent reductions in SpC datalogger concentrations: they were similar at TB7Bout, were double at TB15B combined and TB19 combined, and about half at TB9A.

SpC data collected over four years or more of the post-construction time period suggest that both dry and wet bioswales are effective at reducing SpC in roadway runoff, and that the wet bioswale TB7B was the most efficient, likely due to infiltration of runoff. Bioswale performance at reducing SpC declined over time at TB7B, likely due to a larger amount of salt applied in Years 4 and 5 due to many snowfall events and lower temperatures or infiltration rates decreasing as sediment built up in the bioswale. The other bioswales either had slight increases in performance over time (TB9A) or performed consistently (both dry bioswales). Post-construction SpC values were generally lower than pre-construction at TB15 and TB19, showing that the bioswales offset any increase in TDS caused by the constructed additional roadway area.

We found that a region-specific model between SpC and TDS could be used to model measurements of TDS. Although the linear regression had a very good fit (R^2=0.99), it calculated higher modeled TDS mean percent reductions than lab measured mean percent reductions of TDS by 5% to 31%, possibly due to the decrease in fit when SpC values were over approximately 20,000 µS/cm. The percent reductions in Year 5 were affected by the lack of winter discharge measurements at TB7Bin due to a malfunctioning Isco, which had an affect on the calculated TDS loads. The differences in TDS measured from composite water samples versus SpC measured by ATs can be accounted for by the difference in methods. Overall, the similarities between SpC reductions and TDS reductions are promising and suggests that for studies on reductions of TDS on long time scales, SpC data loggers could be used as a less expensive and less labor-intensive alternative to collecting and analyzing water samples. Installation locations need to be considered carefully to decrease the amount of error involved due to any site variations.

FUTURE WORK

Monitoring of selected bioswales with turbidity and SpC data loggers will continue through 2019 in order to confirm and follow trends over a longer period of time. No additional water samples will be collected.

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APPENDIX A. Comprehensive summary of data-logged turbidity. Statistical values in NTUs.

	Number of Readings	Minimum	1st quartile	Median	Mean	3rd quartile	Max	Percent Reduction (mean) vs. TB7Bin	Percent Reduction (median) vs. TB7Bin
TB7Bin									
Year 2*	369	0.9	29.8	51.9	85.9	100.2	819.1		
Year 3	560	10.8	33.7	59.1	117.0	108.9	1,301.4		
Year 4	2,149	0.9	6.2	33.9	100.5	94.2	1,909.2		
Year 5	856	0.3	9.5	22.0	145.6	88.3	2,063.4		
Years 2-5	**3,934**	**0.3**	**12.0**	**38.4**	**111.3**	**97.0**	**2,063.4**		
TB7Bout									
Year 1	583	6.0	17.2	32.2	60.6	72.7	771.9	ND[1]	ND
Year 2	1,059	0.7	15.3	21.6	34.2	38.6	680.1	60.3	58.4
Year 3	144	0.8	23.7	31.4	52.4	58.6	472.1	55.2	46.8
Year 4	712	4.3	18.6	29.0	94.5	55.6	2,322.4	5.9	14.5
Year 5	407	6.5	14.0	18.7	39.6	26.6	1,647.0	72.8	14.8
Years 1-5	**2,905**	**0.7**	**16.1**	**24.2**	**55.9**	**47.7**	**2,322.4**	**49.7**	**37.0**
TB9Ac2N									
Year 4	736	1.1	3.6	5.4	18.7	15.7	607.8	81.4	84.1
Year 5	442	0.1	6.0	27.4	209.7	187.2	2,238.0	-44.0	-24.8
Years 4-5	**1,178**	**0.1**	**4.1**	**8.8**	**90.4**	**31.9**	**2,238.0**	**18.8**	**77.1**
TB9A									
Year 2*	1,750	0.1	1.6	5.7	13.3	14.6	501.1	84.5	53.8
Year 3	3,382	0.1	4.8	10.1	33.2	22.0	1,867.0	71.6	41.9
Year 4	2,644	0.1	5.8	13.3	36.4	25.6	1,154.5	63.8	20.5
Year 5	3,209	0.1	2.7	9.2	17.5	15.5	531.3	87.9	8.8
Years 2-5	**10,985**	**0.1**	**3.7**	**9.7**	**26.2**	**19.6**	**1,867.0**	**76.4**	**25.8**
TB15Bc1N									
Year 4	1,334	0.3	11.5	29.5	151.2	109.7	1,761.5	-50.5	13.0
Year 5	1,085	0.1	2.8	13.1	94.8	89.0	1,777.4	34.9	40.3
Years 4-5	**2,419**	**0.1**	**6.1**	**23.3**	**125.9**	**101.6**	**1,777.4**	**-13.1**	**39.3**
TB15Bgw									
Year 2*	4,150	0.6	6.6	19.7	47.6	63.9	727.7	44.6	62.0
Year 3	5,837	0.4	7.6	14.2	40.9	34.4	1,474.6	65.0	-165.0
Year 4	12,184	0.1	2.5	6.1	21.7	23.8	612.5	78.4	-568.6
Year 5	4,914	0.1	4.4	12.0	43.6	33.9	1,111.9	70.0	92.7
Years 2-5	**27,085**	**0.1**	**4.2**	**10.4**	**33.8**	**33.0**	**1,474.6**	**69.6**	**72.9**
TB15Bsw									
Year 2*	18	240.3	646.3	1,901.8	1,622.4	2,451.3	2,558.4	-1,788.0	-3,564.4
Year 3	18	14.4	22.2	31.6	61.1	45.3	504.8	47.8	46.5
Year 4	60	2.1	28.6	47.0	120.6	108.7	730.2	-20.0	-38.6
Year 5	69	5.5	45.5	46.3	165.8	247.5	1,068.0	-13.9	-110.9
Years 2-5	**165**	**2.1**	**36.0**	**48.6**	**296.9**	**259.4**	**2,558.4**	**-166.8**	**-26.6**
TB19gw									
Year 2*	2,901	0.7	18.2	42.5	89.2	109.7	994.9	-3.8	18.1
Year 3	2,094	0.2	15.4	30.5	65.5	70.4	688.8	44.0	48.4
Year 4	4,332	0.7	19.4	46.7	75.5	95.4	713.0	24.9	-37.6
Year 5	3,966	0.7	13.6	36.1	51.5	69.5	536.4	64.7	-64.5
Years 2-5	**13,293**	**0.2**	**16.5**	**39.1**	**69.7**	**85.1**	**994.9**	**37.3**	**-1.8**
TB19sw									
Year 2*	42	52.6	72.5	82.5	124.5	152.6	543.4	-44.9	-58.9
Year 3	14	64.5	114.3	156.5	146.6	180.4	217.0	-25.3	-165.0
Year 4	126	0.1	85.6	226.7	202.0	237.1	918.9	-101.0	-568.6
Year 5	199	1.0	1.3	1.6	28.5	31.2	265.0	80.4	92.7
Years 2-5	**381**	**0.1**	**1.5**	**55.2**	**101.6**	**189.2**	**918.9**	**8.7**	**-43.8**
TB15A									
Pre-construction	4,340	2.1	7.9	19.6	105.5	76.5	2,946.0		
TB19									
Pre-construction	2,375	2.1	13.6	29.1	76.5	60.7	2,506.0		

*At TB9, TB15B, TB19, and TB7Bin, Year 2 was only monitored with dataloggers for part of the year (March through August).

[1] no data

Shades of green indicate percent reductions >0, shades of yellow indicate percent increases 1 to 25%, and shades of red indicate percent increases

APPENDIX B. Calculations for determining combined effects of groundwater and surface-water outputs at dry bioswales.

	Mean Turbidity (NTU)	Discharge (ft^3) from time period that FTS was deployed	Turbidity x Volume (FTS) (used to calculate TB15 and TB19 sums) (NTU/ft^3)	Mean turbidity reduction vs TB7Bin (%)	Lab calculated TSS (kg)	Discharge (ft^3) for time period that samples were collected	TSS x Volume (samples) (kg/ft)	Lab measured TSS Standardized concentration (kg/L)	Lab measured TSS reduction vs TB7Bin (%)	Percent Reduction of Mean Turbidity Pre vs Post at same site	Percent of total discharge for bioswale
TB7Bin											
Year 2	85.9				316.0	139,013		80.3			
Year 3	117.0				319.0	172,000		65.5			
Year 4	100.5				846.0	181,000		165.1			
Year 5	145.6				448.0	173,000		91.5			
Years 2-5	**111.3**				**1,929.0**	**665,013**		**102.4**			
TB15Bgw											
Year 2	47.6	290,587	13,827,971	44.6	157.0	507,445	79,668,865	10.9	86.4		99.3
Year 3	40.9	658,619	26,930,239	65.0	408.0	659,000	268,872,000	21.9	66.6		90.4
Year 4	21.7	781,919	16,998,402	78.4	238.0	782,000	186,116,000	10.7	93.5		94.5
Year 5	43.6	448,834	19,589,312	70.0	228.0	449,000	102,372,000	17.9	80.4		93.6
Years 2-5	**33.8**	**2,179,959**	**73,684,401**	**69.6**	**1,031.0**	**2,397,445**	**2,471,765,795**	**15.2**	**85.2**		**93.7**
TB15Bsw											
Year 2	1,622.4	1,931	3,132,833	-1,788.0	81.9	5,036	412,448	574.3	-615.4		0.7
Year 3	61.1	70,028	4,278,711	47.8	266.0	70,000	18,620,000	134.2	-104.9		9.6
Year 4	120.6	45,080	5,436,949	-20.0	144.0	45,100	6,494,400	112.8	31.7		5.5
Year 5	165.8	30,527	5,062,660	-13.9	118.0	30,500	3,599,000	136.6	-49.4		6.4
Years 2-5	**296.9**	**147,566**	**43,806,800**	**-166.8**	**609.9**	**150,636**	**91,872,896**	**143.0**	**-39.6**		**6.3**
TB15Bsw+TB15Bgw											
Year 2	58.0	292,518		32.5	238.9	512,481		16.5	79.5		
Year 3	42.8	728,647		63.4	674.0	729,000		32.7	50.1		
Year 4	27.1	826,999		73.0	382.0	827,100		16.3	90.1		
Year 5	51.4	479,361		64.7	346.0	479,500		25.5	72.1		
Years 2-5	**50.5**	**2,327,525**		**54.6**	**1,640.9**	**2,548,081**		**22.7**	**77.8**		
TB19gw											
Year 2	89.2	216,050	19,267,534	-3.8	145.0	290,339	42,099,155	17.6	78.0		98.7
Year 3	65.5	511,701	33,507,618	44.0	272.0	512,000	139,264,000	18.8	71.4		88.7
Year 4	75.5	425,235	32,101,846	24.9	515.0	425,000	218,875,000	42.8	74.1		84.5
Year 5	51.5	311,862	16,048,705	64.7	124.0	312,000	38,688,000	14.0	84.7		95.8
Years 2-5	**69.7**	**1,464,848**	**102,148,183**	**37.3**	**1,056.0**	**1,539,339**	**1,625,541,984**	**24.2**	**76.4**		**90.2**
TB19sw											
Year 2	124.5	2,911	362,558	-44.9	24.7	7,734	191,030	112.8	-40.5		1.3
Year 3	146.6	65,164	9,552,732	-25.3	164.0	65,200	10,692,800	88.8	-35.6		11.3
Year 4	202.0	77,871	15,726,419	-101.0	210.0	77,900	16,359,000	95.2	42.3		15.5
Year 5	28.5	13,781	392,288	80.4	37.4	13,800	516,120	95.7	-4.7		4.2
Years 2-5	**101.6**	**159,727**	**16,228,140**	**8.7**	**436.1**	**164,634**	**71,796,887**	**93.5**	**8.7**		**9.8**
TB19sw+TB19gw											
Year 2	89.7	218,961		-4.3	169.7	298,073		20.1	75.0		
Year 3	74.6	576,865		36.2	436.0	577,200		26.7	59.3		
Year 4	95.1	503,106		5.4	725.0	502,900		50.9	69.2		
Year 5	50.5	325,643		65.3	161.4	325,800		17.5	80.9		
Years 2-5	**72.9**	**1,624,575**		**34.5**	**1,492.1**	**1,703,973**		**30.9**	**69.8**		
TB15A											
Pre-construction	105.5									52.2	
TB19											
Pre-construction	76.5									4.8	

*Percent reduction calculations use mass for TB7B and standardized concentrations for all others.
**Water sample data presented in Miner et al. 2016.
Shades of green indicate percent reductions >0, shades of yellow indicate percent increases 1 to 25%, and shades of red indicate percent increases >25%.
Mean turbidity for groundwater and surface-water sites combined calculated with equation [(TurbGW*VolGW)+(TurbSW*VolSW)]/(VolGW+VolSW)

APPENDIX C. Calculations for lab and modeled TSS standardized concentrations and percent reductions.

	Lab: Total TSS load (kg)	Model: Total TSS load (kg)	Discharge (ft^3) for time period that FTS was deployed	Discharge (ft^3) for time that flow-composite samples were collected	Volume (L) for time period that FTS was deployed	Volume (L) for time that flow-composite samples were collected	Lab: Standardized concentration (mg/L)	Model: Standardized concentration (mg/L)	Lab: TSS percent reduction vs. TB7Bin**	Model: TSS percent reduction vs. TB7Bin**
TB7Bin										
Year 2*	316.0	126.8	71,996	139,013	2,543	4,909	80.3	62.2		
Year 3	319.0	252.1	172,263	172,000	6,083	6,074	65.5	51.7		
Year 4	846.0	1,261.9	181,307	181,000	6,403	6,392	165.1	245.8		
Year 5	448.0	421.2	172,649	173,000	6,097	6,109	91.5	86.2		
Years 2 - 5	**1,929.0**	**2,062.0**	598,215	665,013	21,126	23,485	**102.4**	**121.7**		
TB7Bout										
Year 1		145.9								
Year 2*	82.8	95.8	74,696	74,696	2,638	2,638			73.8	24.4
Year 3	149.0	41.3	52,932	52,900	1,869	1,868			53.3	83.6
Year 4	141.0	278.2	126,661	127,000	4,473	4,485			83.3	78.0
Year 5	73.8	54.2	107,297	107,000	3,789	3,779			83.5	87.1
Years 2 - 5	**446.6**	**469.5**	361,586	361,596	12,769	12,770			**76.8**	**77.2**
TB9A										
Year 2*	467.0	259.8	304,831	1,117,117	10,765	39,451	14.8	30.1	81.6	51.6
Year 3	2,290.0	1,884.5	1,535,549	1,540,000	54,227	54,385	52.5	43.3	19.8	16.1
Year 4	547.0	1,408.9	1,162,656	1,160,000	41,059	40,965	16.7	42.8	89.9	82.6
Year 5	1,140.0	441.0	1,015,308	1,020,000	35,855	36,021	39.5	15.3	56.8	82.2
Years 2 - 5	**4,444.0**	**3,994.2**	4,018,344	4,837,117	141,907	170,821	**32.4**	**35.1**	**68.3**	**71.2**
TB15Bsw										
Year 2*	81.9	24.2	1,931	5,063	68	179	571.3	442.6	-611.6	-611.6
Year 3	266.0	23.8	70,028	70,000	2,473	2,472	134.2	12.0	-104.9	76.8
Year 4	144.0	101.6	45,080	45,100	1,592	1,593	112.8	79.6	31.7	67.6
Year 5	118.0	80.2	30,527	30,500	1,078	1,077	136.6	92.8	-49.4	-7.7
Years 2 - 5	**609.9**	**229.8**	147,566	150,663	5,211	5,321	**143.0**	**55.0**	**-39.6**	**54.8**
TB19sw										
Year 2*	24.7	9.4	2,911	7,734	103	273	112.9	114.0	-40.7	-83.3
Year 3	164.0	62.2	65,164	65,200	2,301	2,303	88.8	33.7	-35.6	34.8
Year 4	210.0	207.3	77,871	77,900	2,750	2,751	95.2	94.0	42.3	61.8
Year 5	37.4	107.1	13,781	13,800	487	487	95.7	274.5	-4.7	-218.6
Years 2 - 5	**436.1**	**386.0**	159,727	164,634	5,641	5,814	**93.6**	**85.3**	**8.7**	**29.9**

*At TB9, TB15B, TB19, and TB7Bin, Year 2 was only monitored with dataloggers for part of the year (March through August). Samples were collected through the entire year.

**Percent reduction calculations use mass for TB7B and standardized concentrations for all others.

Shades of green indicate percent reductions >0, shades of yellow indicate percent increases 1 to 25%, and shades of red indicate percent increases >25%.

APPENDIX D. Comprehensive summary of data-logged SpC.

	Number of Readings	Minimum	1st quartile	Median	Mean	3rd quartile	Max	Percent Reduction (mean) vs. TB7Bin	Percent Reduction (median) vs. TB7Bin
TB7Bin									
Year 1	1,084	100.2	5,429.8	9,759.1	8,939.5	12,569.8	15,087.4		
Year 2	2,559	77.7	5,142.2	7,855.6	8,365.7	10,762.7	47,805.6		
Year 3	2,462	518.1	6,916.9	11,000.8	13,276.8	19,755.7	66,161.3		
Year 4	2,468	29.2	5,541.8	33,358.2	24,851.5	37,815.3	49,703.7		
Year 5	8,528	12.3	5,318.3	12,812.1	13,149.1	21,391.4	81,230.8		
Years 1-5	**17,101**	12.3	5,607.0	10,655.0	13,873.8	21,209.0	81,230.8		
TB7Bout									
Year 2	4	119.2	140.3	156.4	157.3	173.4	197.0	98.1	98.0
Year 3	110	48.7	249.7	436.3	909.2	1,009.3	5,851.0	93.2	96.0
Year 4	1,404	62.8	636.6	1,910.5	3,905.4	4,943.8	23,973.0	84.3	94.3
Year 5	1,025	23.2	438.9	814.3	1,434.3	1,025.0	10,420.2	89.1	93.6
Years 2-5	**2,543**	23.2	502.3	1,107.8	2,773.9	3,435.9	23,973.0	80.0	89.6
TB9A									
Year 1	260	237.5	5,528.0	6,480.1	6,658.5	8,729.9	12,125.4	25.5	33.6
Year 2	2,041	87.6	3,904.1	7,897.2	7,120.7	10,177.8	20,994.6	14.9	-0.5
Year 3	636	179.0	1,937.6	8,206.6	9,286.0	16,236.4	24,404.3	30.1	25.4
Year 4	2,071	208.4	8,523.5	16,640.0	17,139.4	24,047.2	37,487.5	31.0	50.1
Year 5	2,282	1,370.8	4,630.2	7,240.9	8,768.3	12,528.8	20,891.3	33.3	43.5
Years 1-5	**7,290**	87.6	4,752.8	8,988.3	10,655.1	15,242.3	37,487.5	23.2	15.6
TB9Ac2N									
Year 4	928	55.1	9,779.1	18,928.6	16,325.4	21,638.7	45,401.2	34.3	43.3
Year 5	395	20.2	148.9	591.5	4,224.6	2,537.1	73,293.3	67.9	95.4
Years 3-4	**1,323**	20.2	1,096.2	12,683.7	12,712.6	20,450.2	73,293.3	8.4	-19.0
TB15Bgw									
Year 2	3,701	468.5	2,482.6	4,158.0	4,894.0	7,341.1	10,809.8	41.5	47.1
Year 3	4,331	396.7	2,217.2	2,827.7	4,294.0	5,173.6	17,456.1	67.7	74.3
Year 4	12,955	3.3	2,678.8	5,582.5	6,987.7	11,581.7	21,710.6	71.9	83.3
Year 5	10,003	222.5	2,453.8	4,823.2	6,147.5	9,053.5	25,260.0	53.2	62.4
Years 2-5	**30,990**	3.3	2,439.5	4,557.6	6,090.0	9,679.5	25,260.0	56.1	57.2
TB15Bsw									
Year 1	7	26.2	62.0	81.2	102.0	93.4	295.5	98.9	99.2
Year 2	0	ND[1]	ND	ND	ND	ND	ND	ND	ND
Year 3	14	75.1	111.9	268.0	261.2	345.0	535.5	98.0	97.6
Year 4	48	11.3	78.1	128.8	313.0	541.9	1,067.3	98.7	99.6
Year 5	35	35.7	75.9	284.9	696.2	579.5	2,719.0	94.7	97.8
Years 1-5	**104**	11.3	78.8	147.8	420.8	465.3	2,719.0	97.0	98.6
TB15Bc1N									
Year 4	872	2.7	91.0	794.6	3,031.0	2,901.7	39,312.5	87.8	97.6
Year 5	425	20.1	110.5	265.7	894.3	743.7	10,885.4	93.2	97.9
Years 4-5	**1,297**	2.7	100.8	484.3	2,330.8	2,126.8	39,312.5	83.2	95.5
TB19gw									
Year 2	1,692	66.6	1,434.3	1,789.9	2,053.7	2,161.1	10,229.7	75.5	77.2
Year 3	3,325	268.4	1,543.2	2,425.9	4,102.0	4,551.0	32,443.2	69.1	77.9
Year 4	7,850	26.3	1,650.8	2,343.5	4,505.0	6,915.4	16,273.6	81.9	93.0
Year 5	8,655	494.7	1,627.0	2,995.5	4,346.4	6,071.1	15,328.3	66.9	76.6
Years 2-5	**21,522**	26.3	1,593.3	2,548.0	4,186.2	5,902.4	32,443.2	69.8	76.1
TB19sw									
Year 2	12	45.4	137.1	1,612.6	2,864.3	2,936.3	14,810.1	65.8	79.5
Year 3	17	143.1	160.7	271.4	1,341.1	654.3	16,580.8	89.9	97.5
Year 4	84	52.2	119.4	362.7	3,004.4	6,137.8	24,456.5	87.9	98.9
Year 5	28	29.1	82.4	139.4	208.6	311.7	635.0	98.4	98.9
Years 2-5	**141**	29.1	106.1	288.5	2,236.7	1,703.3	24,456.5	83.9	97.3
TB15A									
Pre-construction	6,000	32.7	3,132.0	4,745.5	7,143.0	9,733.0	28,641.0		
TB19									
Pre-construction	3,688	88.5	3,159.5	8,559.0	10,068.4	15,359.3	66,192.0		

[1] no data

Shades of green indicate percent reductions >0, shades of yellow indicate percent increases 1 to 25%, and shades of red indicate percent increases >25%.

APPENDIX E. Calculations for determining combined effects of groundwater and surface-water outputs at dry bioswales.

	Mean SpC (µS/cm)	Discharge (ft^3) from time period that AquaTROLL was deployed	SpC x Volume (AT) (used to calculate TB15B and TB19 sums) (µS/cm/ft^3)	Mean SpC reduction vs TB7Bin (%)	Lab calculated TDS (kg)	Discharge (ft^3) for time period that samples were collected	TDS x Volume (samples) (kg/ft^3)	Lab measured TDS Standardized concentration (kg/L)	Lab measured TDS reduction vs TB7Bin (%)	Percent Reduction of Mean TDS Pre vs Post at same site	Percent of total discharge for bioswale
TB7Bin											
Year 1	8,939.5				8,720.0	194,432		1583.8			
Year 2	8,365.7				9,640.0	139,013		2448.9			
Year 3	13,276.8				25,800.0	172,000		5297.2			
Year 4	24,851.5				18,100.0	181,000		3531.5			
Year 5	13,149.1				16,600.0	173,000		3388.6			
Years 1-5	**13,873.8**				**78,860.0**	**859,445**		**3240.4**			
TB15Bgw											
Year 2	4,894.0	507,445	2,483,460,559	41.5	29,100.0	507,445	14,766,649,500	2025.2	17.3		99.0
Year 3	4,294.0	659,000	2,829,739,796	67.7	32,700.0	659,000	21,549,300,000	1752.3	66.9		90.4
Year 4	6,987.7	782,000	5,464,349,447	71.9	68,900.0	782,000	53,879,800,000	3111.5	11.9		94.5
Year 5	6,147.5	449,000	2,760,207,050	53.2	34,400.0	449,000	15,445,600,000	2705.6	20.2		93.6
Years 2-5	**6,090.0**	**2,397,445**	**14,600,374,962**	**56.1**	**165,100.0**	**2,397,445**	**395,818,169,500**	**2431.9**	**24.9**		**92.4**
TB15Bsw											
Year 1	102.0	45,502	4,639,325	98.9	86.3	45,502	3,926,823	67.0	95.8		
Year 2	ND[1]	5,063	ND	ND	77.3	5,063	391,370	539.2	78.0		1.0
Year 3	261.2	70,000	18,283,185	98.0	311.0	70,000	21,770,000	156.9	97.0		9.6
Year 4	313.0	45,100	14,116,088	98.7	444.0	45,100	20,024,400	347.7	90.2		5.5
Year 5	696.2	30,500	21,234,591	94.7	1,070.0	30,500	32,635,000	1238.9	63.4		6.4
Years 1-5	**420.8**	**196,165**	**82,543,374**	**97.0**	**1,988.6**	**196,165**	**390,093,719**	**358.0**	**89.0**		**7.6**
TB15Bsw+TB15Bgw											
Year 2	4,845.7	512,508		42.1	29,177.3	512,508		2010.5	17.9		
Year 3	3,906.8	729,000		70.6	33,011.0	729,000		1599.1	69.8		
Year 4	6,623.7	827,100		73.3	69,344.0	827,100		2960.8	16.2		
Year 5	5,800.7	479,500		55.9	35,470.0	479,500		2612.3	22.9		
Years 2-5	**5,661.2**	**2,593,610**		**59.2**	**167,088.6**	**2,593,610**		**2275.1**	**29.8**		
TB19gw											
Year 2	2,053.7	290,339	596,260,880	75.5	10,100.0	290,339	2,932,423,900	1228.5	49.8		97.4
Year 3	4,102.0	512,000	2,100,243,968	69.1	42,600.0	512,000	21,811,200,000	2938.3	44.5		88.7
Year 4	4,505.0	425,000	1,914,618,780	81.9	36,600.0	425,000	15,555,000,000	3041.2	13.9		84.5
Year 5	4,346.4	312,000	1,356,075,714	66.9	17,300.0	312,000	5,397,600,000	1958.2	42.2		95.8
Years 2-5	**4,186.2**	**1,539,339**	**6,444,044,732**	**69.8**	**106,600.0**	**1,539,339**	**164,093,537,400**	**2445.6**	**24.5**		**90.3**
TB19sw											
Year 2	2,864.3	7,734	22,152,351	65.8	31.4	7,734	242,848	143.4	94.1		2.6
Year 3	1,341.1	65,200	87,440,257	89.9	366.0	65,200	23,863,200	198.2	96.3		11.3
Year 4	3,004.4	77,900	234,040,897	87.9	1,750.0	77,900	136,325,000	793.3	77.5		15.5
Year 5	208.6	13,800	2,878,019	98.4	99.6	13,800	1,374,480	254.9	92.5		4.2
Years 2-5	**2,236.7**	**164,634**	**368,239,863**	**83.9**	**2,247.0**	**164,634**	**369,932,598**	**482.0**	**85.1**		**9.7**
TB19sw+TB19gw											
Year 2	2,074.7	298,073		75.2	10,131.4	298,073		1200.3	51.0		
Year 3	3,790.2	577,200		71.5	42,966.0	577,200		2628.8	50.4		
Year 4	4,272.5	502,900		82.8	38,350.0	502,900		2693.0	23.7		
Year 5	4,171.1	325,800		68.3	17,399.6	325,800		1886.0	44.3		
Years 2-5	**3,997.9**	**1,703,973**		**71.2**	**108,847.0**	**1,703,973**		**2255.8**	**30.4**		
TB15A											
Pre-construction	7,143.0									20.7	
TB19											
Pre-construction	10,068.4									60.3	

*Percent reduction calculations use mass for TB7B and standardized concentrations for all others.

**Water sample data presented in Miner et al. 2016.

[1] no data

Shades of green indicate percent reductions >0, shades of yellow indicate percent increases 1 to 25%, and shades of red indicate percent increases >25%.

Mean SpC for groundwater and surface-water sites combined calculated with equation [(SpCGW*VolGW)+(SpCSW*VolSW)]/(VolGW+VolSW)

APPENDIX F. Calculations for lab and modeled TDS standardized concentrations and percent reductions.

	Lab: Total TDS load (kg)	**Model: Total TDS load (kg)**	**Discharge (ft^3) for time period that AT was deployed**	**Discharge (ft^3) for time that flow-composite samples were collected**	**Volume (L) for time period that AT was deployed**	**Volume (L) for time that flow-composite samples were collected**	**Lab: Standardized concentration (mg/L)**	**Model: Standardized concentration (mg/L)**	**Lab: TDS percent reduction vs. TB7Bin****	**Model: TDS percent reduction vs. TB7Bin****
TB7Bin										
Year 1*	8,720.0	1,431.3	54,406	194,432	1,921	6,866	1,583.8	929.1		
Year 2	9,640.0	5,229.5	139,013	139,013	4,909	4,909	2,448.9	1,328.5		
Year 3	25,800.0	9,523.0	172,000	172,000	6,074	6,074	5,297.2	1,955.2		
Year 4	18,100.0	56,093.5	181,000	181,000	6,392	6,392	3,531.5	10,944.3		
Year 5^	16,600.0	6,812.4	173,000	173,000	6,109	6,109	3,388.6	1,390.6		
Years 1 - 5	**78,860.0**	**79,089.7**	**719,419**	**859,445**	**25,406**	**30,351**	**3,240.4**	**3,882.3**		
TB7Bout										
Year 2*	1,550.0	0.3	3,341	74,696	118	2,638			83.9	100.0
Year 3	956.0	114.6	52,932	52,900	1,869	1,868			96.3	98.8
Year 4	3,980.0	2,605.8	126,661	127,000	4,473	4,485			78.0	95.4
Year 5	1,490.0	984.6	107,297	107,000	3,789	3,779			91.0	85.5
Years 2 - 5	**7,976.0**	**3,705.3**	**290,231**	**361,596**	**10,249.4**	**12,769.7**			**89.9**	**95.3**
TB9A										
Year 1*	10,500.0	4,743.8	208,334	655,352	7,357	23,144	565.8	804.1	64.3	13.4
Year 2	42,000.0	21,214.9	1,117,117	1,117,117	39,451	39,451	1,327.7	670.7	45.8	49.5
Year 3	56,100.0	26,078.3	1,535,549	1,540,000	54,227	54,385	1,286.5	599.8	75.7	69.3
Year 4	88,400.0	129,284.2	1,162,656	1,160,000	41,059	40,965	2,691.2	3,926.9	23.8	64.1
Year 5	67,000.0	82,294.6	1,015,308	1,020,000	35,855	36,021	2,319.7	2,862.4	31.5	-105.8
Years 1 - 5	**264,000.0**	**263,615.8**	**5,038,964**	**5,492,469**	**177,949.6**	**193,965.0**	**1,697.4**	**1,847.5**	**47.6**	**52.4**
TB15Bgw										
Year 2	29,100.0	7,025.6	507,445	507,445	17,920	17,920	2,025.2	488.9	17.3	63.2
Year 3	32,700.0	7,846.3	659,000	659,000	23,272	23,272	1,752.3	420.5	66.9	78.5
Year 4	68,900.0	48,953.7	782,000	782,000	27,616	27,616	3,111.5	2,210.7	11.9	79.8
Year 5	34,400.0	30,317.4	449,000	449,000	15,856	15,856	2,705.6	2,384.5	20.2	-71.5
Years 1 - 5	**165,100.0**	**94,143.0**	**2,397,445**	**2,397,445**	**84,665.1**	**84,665.1**	**2,431.9**	**1,386.7**	**24.9**	**64.3**
TB15Bsw										
Year 1	86.3	0.8	45,502	45,502	1,607	1,607	67.0	0.6	95.8	99.9
Year 2	77.3	ND[1]	5,063	5,063	179	179	539.2	ND	78.0	ND
Year 3	311.0	38.9	70,000	70,000	2,472	2,472	156.9	19.6	97.0	99.0
Year 4	444.0	76.0	45,100	45,100	1,593	1,593	347.7	59.5	90.2	99.5
Year 5	1,070.0	96.1	30,500	30,500	1,077	1,077	1,238.9	111.3	63.4	92.0
Years 1 - 5	**1,988.6**	**211.8**	**150,663**	**196,165**	**6,927.5**	**6,927.5**	**358.0**	**49.6**	**89.0**	**98.7**
TB19gw										
Year 2	10,100.0	2,065.8	290,339	290,339	10,253	10,253	1,228.5	251.3	49.8	81.1
Year 3	42,600.0	10,374.9	512,000	512,000	18,081	18,081	2,938.3	715.6	44.5	63.4
Year 4	36,600.0	29,288.9	425,000	425,000	15,009	15,009	3,041.2	2,433.7	13.9	77.8
Year 5	17,300.0	14,816.4	312,000	312,000	11,018	11,018	1,958.2	1,677.0	42.2	-20.6
Years 2 - 5	**106,600.0**	**56,546.0**	**1,539,339**	**1,539,339**	**54,361.3**	**54,361.3**	**2,445.6**	**1,297.2**	**24.5**	**66.6**
TB19sw										
Year 2	31.4	56.5	7,734	7,734	273	273	143.4	258.0	94.1	80.6
Year 3	366.0	32.3	65,200	65,200	2,303	2,303	198.2	17.5	96.3	99.1
Year 4	1,750.0	725.1	77,900	77,900	2,751	2,751	793.3	328.7	77.5	97.0
Year 5	99.6	16.7	13,800	13,800	487	487	254.9	42.7	92.5	96.9
Years 2 - 5	**2,247.0**	**830.6**	**164,634**	**164,634**	**5,814.0**	**5,814.0**	**482.0**	**178.2**	**85.1**	**95.4**

*At TB7Bin, TB9A, and TB15Bsw, Year 1 was only monitored with dataloggers for part of the year (June through August). And at TB7Bout, Year 2 was only monitored for part of the year (May through August). Samples were collected

**Percent reduction calculations use mass for TB7B and standardized concentrations for all others.

^Loads of TDS in Year 5 at TB7Bin were affected by the lack of winter discharge measurments due to a malfunctioning Isco. Loads are much lower than expected.

[1] no data

Shades of green indicate percent reductions >0, shades of yellow indicate percent increases 1 to 25%, and shades of red indicate percent increases >25%.