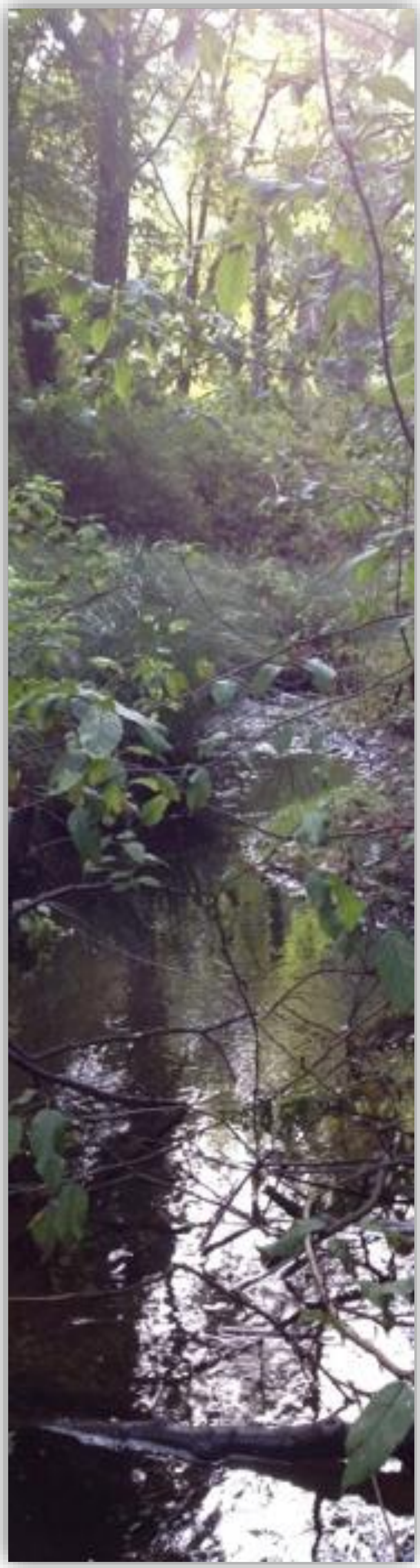

MURDEN COVE WATERSHED

Nutrient and Bacteria Reduction Project (2013 – 2015)

A Partnership of Local Government, Business, Schools, and Citizens

Prepared by

Cami Apfelbeck

Water Resources Specialist

City of Bainbridge Island
Public Works
Water Resources Program

March 2017

The Partnership

City of Bainbridge Island

Kitsap Public Health District

Bainbridge Island Watershed Council

Islandwood

Kitsap Conservation District

Sonoji Sakai
Intermediate School

Far Bank enterprises

3M

Cover photo: Downstream reach of Murden Creek. Photo taken by Deborah Rudnick, Bainbridge Island Watershed Council Chair and citizen volunteer.

Acknowledgements

The City would like to thank the partnership: Kitsap Public Health District, Bainbridge Island Watershed Council, Sonoji Sakai Intermediate School, Islandwood, and Kitsap Conservation District.

A special thank you to: the Bainbridge Island School District/School Board and the faculty, staff, and, most especially, the student scientists of Sonoji-Sakai Intermediate School; and all of our citizen volunteers: Mark Dettman, Gene DiPietro, Rose Eppers, Ken Fabert, Daniel Groff, Katrina Godshalk, Charlie Kratzer, Elisa Kratzer, Thomas Kratzer, Liam Kratzer, Diane Landry, Lisa Martin, Rachel Moss, Monica Ponce-McDermott, Bryan Ransom, Bob Ross, Deb Rudnick, and Kathleen Torso.

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1.0 INTRODUCTION

The objectives of this project were to **define the severity and extent of Murden Cove Watershed's water quality challenges** identified by the Washington State Department of Ecology (Ecology) and the City of Bainbridge Island's Water Quality and Flow Monitoring Program (WQFMP) and to **identify and reduce sources of nutrients and bacteria in the watershed** by providing educational outreach and technical assistance to watershed residents.

The Murden Cove Watershed is located on the central eastern side of Bainbridge Island in mid Puget Sound (Figure 1). At 2,041 acres, the Murden Cove Watershed is one of the largest watersheds on the Island. The primary stream in the watershed, Murden Creek, is comprised of a mainstem and two significant tributaries (Woodward Creek and Meig's Creek) totaling 3.7 miles. Along with several smaller drainages directly to the shoreline, Murden Creek delivers drainage to Murden Cove which is bounded by 3.3 miles of shoreline.

Land use within this watershed consists of various densities of residential, commercial and light industrial development, schools, and a portion of the Rolling Bay Neighborhood Service Center. The watershed encompasses 2.2 miles of State Highway 305 and 146 acres of parkland. There are agriculture and livestock farms spread throughout the watershed, and, while sanitary sewer services are provided for a small portion of the watershed, most land uses use onsite sewage systems.

1.1 The Challenge

The Murden Cove Watershed provides habitat for numerous species including shellfish and salmonids, specifically coho, chum, and cutthroat trout. However, Murden Cove's aquatic habitat has been listed impaired by Ecology since 2004 due to what Ecology states is a "….continuous cover of ulvoid macroalgae [that] are impairing aquatic life from identified human causes at Murden Cove" (DOE, 2016).

The watershed's cove, 3.3-mile shoreline, and 3.7 miles of stream also provide numerous recreational opportunities for residents and visitors. However, Ecology's 2012 assessment listed Murden Cove impaired by fecal coliform bacteria, and their 2014 assessment added the watershed's mainstem, Murden Creek, to the impaired list for fecal coliform bacteria (DOE, 2016). Additionally, Ecology's Eyes over Puget Sound program reported seasonal algal blooms in the cove starting earlier and lasting longer over the last few years (DOE, 2017).

The City's status and trends monitoring in Murden Cove nearshore and Murden Creek indicated chronic high levels of bacteria and nutrients and low oxygen levels (COBI, 2012). In addition, the cove periodically exceeded pH criteria and frequently failed to meet temperature criteria. Targeted storm event monitoring in both water bodies revealed increased ammonia concentrations exceeding chronic criteria in the creek and acute criteria in the cove during heavy rain events.

Benthic macroinvertebrates are a vital food source for fish and other aquatic animals and are excellent indicators of overall stream health. Unfortunately, the City's annual benthic macroinvertebrate monitoring in Murden Creek showed that the stream's biological community is stressed, achieving an average rating of "poor" and demonstrating a significant downward trend in pollution-sensitive species richness and population (KC, 2015).

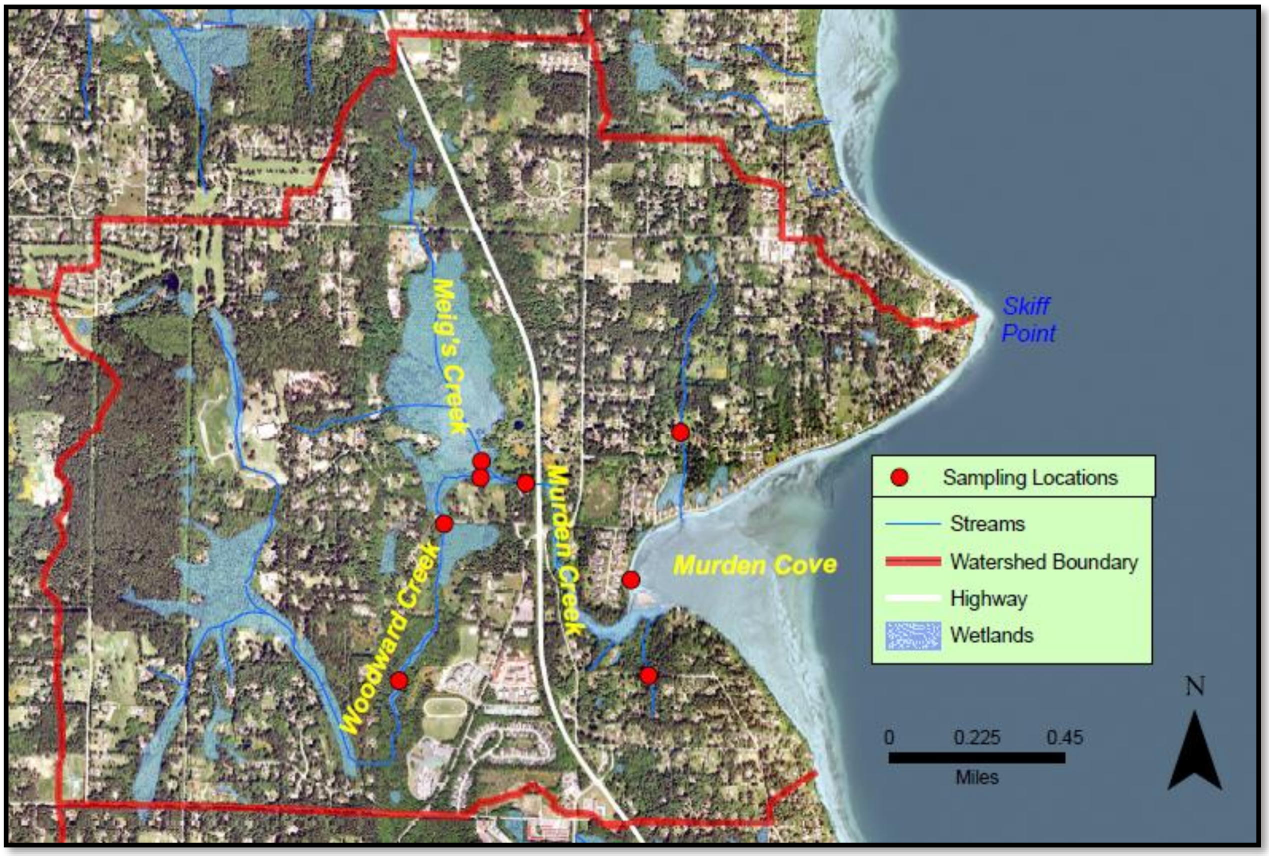


Figure 1. Murden Cove Watershed

1.2 The Approach

Given the number of challenges facing the watershed, meeting project objectives required a comprehensive multi-agency and community approach, tapping the collective expertise and resources of the City, Kitsap Public Health District, Kitsap Conservation District, Bainbridge Island Watershed Council, Sonoji-Sakai Intermediate School, Islandwood, and citizen volunteers (see partner profiles in Appendix A for specific partner contributions).

The City served as the project lead – facilitating partner collaboration; providing training, equipment, and oversight to partners and volunteers; conducting monitoring; compiling and assessing all monitoring data; and reporting on findings.

1.3 Activities

Over the course of this three-year project, project partners conducted 193 stream-side property inspections assessing onsite septic system maintenance, pet and livestock waste management, and yard/landscaping practices; walked Murden Creek's stream channel looking for potential illicit discharges to the stream; and conducted water quality and flow monitoring at eight sampling locations in the watershed (Figure 1).

Partners also hosted a Walk-Your-Watershed event, surveyed watershed resident's understanding of the watershed, and provided coordinated education and outreach focused on the value and status of the watershed, the observed pollutants and their common sources, and how residents can help restore the watershed.

Of particular note, Sonoji-Sakai Intermediate School students created a one-of-a-kind mobile watershed interpretive sign featuring student art and educational messages. Graphic artist and Island resident, Joe Tschida, and architect and Island resident, Rob Smallwood, donated their expertise in making the sign a reality. Fabrication and construction were completed in late 2016, and the sign was unveiled on the school grounds in early 2017 (photo below).

Finally, project partners hosted public meetings and presented at City Council and Bainbridge Island School Board meetings to inform residents and stakeholders about project activities and findings.

2.0 FINDINGS

2.1 Property Inspections and Stream Walk

The stream walk and property inspections identified and corrected two failing septic systems and one occurrence of improperly-managed livestock waste along the stream channel (KPHD, 2016).

2.2 Water Quality and Flow Monitoring

Two of the sampling locations located on small drainages that drain directly to the cove (one from the north and one from the south) were only sampled during the first year of the project, as preliminary assessment showed that pollutant contribution from these drainages were fairly insignificant relative to the mainstem Murden Creek and tributaries (Figure 1). Sampling results from these drainages are not included in this assessment.

Additionally, one sampling location along Woodward Creek at NE Wardwell Road was added to the project in May, 2014, for bacteria and physiochemistry only. These data are included in this assessment.

2.2.1 Physiochemistry

WAC 173-201A, Washington Administrative Code for water quality standards sets physiochemical water quality criteria for two important salmonid habitat seasons pertinent to this project: Salmonid Spawning, Rearing and Migration (September 16 – June 14) during which salmonids navigate into freshwaters to spawn and rear young and Core Summer Salmonid Habitat (June 15 – September 15) during which young salmon summer-over in freshwater before migrating to saltwater (DOE, 2011).

Most monitoring sites met the criteria for pH with only Meig's Creek and the cove periodically exceeding the standard during the salmonid spawning, rearing and migration season.

Unfortunately, the daily maximum temperatures at all three sites monitored with continuous dataloggers (Woodward Creek @ Sakai, Woodward Creek @ NE Wardwell Rd, and Murden Creek @ Hwy 305) exceeded the standard during the core summer salmonid habitat season with temperatures increasing and exceeding more often in the downstream reaches (Figure 2).

Further, the daily minimum dissolved oxygen levels at these three sites failed to meet the standard with levels decreasing and failing more often as you move downstream. Mid-watershed reaches only failed during the core summer salmonid habitat season; however, lower watershed reaches failed to meet the standard year-round (Figure 3).

Monthly instantaneous measurements indicated that the cove failed to meet both dissolved oxygen and temperature criteria during the core summer salmonid habitat season (Figure 4).

Monthly instantaneous turbidity measurements indicated that all stream monitoring sites stayed below the benchmark of concern for suspended sediment, although small increases were noted during rain events. Turbidity was not measured in the cove.

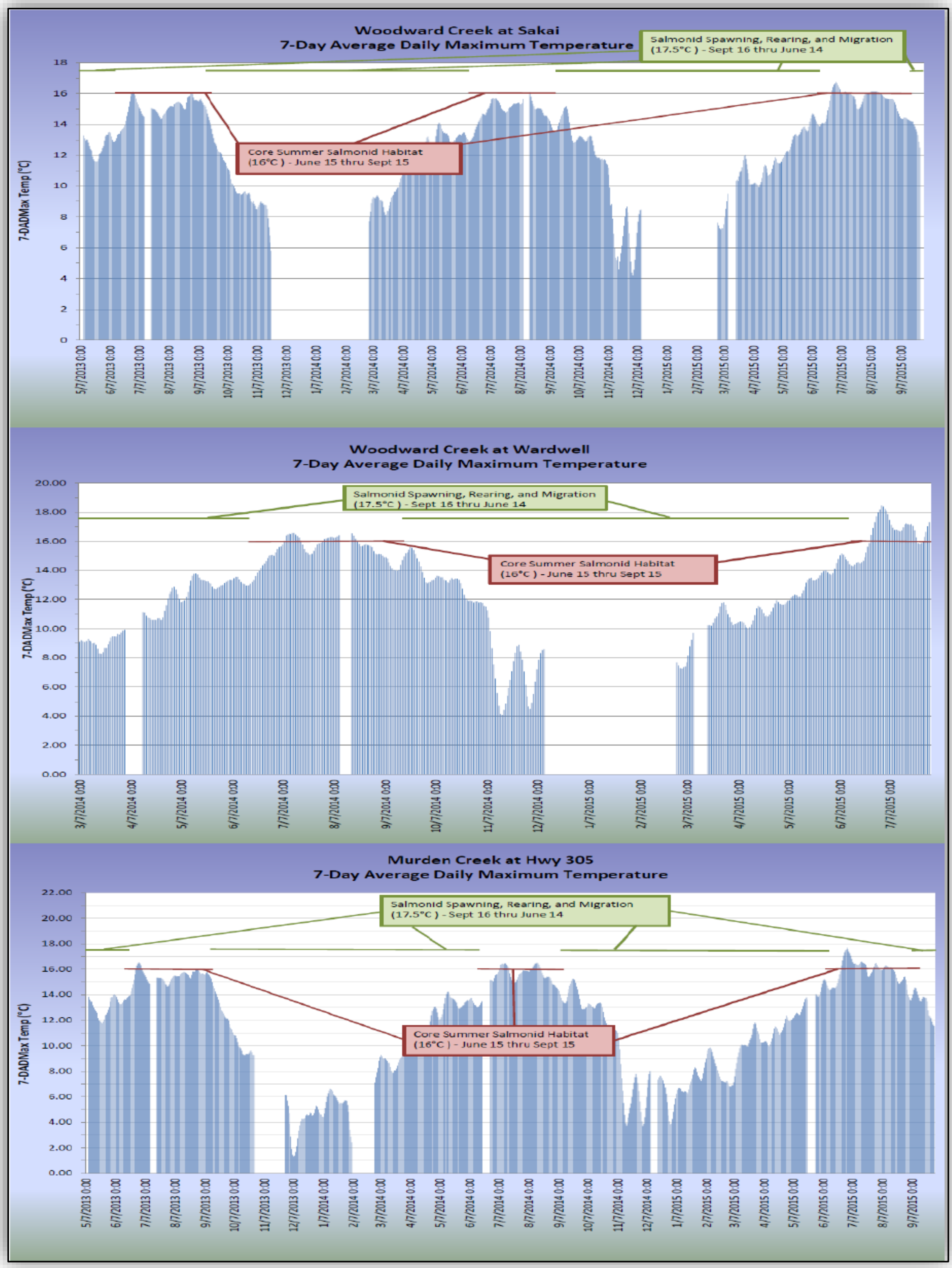


Figure 2. Daily Maximum Temperatures in Streams

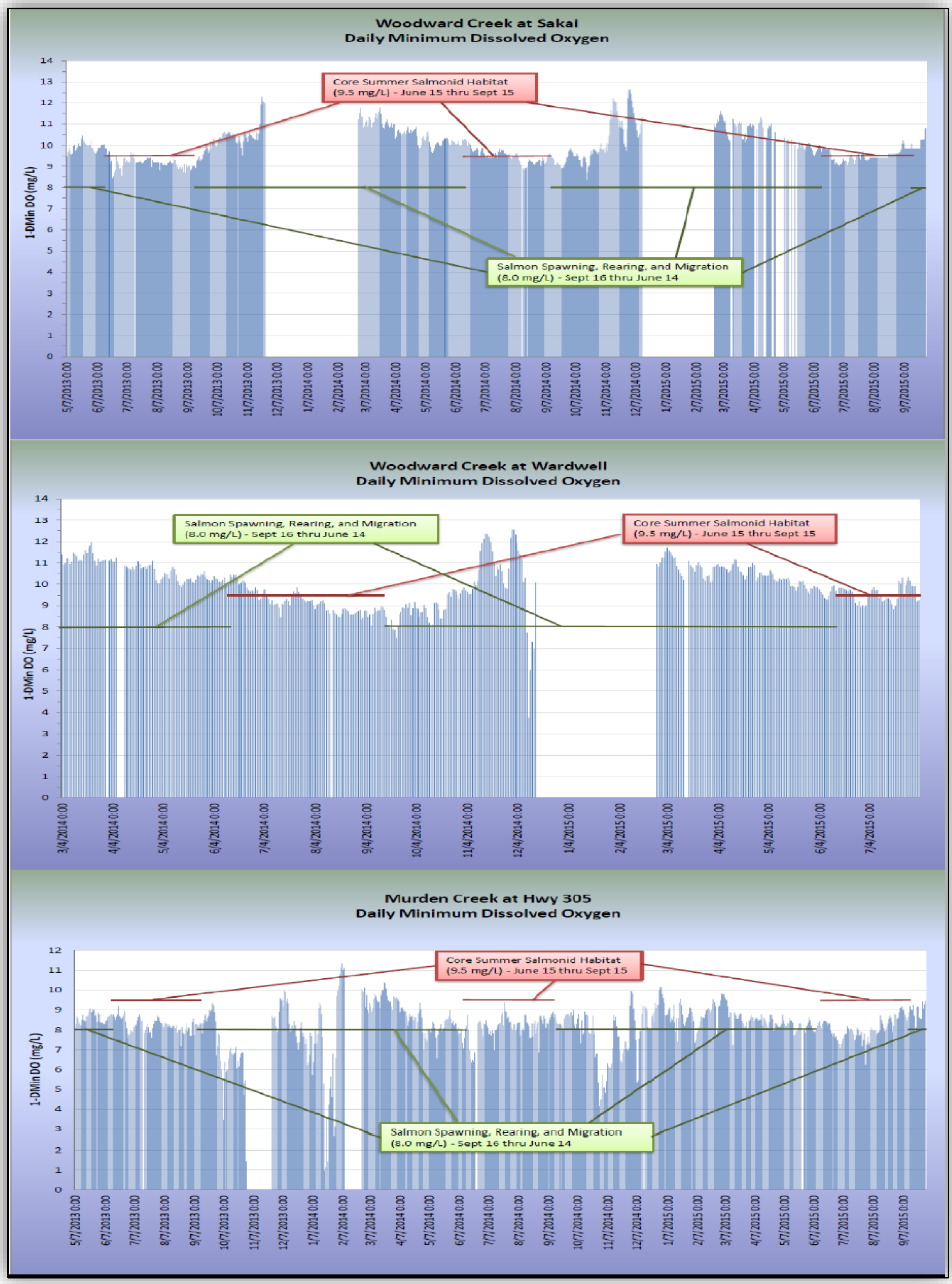
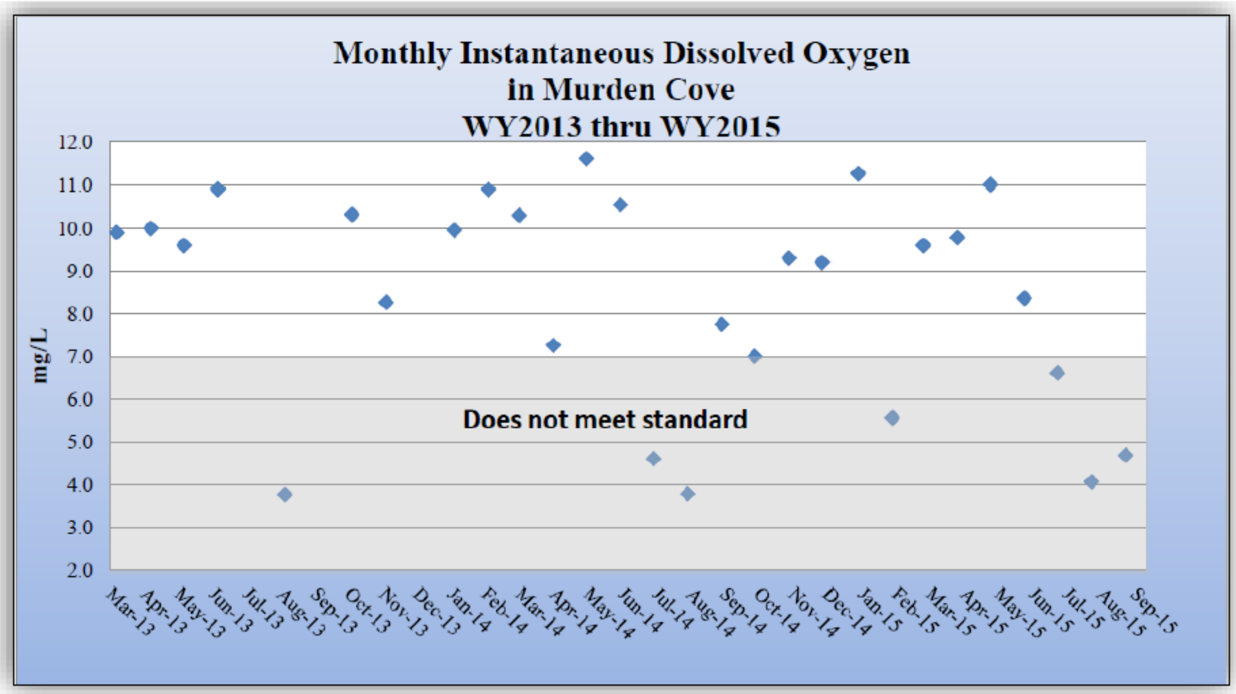


Figure 3. Daily Minimum Dissolved Oxygen in Streams



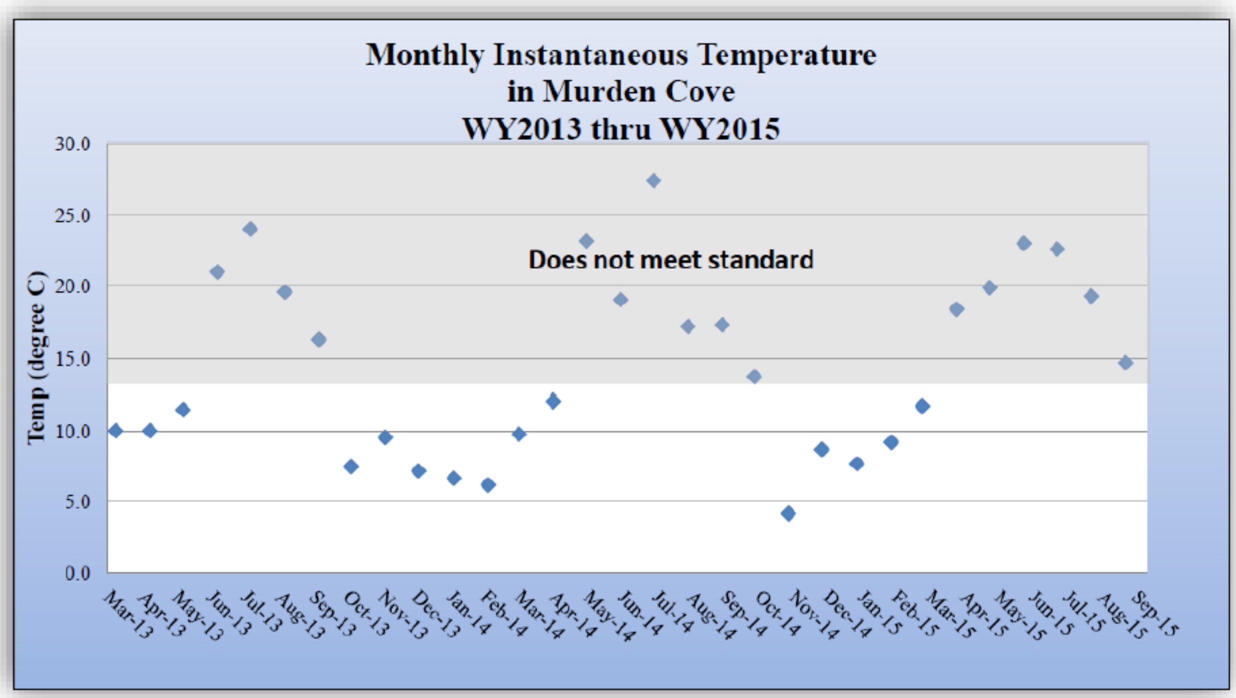


Figure 4. Murden Cove Instantaneous Dissolved Oxygen and Temperature

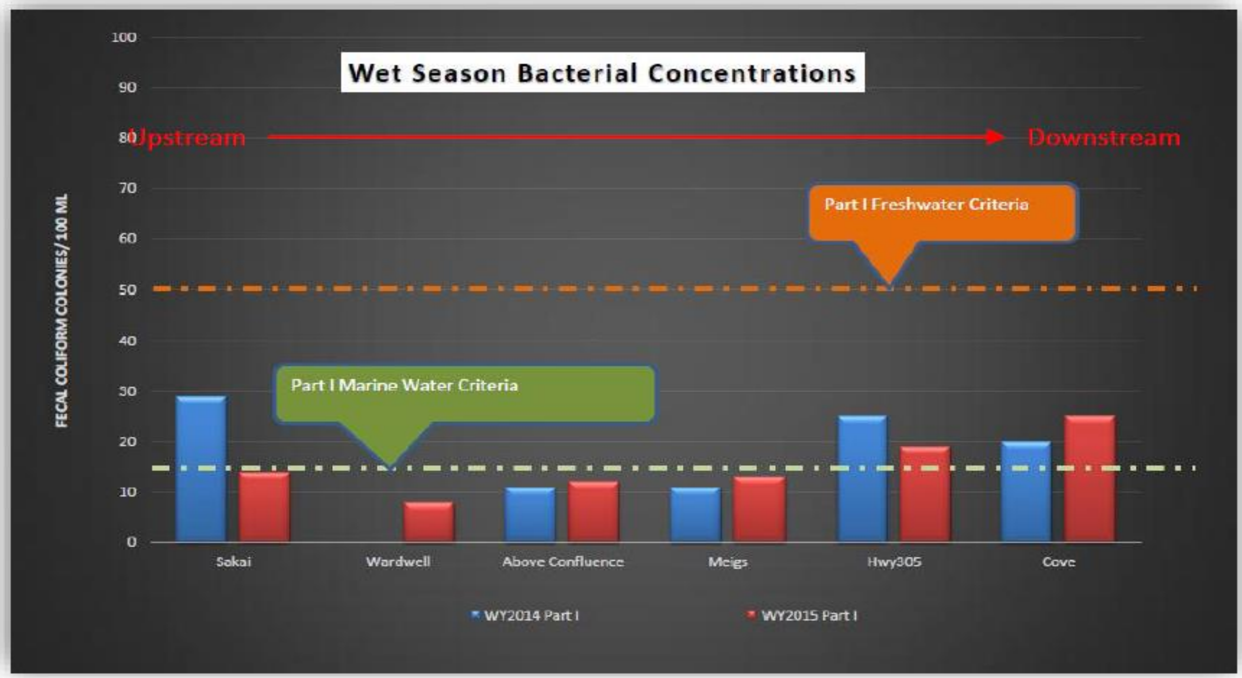
2.2.2 Bacteria

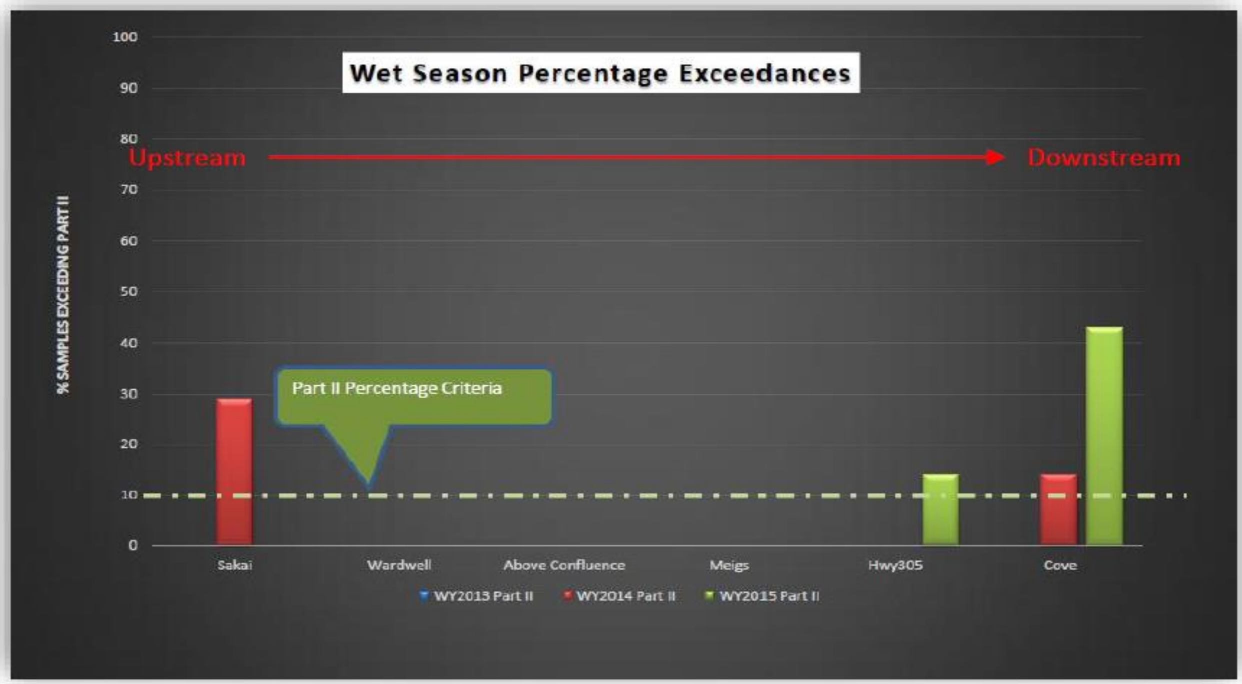
WAC 173-201A establishes a two-part criteria for fecal coliform bacteria: Part I – a geometric mean value (50 colonies/100 ml for streams and 14 colonies/100 ml for the cove) which cannot be exceeded and Part II – a 90th percentile value (100 colonies/100 ml for streams and 43 colonies/100 ml for the cove) which no more than 10% of all samples can exceed. Both parts of the criteria must be met on both a seasonal and an annual basis.

The wet season is typically the most challenging for bacteria in marine waters due to seepage and runoff along shorelines and increased flow from streams. This is evident in the wet season sampling results for Murden Cove which failed to meet both parts of the criteria (Figure 5). Though not as common, wet seasons periodically can be challenging for streams as well. Woodward Creek at Sakai failed Part II of the criteria in the first project wet season, and Murden Creek at Hwy 305 failed Part II of the criteria in the last project wet season.

The dry season is typically the most challenging for bacteria in streams due to low flows (less dilution) and warmer temperatures which encourage growth. Unfortunately, all sites, including the cove, failed to meet both parts of the criteria during the dry season with an increasing trend in concentration and percentage of exceedances moving downstream with two to three times higher concentrations in the lower reaches (Figure 6).

Mid to lower reaches also failed to meet Part I of the criteria on an annual basis, especially in the first two years of the project, and all sites failed to meet Part II of the criteria on an annual basis for all years of the project (Figure 7).





Notes:

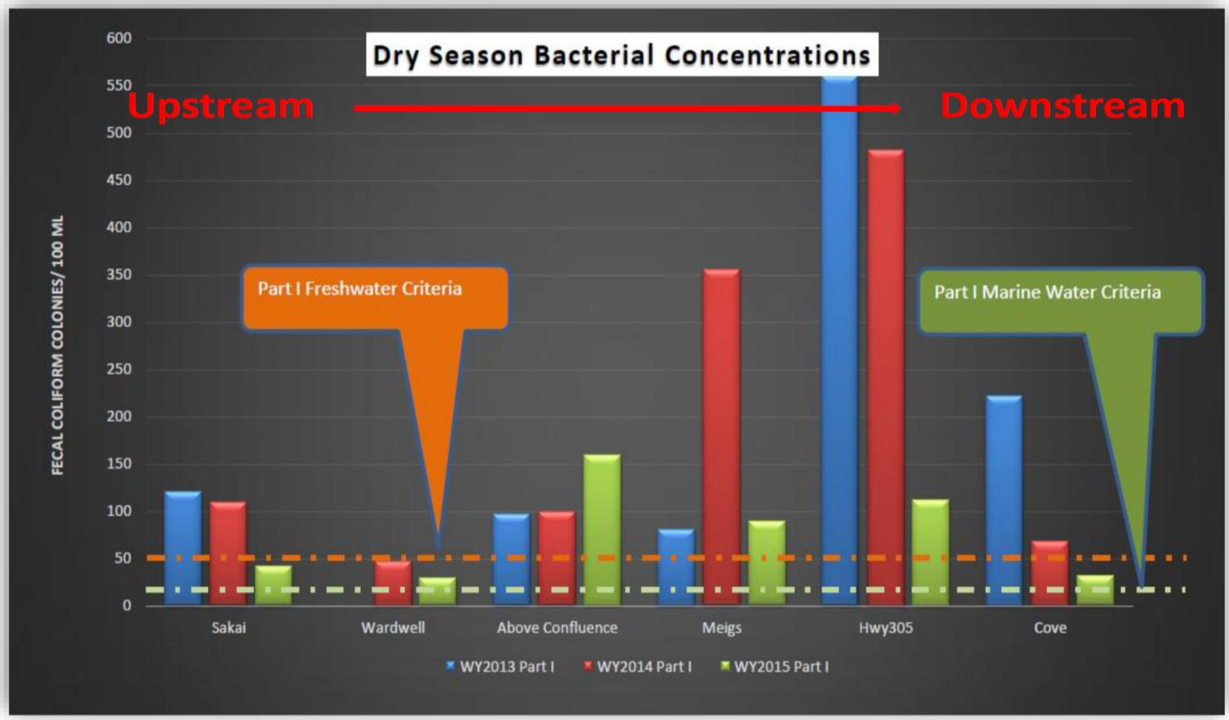
1. WY = Water Year (October 1st – September 30th)

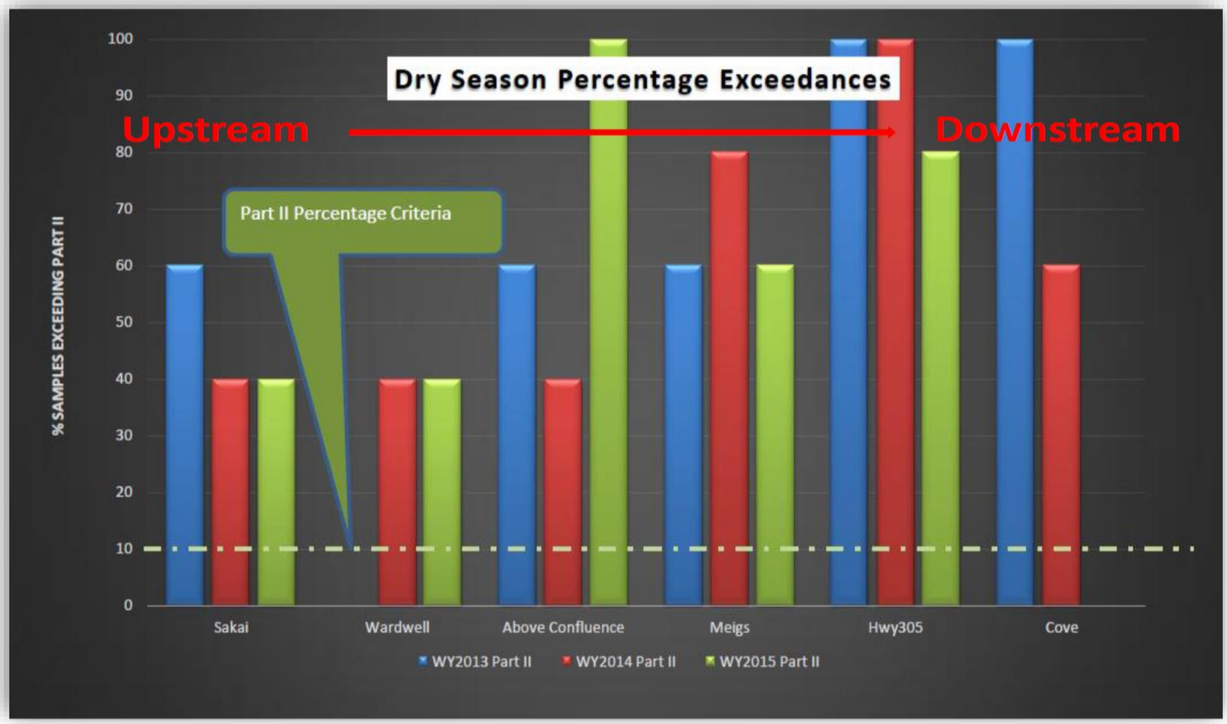
2. Project sampling began in March, 2013, so there were only two sampling events during WY2013's wet season. WAC 173-201A requires at least 5 samples to calculate a geometric mean. Therefore, a geometric mean could not be calculated for Part I of the criteria for WY2013.

3. The Wardwell monitoring station was added to the project in May, 2014. Therefore, there is no WY2014 wet season geometric mean for this site.

4. Due to stream dynamics, the Above Confluence sampling location was moved immediately upstream from original location in WY2015.

Figure 5. Wet Season Bacteria by Water Year

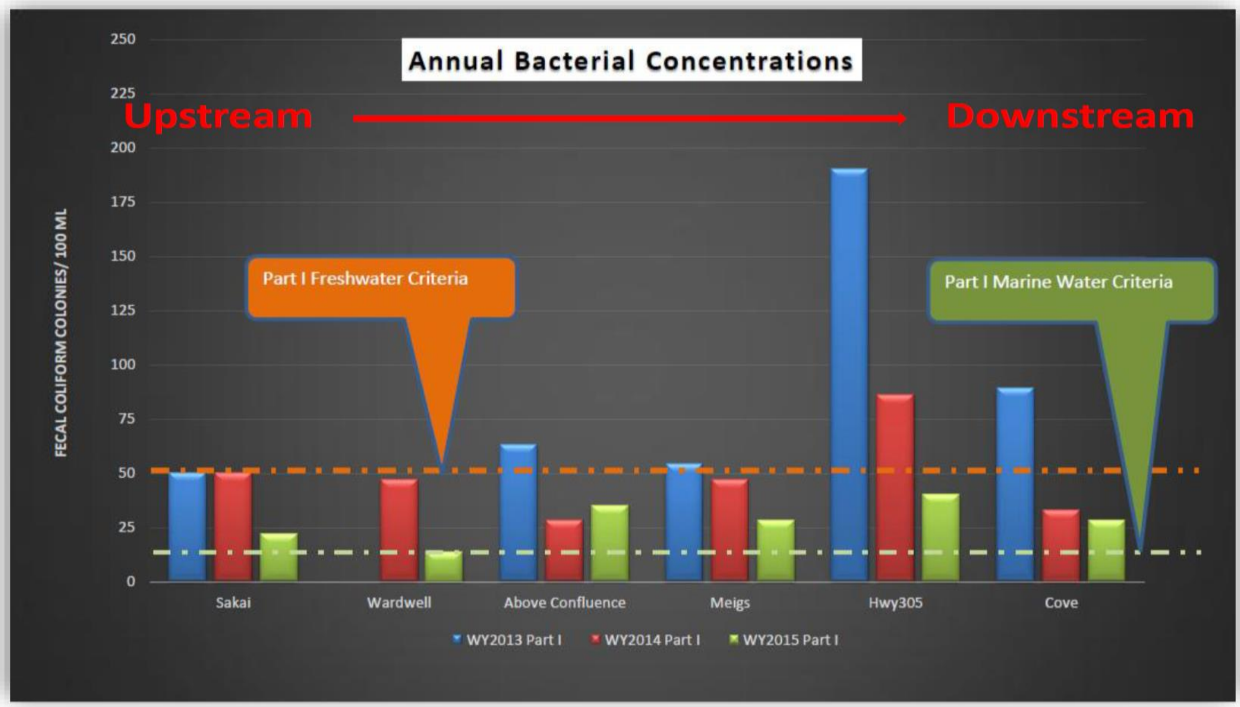


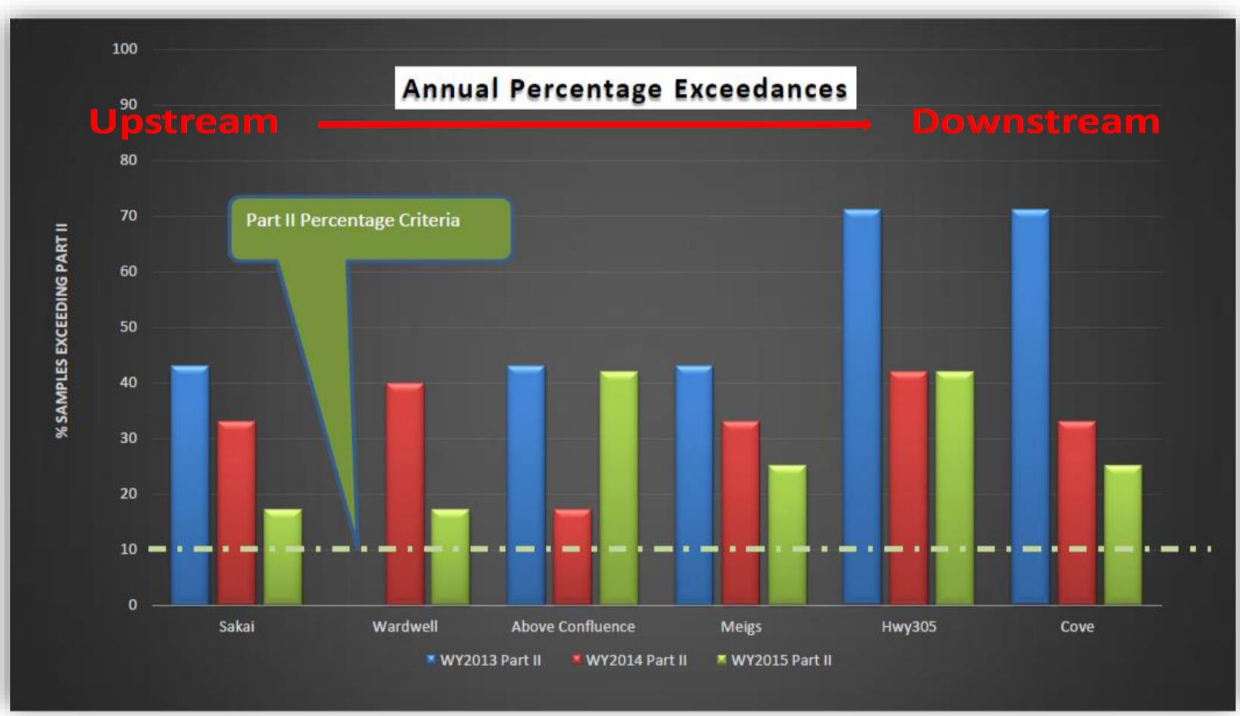


Notes:

1. *WY = Water Year (October 1st – September 30th)*
2. *The Wardwell monitoring station was added to the project in May, 2014. Therefore, there is no WY2013 dry season geometric mean for this site.*
3. *Due to stream dynamics, the Above Confluence sampling location was moved immediately upstream from original location in WY2015.*

Figure 6. Dry Season Bacteria by Water Year





Notes:

1. *WY = Water Year (October 1st – September 30th)*
2. *The Wardwell monitoring station was added to the project in May, 2014. Therefore, there is no WY2013 geometric mean or percentage exceedance for this site.*
3. *Due to stream dynamics, the Above Confluence sampling location was moved immediately upstream from original location in WY2015.*

Figure 7. Annual Bacteria by Water Year

2.2.3 Nutrients

WAC 173-201A does not establish numeric criteria for nutrient levels in streams or estuaries as the healthy level of nutrients for these systems can vary, and each system must be evaluated and assessed to establish individual criteria. However, EPA provides general guidance based upon a waterbody's designated uses. These nutrient benchmarks, described in the following sections and used in the assessment of project data, are summarized in Bartenhagen, et al., 2017.

Though nitrogen and phosphorus are present in both freshwater and marine water environments, they differ in their influence on aquatic plant growth depending upon which environment they are in.

2.2.3.1 Streams

In the freshwater environment, phosphorus is usually the nutrient that drives growth. EPA recommends keeping total phosphorus concentrations in streams below 0.1 mg/l to avoid excessive algae and other aquatic plant growth.

Over the course of the project, total phosphorus concentrations ranged from 0.03 – 0.84 mg/l in Murden Creek's mainstem and tributaries, often exceeding EPA's benchmark of concern. The highest concentrations (>0.25 mg/l) were observed in Meig's Creek.

Unlike Woodward Creek and mainstem Murden Creek, Meig's Creek is bound by wetlands throughout nearly its entire course, and phosphorus is a natural component of the decomposition of wetland organics. However, the phosphorus cycle in wetlands is complex, and phosphorus exists in several forms (dissolved, particulate, organic, inorganic). Some of these are natural such as phosphorus generated through leaf litter decomposition, and some are typically from human sources such as fertilizer. This project only looked at total phosphorus, so data are insufficient in determining source. Though a wetland's capacity to sequester phosphorus depends upon many factors such physical, chemical and biological characteristics of the system, wetlands are generally phosphorus sinks not sources.

Further, as discussed in Section 2.2.4.1 below, despite having higher concentrations of total phosphorus, Meig's Creek was not the most significant carrier of phosphorus by mass (load). Certainly all of the water quality benefits provided by wetlands far outweigh any potential negative impact to total phosphorus concentration in the water column.

There did not appear to be a significant difference upstream vs. downstream, nor a correlation between concentrations and wet/dry seasons or intense storms.

Though not as critical as phosphorus in the freshwater environment for promoting aquatic plant growth, the different forms of nitrogen present, can help identify potential human-generated pollution impacting the waterbody.

Nitrogen can be grouped into organic and inorganic nitrogen. Organic nitrogen is often referred to as total Kjeldahl nitrogen (TKN). Inorganic nitrogen is the sum of the remaining species – nitrate ($NO3^-$), nitrite ($NO2^-$), and ammonia (NH3). Nitrite is highly unstable and normally converts to nitrate very quickly in the environment. In fact, nitrite was detected only once and at only one site (Woodward Creek at Sakai) over the course of the project. Therefore, nitrate concentration often serves as a surrogate for nitrate + nitrite in nitrogen assessments.

Examining the relative mass proportions of nitrogen species can give a sense of whether a likely human source of pollution such as nitrate and ammonia from septic systems and fertilizer applications may be impacting a waterbody. An influx of manmade sources of nitrogen will increase nitrate and ammonia concentrations relative to total Kjeldahl nitrogen in the waterbody (Mahler, et al., 2011) (Wernick, et al., 1998) (Wieben, et al., 2012).

Tributary Meig's Creek is particularly rich in organic nitrogen with generally 85-95% TKN, up to 10% nitrate, and less than 10% ammonia (Figure 8 and Appendix B). This is typical for a highly wetland-dominated stream as wetlands are naturally organic rich. However, there were notable spikes in both nitrate and ammonia over the course of the project.

Meig's Creek nitrate concentrations ranged from 0.015 – 1.27 mg/l and mass percent ranged from 0.61 – 52.74% with the greatest concentrations and percentages occurring in WY2014 and 2015. Most notably, significant increases occurred approximately 48-72 hours after significant rain events in February (52.74%), June (69.61%), and December 2014 (36.98%) and March 2015 (35.71%). The June spike occurred after a dry season storm event resulting in 0.73 inches of rainfall in the proceeding 72 hours, and both the February and the December rain events resulted in over 2 inches of rainfall in the proceeding 72 hours and nearly 12 times the wet season baseflow at the time of sampling.

Ammonia concentrations ranged from nondetect – 0.68 mg/l and mass percent ranged from 0 – 39.46% with the greatest concentrations and percentages occurring during extended dry periods in WY2014 and 2015. Two extreme spikes occurred in WY2015 – 27.72% in November 2014 and 39.46% in January 2015.

In contrast, Woodward Creek and mainstem Murden Creek sites demonstrated significantly higher background levels of inorganic nitrogen relative to organic nitrogen (Figures 9 – 11 and Appendix B).

There is a distinct oscillation in nitrate mass percentage - one peak in the January/February timeframe and one in the June/July timeframe. The oscillation has a slightly longer duration at the lower mid-watershed location (mainstem Murden above the confluence with Meig's Creek) where the highest concentrations and mass percentages were observed, but the oscillation is also evident in the upper mid-watershed (Woodward Creek at Sakai) and lower watershed (Murden Creek at Hwy 305).

Similarly to Meig's Creek, these sites also exhibited the highest mass percentages in response to significant rain events. Nitrate concentrations in the upper mid-watershed ranged from 0.14 – 1.65 mg/l and mass percent ranged from 7.17 – 54.86%. Concentrations in the lower mid-watershed ranged from nondetect – 2.31 mg/l and mass percent ranged from 0 – 73.23%. Concentrations in the lower watershed ranged from nondetect – 1.71 mg/l and mass percent ranged from 0 – 61.89%.

Ammonia concentrations in the upper mid-watershed ranged from nondetect – 3.16 mg/l and mass percent ranged from 0 – 68.59%, the highest concentrations and mass percentages of all the stream sites. Concentrations in the lower mid-watershed ranged from nondetect – 0.186 mg/l, and mass percent ranged from 0-13.39%, the lowest of all the stream sites. The lower watershed concentrations ranged from nondetect – 2.07 mg/l, and mass percent ranged from 0 – 41.32%.

Similar to Meig's Creek, the greatest concentrations and percentages occurred during extended dry periods. Prominent spikes began in WY2014 and became more severe in WY2015 in the upper mid-watershed at Sakai and, to a slightly lesser extent, the lower watershed at Hwy 305. However, this was not observed at the lower mid-watershed site immediately above the confluence with Meig's Creek.

Although included here as a constituent of total inorganic nitrogen, ammonia is considered a priority pollutant by the EPA, rather than a nutrient, since it is toxic to both human and aquatic life. The EPA established acute and chronic criteria for ammonia in surface waters. Acute criterion is the concentration of a substance at which injury or death to an organism can occur as a result of short-term exposure. Chronic criterion is the concentration of a substance at which injury or death to an organism can occur as a result of repeated or constant exposure.

Meig's Creek, the upper mid-watershed (Sakai), and the lower mid-watershed (above the confluence between the mainstem and Meig's Creek) frequently exceeded the chronic criteria with the lower mid-watershed having the fewest exceedances. However, the lower watershed (Murden Creek at Hwy 305) consistently exceeded the chronic criteria. None of the stream sites exceeded the acute criteria over the course of the project.

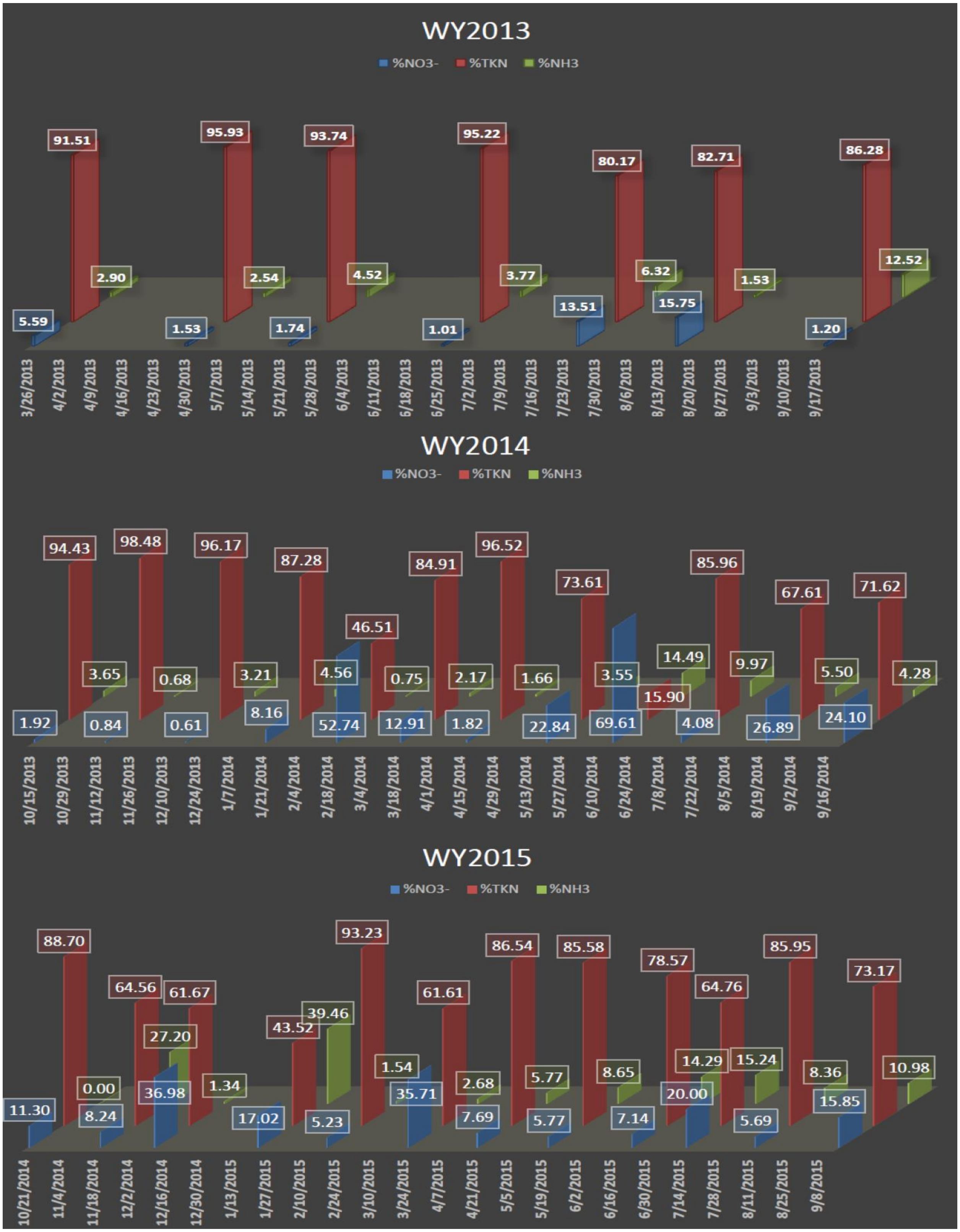


Figure 8. Meig's Creek Nitrogen Speciation by Mass Percent

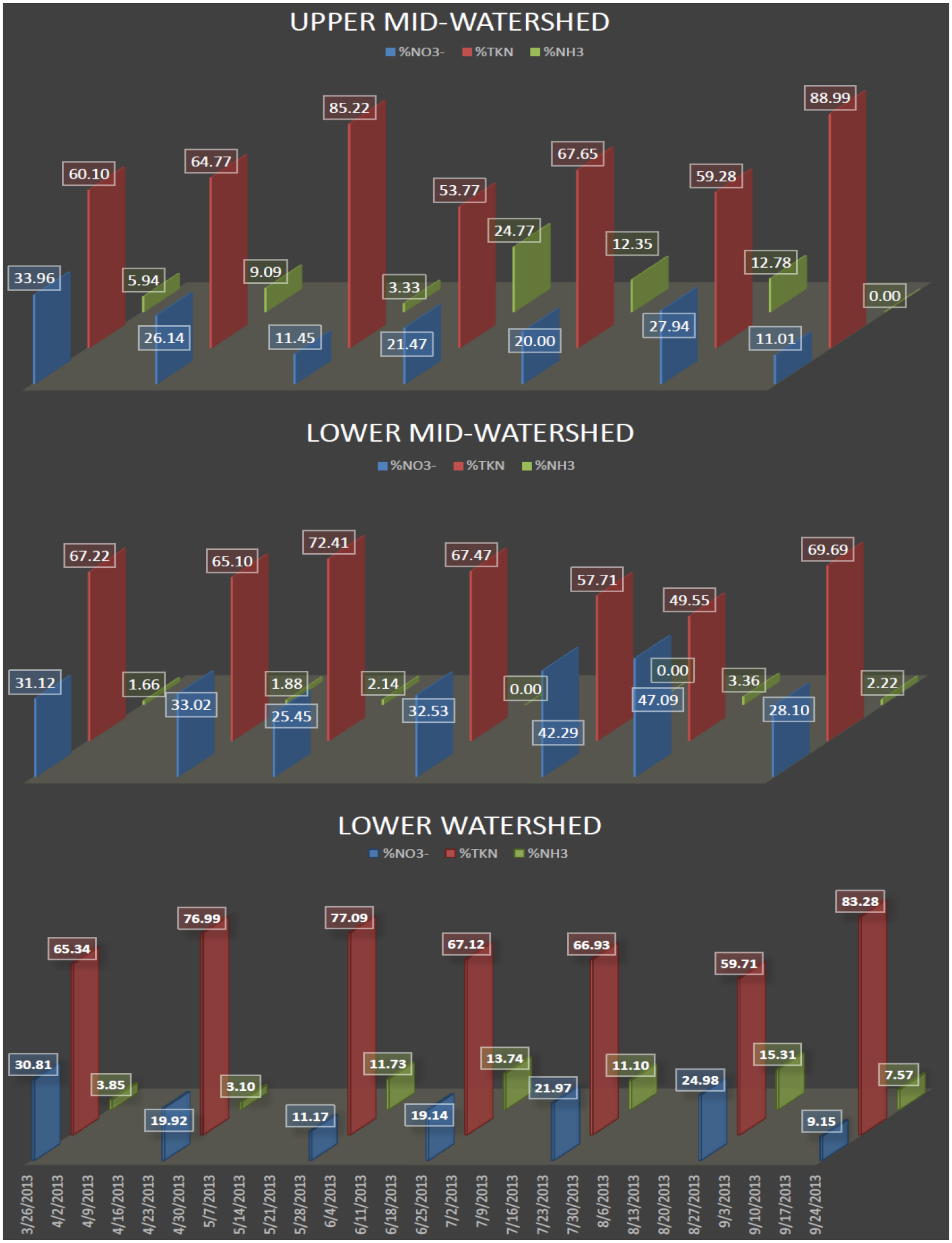


Figure 9. WY2013 Woodward and Murden Creek Nitrogen Speciation by Mass Percent

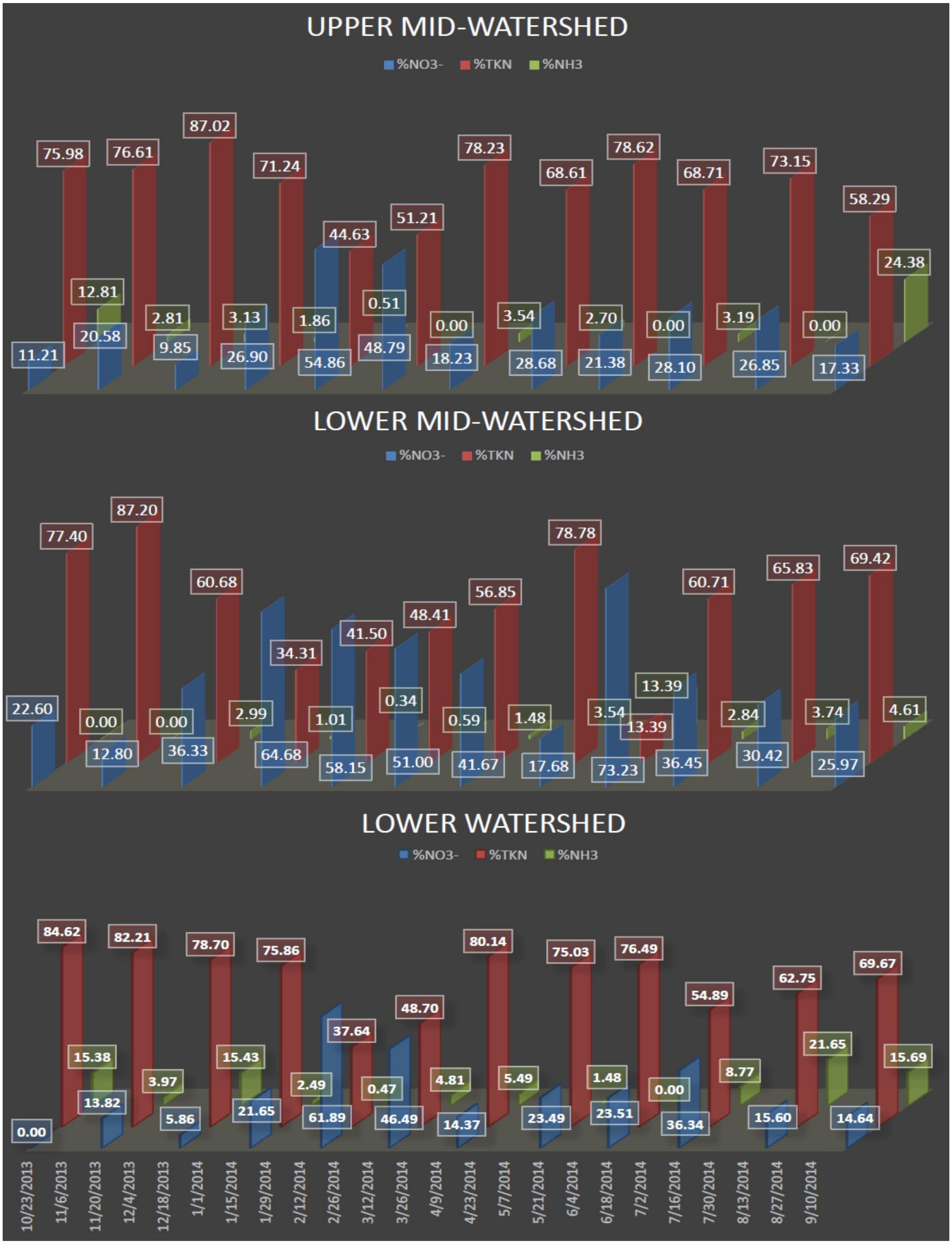


Figure 10. WY2014 Woodward and Murden Creek Nitrogen Speciation by Mass Percent

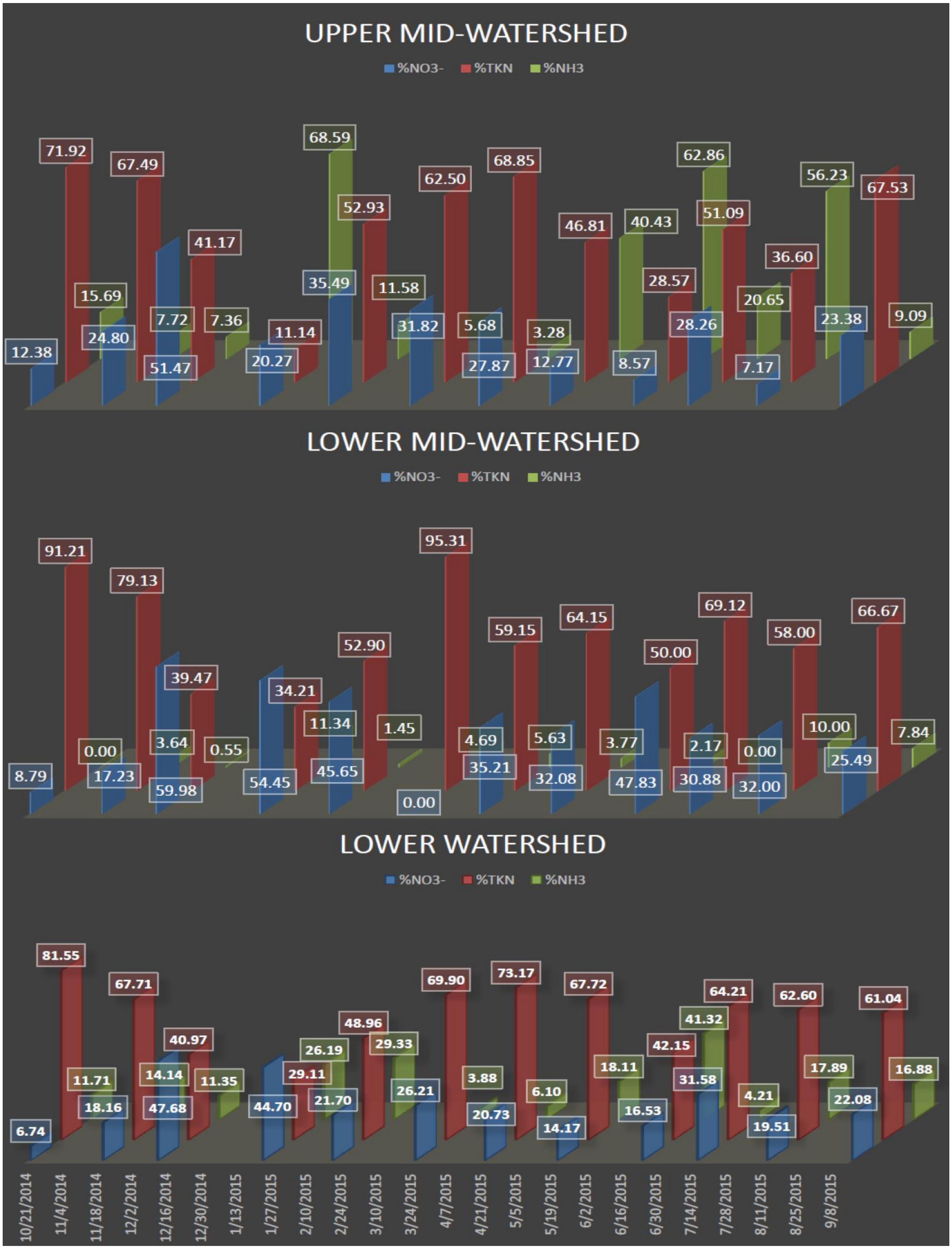


Figure 11. WY2015 Woodward and Murden Creek Nitrogen Speciation by Mass Percent

2.2.3.2 The Cove

In estuarine systems, nitrogen is the nutrient that drives growth, in particular the ratio of total inorganic nitrogen to total phosphorous. The recommended ratio of total inorganic nitrogen to total phosphorus to avoid algal blooms in estuaries is 10:1 with a recommended range of 0.1 to 1 mg/l nitrogen to 0.01- 0.1 mg/l phosphorus. However, environments with concentrations of these nutrients near the high end of these ranges generally have lesser aquatic life diversity.

Only 4 (12%) of the sampling events over the course of the project resulted in ratios in excess of 10:1 (Table 1). However, concentrations of total inorganic nitrogen and total phosphorus often fell near the higher end of the recommended ranges, *potentially* impacting aquatic life diversity, and periodically exceeded the limit of the recommended ranges, *likely* impacting aquatic life diversity and contributing to algal blooms.

As discussed in the previous section, total inorganic nitrogen is the sum of nitrate, nitrite, and ammonia concentration. Total inorganic nitrogen ranged from 0.23 mg/l to 2.48 mg/l in the cove with 12 sampling events (36%) over the course of the project resulting in values toward the higher end of the recommended range (> 0.49 – 1 mg/l). Another 3 sampling events (9%) resulted in values that exceeded the recommended range (>1 mg/l). As nitrite was not detected in any of the cove samples, it is ammonia and nitrate driving the total inorganic nitrogen concentration.

Ammonia concentrations in the cove ranged from no detection to 2.48 mg/l. Ammonia concentration exceeded the chronic criteria year-round, increasing over the dry season and peaking to acute levels in the late summer, then gradually decreasing to chronic levels over the wet season. The cove exceeded the acute criteria 14 times over the course of the project.

Nitrate concentrations in the cove ranged from no detection to 1.71 mg/l. Again, similar to the streams, the highest concentrations were observed during the wet season.

Total phosphorus concentrations ranged from 0.035 mg/l to 0.43 mg/l with 24% of sample results toward the high end of the recommended range (>0.05 mg/l) *potentially* impacting aquatic life diversity and 67% exceeding the recommended range (>0.1 mg/l) *likely* impacting aquatic life diversity.

Similar to streams, there did not appear to be a correlation between significant storm events and phosphorus concentration in the cove, but concentration did appear to increase over the dry season (peaking in August and September) then gradually decreasing over the wet season.

Table 1. Nitrogen and Phosphorus in Murden Cove (mg/l)

Sampling Date	Nitrate + Nitrite	Ammonia	Total Inorganic Nitrogen (TIN)	Total Phosphorus (TP)	TIN:TP
3/26/2013	0.326	0.136	0.462	0.077	6.00
4/29/2013	0.277	ND	0.277	0.035	7.91
5/22/2013	0.285	0.144	0.429	0.101	4.25
6/25/2013	0.321	0.210	0.531	0.138	3.85
7/25/2013	0.104	0.233	0.337	0.124	2.72
8/16/2013	0.096	0.741	0.837	0.37	2.26
9/18/2013	0.217	0.497	0.714	0.131	5.45
10/15/2013	0.222	0.111	0.333	0.123	2.71
11/14/2013	0.177	0.252	0.429	0.164	2.62
12/18/2013	0.327	0.276	0.603	0.172	3.51
1/21/2014	0.721	0.159	0.88	0.084	10.48
2/20/2014	1.71	0.041	1.751	0.04	43.78
3/19/2014	0.59	0.059	0.649	0.054	12.02
4/16/2014	0.272	0.191	0.463	0.101	4.58
5/20/2014	0.248	0.187	0.435	0.12	3.63
6/17/2014	0.271	0.152	0.423	0.122	3.47
7/16/2014	0.144	0.279	0.423	0.138	3.07
8/21/2014	0.142	0.605	0.747	0.302	2.47
9/23/2014	0.115	0.636	0.751	0.221	3.40
10/21/2014	0.136	0.171	0.307	0.11	2.79
11/19/2014	0.299	0.134	0.433	0.085	5.09
12/11/2014	1.29	0.051	1.341	0.102	13.15
1/22/2015	ND	2.480	2.480	ND	---
2/19/2015	0.32	0.060	0.38	0.07	5.43
3/24/2015	0.19	0.100	0.29	0.06	4.83
4/21/2015	0.23	0.160	0.39	0.08	4.88
5/20/2015	0.13	0.310	0.44	0.11	4.00
6/23/2015	0.1	0.360	0.46	0.43	1.07
7/15/2015	0.09	0.430	0.52	0.16	3.25
8/12/2015	0.06	0.440	0.5	0.2	2.50
9/15/2015	0.11	0.540	0.65	0.12	5.42
Targeted Storm Event Sampling					
1/10/2014	ND	0.230	0.230	0.0974	2.36
2/15/2014	0.864	0.091	0.955	0.161	5.93

ND = Nondetect

(yellow) *Values closer to the high end of recommended range; may have impact on aquatic life diversity.*

(red) *Exceeds recommended range or ratio; likely impacting aquatic life diversity and contributing to algal blooms.*

2.2.4 Pollutant Loads

Pollutants in a water sample are measured in a laboratory for concentration which is a mass per unit volume such as milligrams per liter (mg/l). The total mass of a pollutant (or load) in a waterbody such as a stream can be calculated by multiplying the concentration in the sample by the total volume of water in the stream (flow) at the time of sampling.

In-stream flow was measured in conjunction with monthly water quality sampling at each of the sampling sites. This allows for a rough estimate of instantaneous pollutant load, which is the mass of the pollutant being carried by the waterbody at the time of sampling.

Baseflow is the normal, or background, seasonal flow sustained by groundwater in the stream during non-storm conditions. Routine monthly sampling over the course of the project allowed a gross estimate of baseflow pollutant loads.

Additionally, monthly sampling coincided with two significant storms and resultant high flow events over the course of the project – one in February 2014 and one in December 2014. Over 2 inches of rain fell in the 72 hours preceding the sampling event (Appendix B). Fortunately, capturing pollutant concentrations and flow during and immediately following these events allowed an assessment of the potential impacts of stormwater runoff and elevated groundwater table contributions to flow and pollutant loads.

2.2.4.1 Phosphorus

As discussed in a previous section, there did not appear to be a correlation between seasons and total phosphorus concentrations in streams and the cove. This appeared to be the case with instantaneous baseflow total phosphorus loads, as well.

Baseflow loads at the mouth of Murden Creek in the cove did not vary significantly over the course of the project, ranging from 0.1 to 1.2 pounds per day (lbs/dy). However, loads at this location were generally higher than streams during the dry season (Figure 12). No WY2013 wet season samples were collected at this location. However, WY2014 and 2015 wet season baseflow loads were similar in both the cove and the streams (Figure 13).

Baseflow total phosphorus loads in streams were generally <0.8 lbs/dy. Notable exceptions were loads observed in the lower watershed (Murden Creek at Hwy 305) in WY2013 which ranged between 1.0 - 1.3 lbs/dy and Meig's Creek which spiked to 1.35 lbs/dy in WY2014. It should also be noted that although Meig's Creek usually carried the highest concentrations of total phosphorus as discussed previously, it was not usually carrying the highest load (or greatest mass) of total phosphorus. This is likely due to less flow in Meig's Creek relative to Woodward and Murden Creeks.

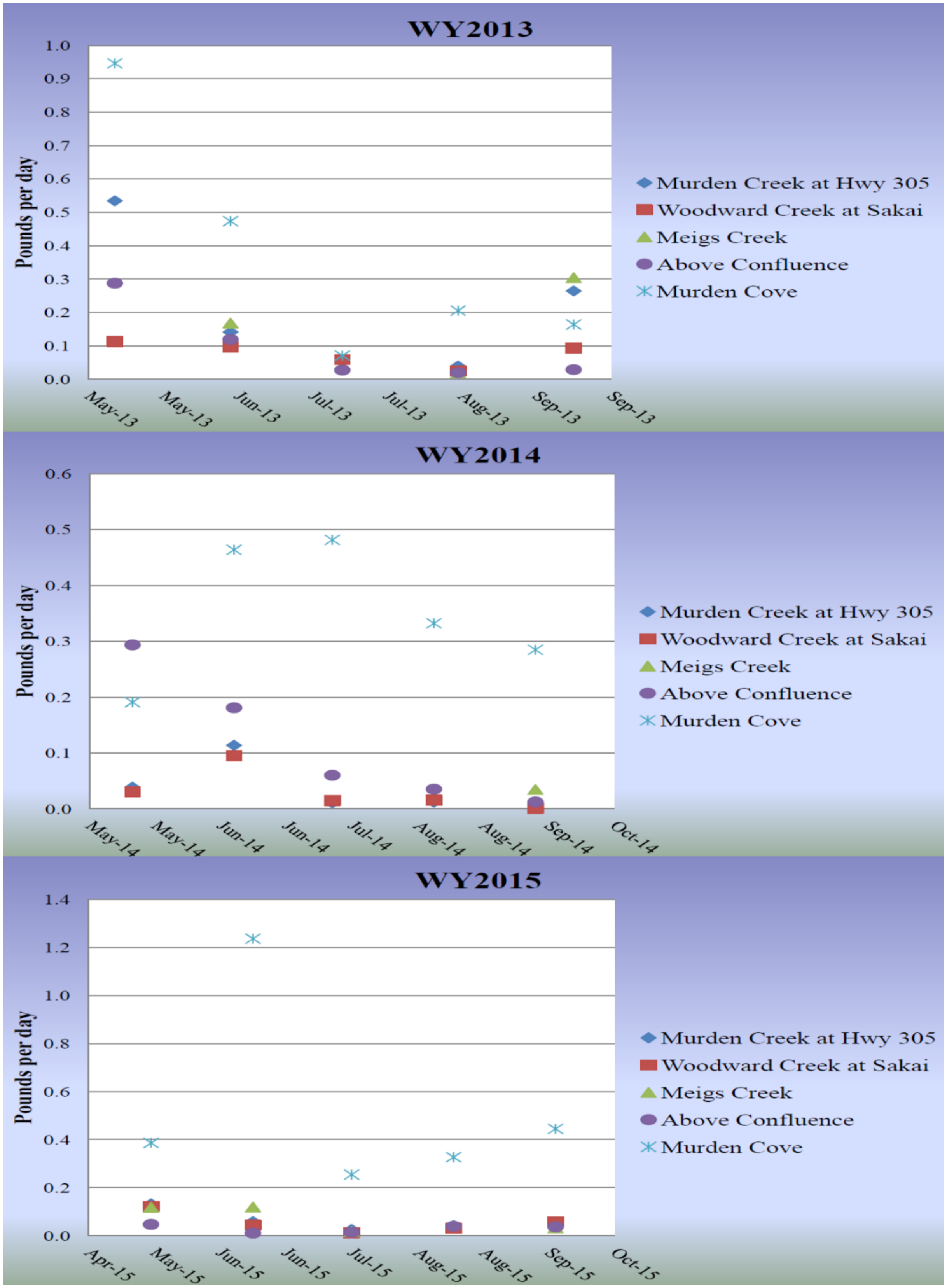


Figure 12. Dry Season Baseflow Instantaneous Total Phosphorus Loads

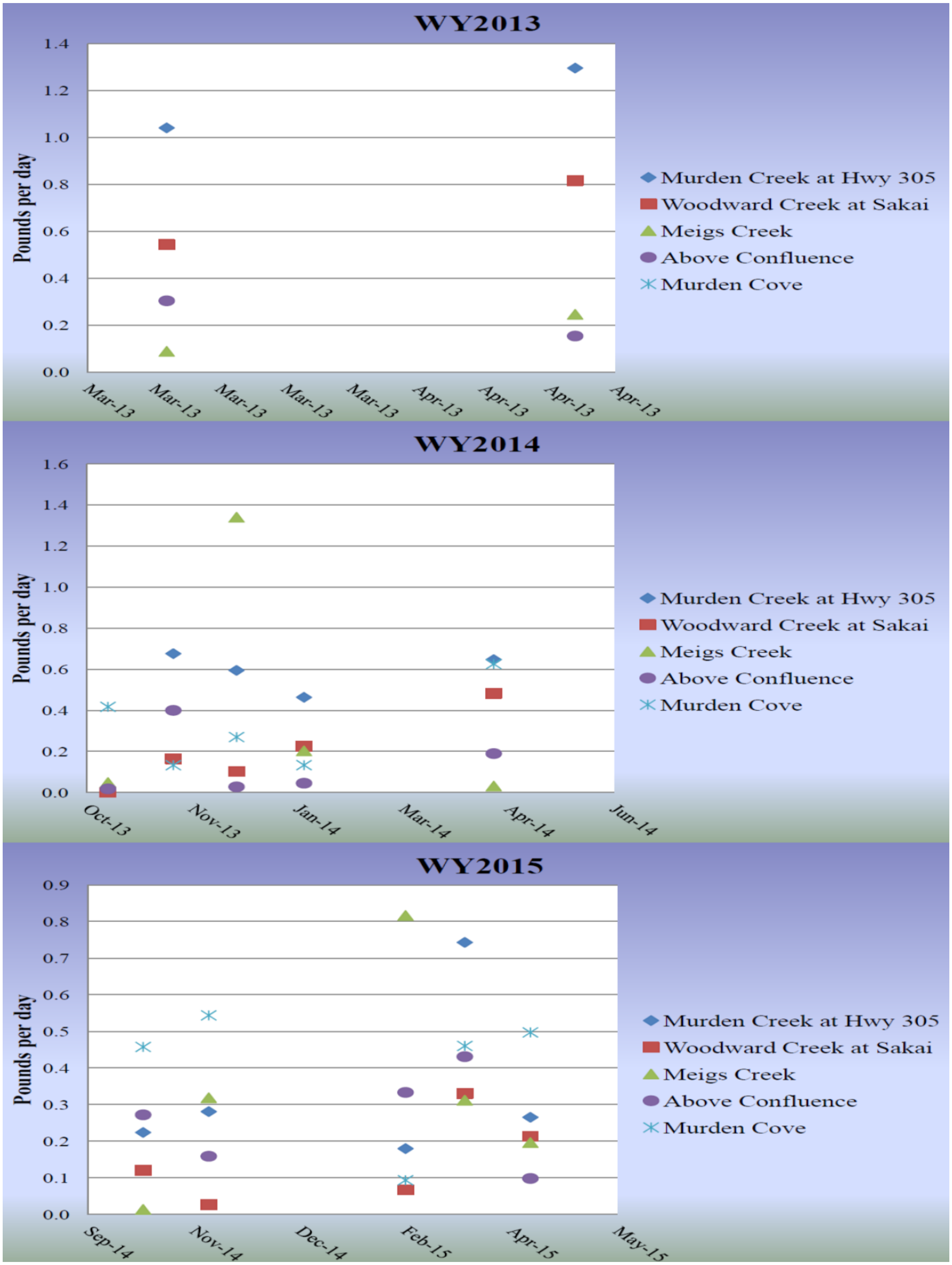


Figure 13. Wet Season Baseflow Instantaneous Total Phosphorus Loads

Although there was no apparent correlation between seasons and baseflow loading, there were moderate increases for some of the sites during the two significant storm events likely due to significant increases in flow. During the February 2014 storm event, flows increased between 12-15 times the normal baseflow (Appendix B). Total phosphorus loads in the streams ranged from 1.0 – 5.5 lbs/dy during this storm and 1 – 1.5 lbs/dy at the mouth of Murden Creek in the cove (Figure 14). During the December 2014 storm, stream loads ranged between 1.5 – 7.5 lbs/dy. However, total phosphorus load spiked to nearly 13 lbs/dy at the mouth of Murden Creek in the cove (Figure 15).

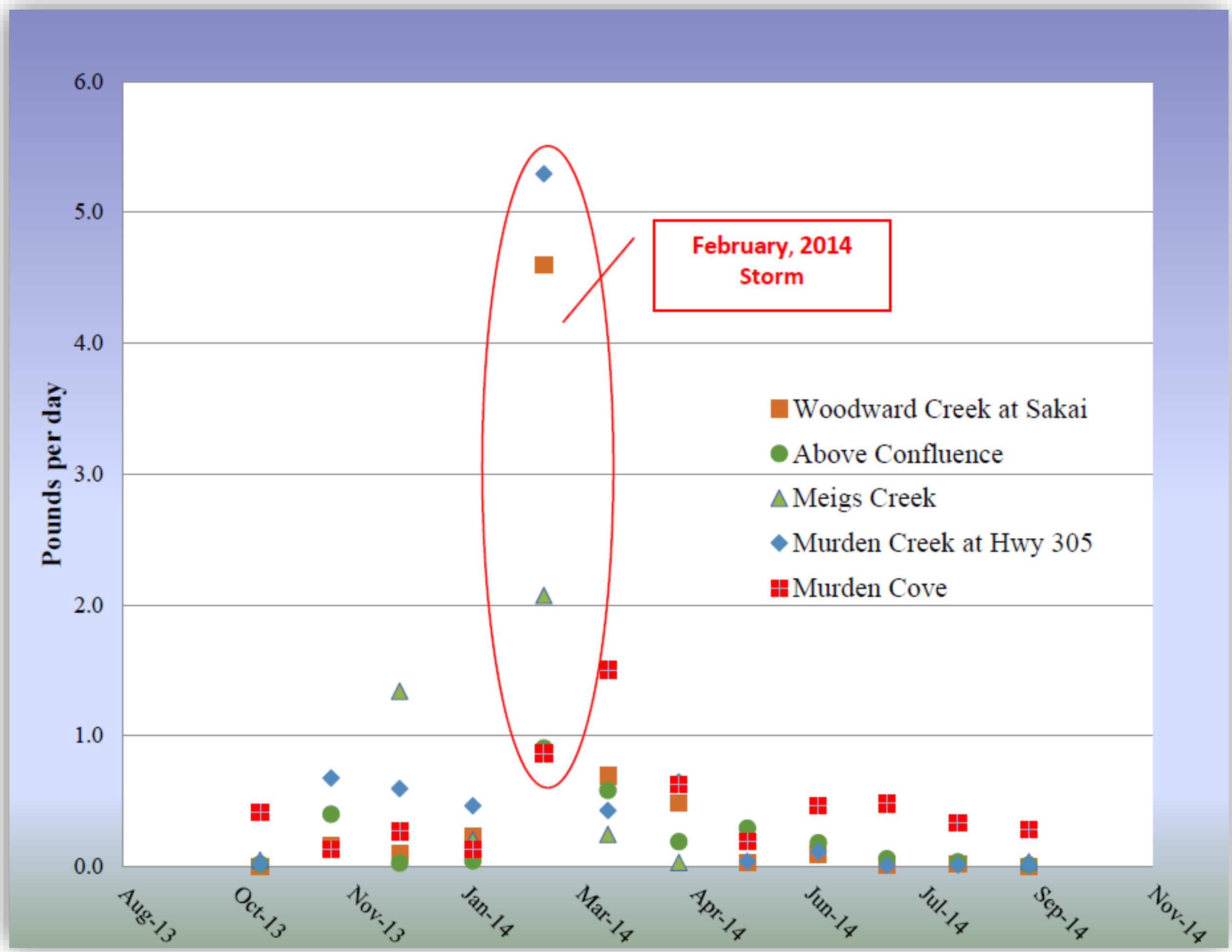


Figure 14. February 2014 Storm Event Instantaneous Total Phosphorus Loads

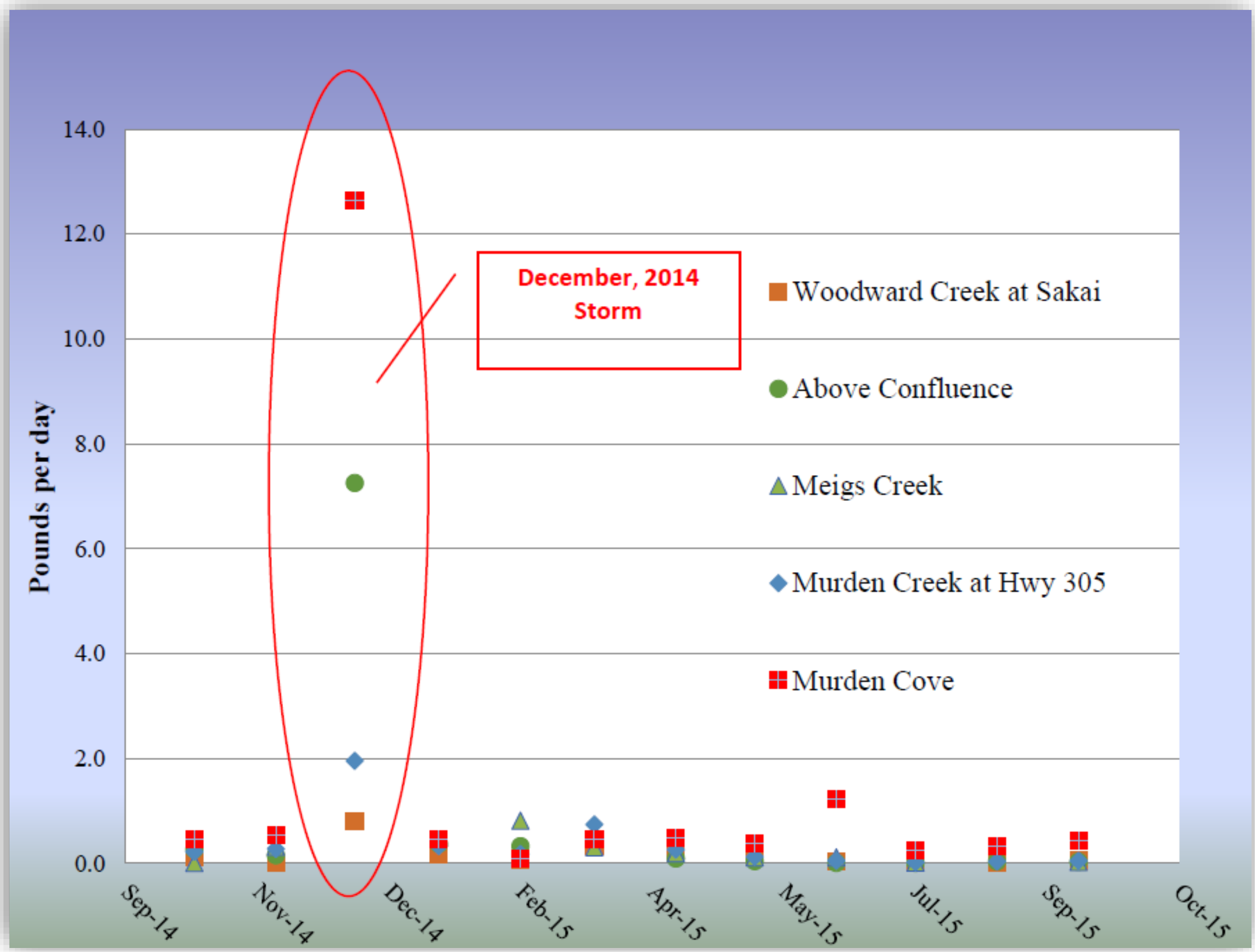


Figure 15. December 2014 Storm Event Instantaneous Total Phosphorus Loads

2.2.4.2 Nitrogen

As discussed previously it is the inorganic components of nitrogen (nitrate and ammonia) that are of most concern in controlling algal blooms in the cove and of most interest in assessing human sources of pollution in waterbodies.

2.2.4.2.1 Nitrate

There was an observed correlation between the wet season (particularly significant rain events) and increases in nitrate concentrations and mass percentages in streams and the cove as discussed previously. This seasonality is clearly seen in nitrate loads over the course of the project as well.

Instantaneous nitrate loads during dry season baseflow conditions in both streams and the mouth of Murden Creek in the cove showed a marked tapering off throughout the dry season (Figure 16). WY2013 stream dry season loads start at approximately 0.75 - 1 lbs/dy and taper off to approximately 0.25 lbs/dy by the end of the season in September.

WY2013 dry season loads observed at the Murden Creek mouth in the cove were slightly higher, starting near 2.75 lbs/dy and tapering off to 0.25 lbs/dy.

This trend was repeated in the following project years, except that slightly drier conditions in WY2014 dry season and significantly drier conditions in WY2015 dry season resulted in lower flows and, correspondingly, lesser loads overall. WY2014 dry season loads in streams start at approximately 0.3 – 0.8 lbs/dy and taper off to approximately 0.1 lbs/dy, and loads at the Murden Creek mouth in the cove start at approximately 1 lbs/dy and taper off to 0.2 lbs/dy.

WY2015 dry season loads in streams start at approximately 0.1 – 0.4 lbs/dy and taper off to < 0.1 lbs/dy, and loads at the Murden Creek mouth in the cove start at approximately 0.5 lbs/dy and taper off to 0.1 lbs/dy. Early onset of the rainy season in WY2015 is reflected in the rebounding loads in September.

Wet season baseflow loads for streams fluctuated somewhat in response to smaller rain events interspersed with dry periods and responding flows (Figure 17). Stream wet season baseflow loads in WY2013 and WY2014 ranged from near 0 lbs/dy (Meig's Creek) to approximately 1.5 – 2 lbs/dy in the mid and lower watershed) and ranged from near 0 lbs/dy (Meig's Creek) up to 3.0 lbs/dy in the mid and lower watershed. Wetter than normal conditions during WY2015 wet season increased stream loads to up near 4.5 lbs/dy.

Wet season baseflow loads in the mouth of Murden Creek in the cove were similar in WY2014 and WY2015, ranging from approximately 0.25 lbs/day to near 2.0 lbs/dy. No WY2013 wet season samples were collected at this location.

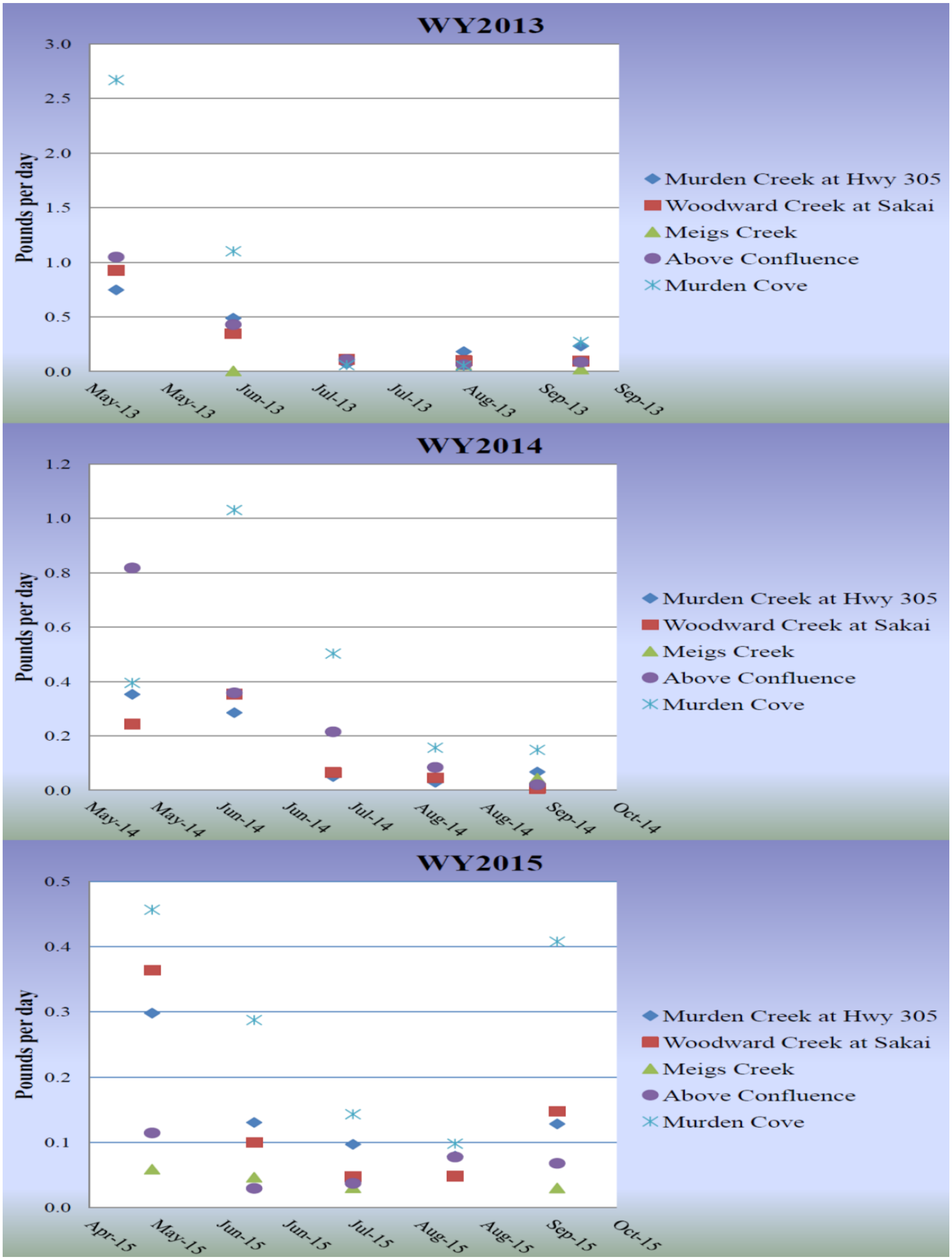


Figure 16. Dry Season Baseflow Instantaneous Nitrate Loads

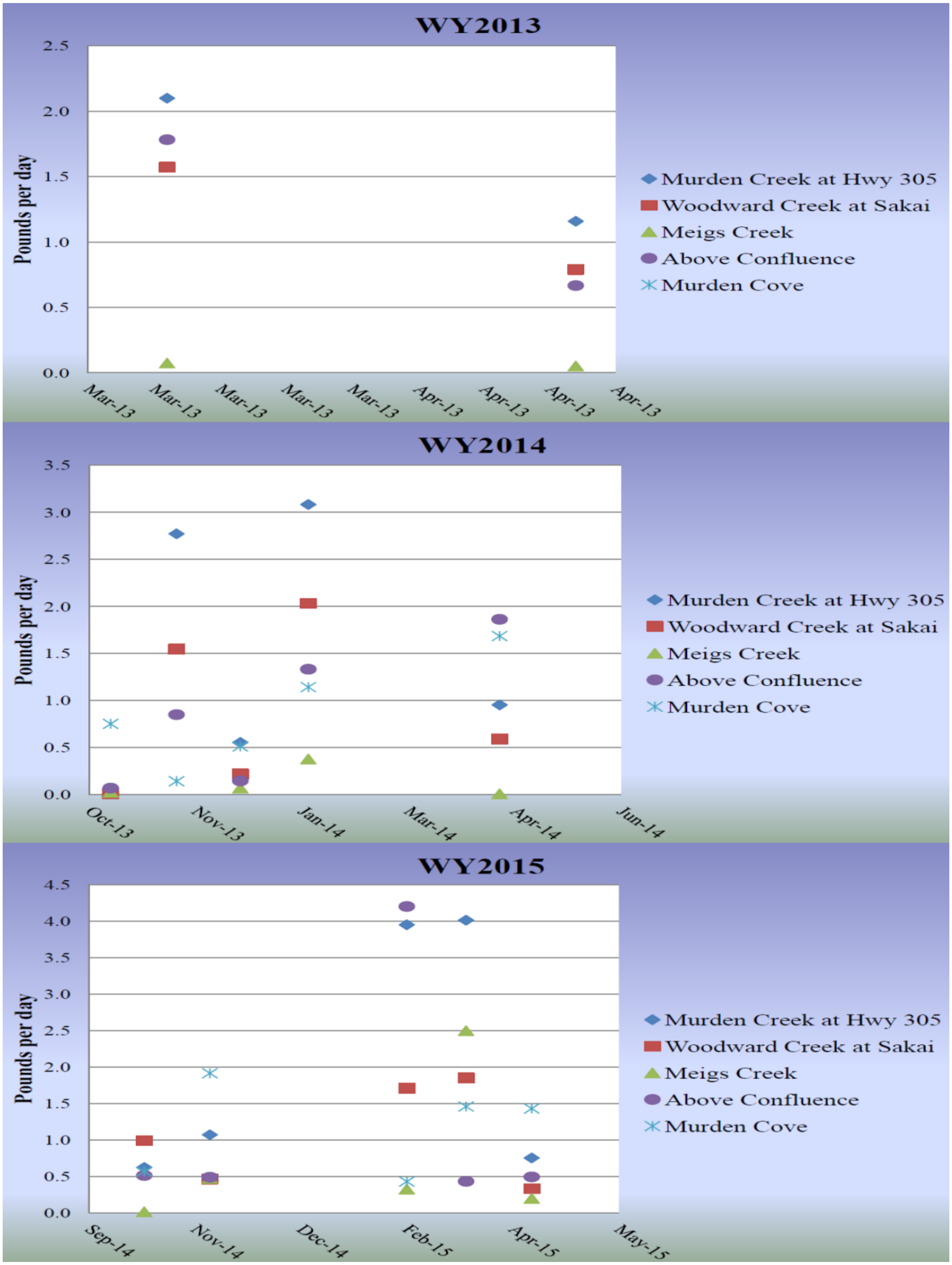


Figure 17. Wet Season Baseflow Instantaneous Nitrate Loads

During the two significant storm events, flows and loads increased dramatically. Nitrate loads increased to approximately 90 – 150 lbs/dy in the upper mid- and lower watershed (including Meig's Creek tributary) and approximately 40 lbs/dy in the lower mid-watershed and in the cove (Figure 18). During the December 2014 storm, the upper mid- and lower watershed loads peaked at 60-135 lbs/dy and the lower mid-watershed and the cove peaked at 160-250 lbs/dy (Figure 19).

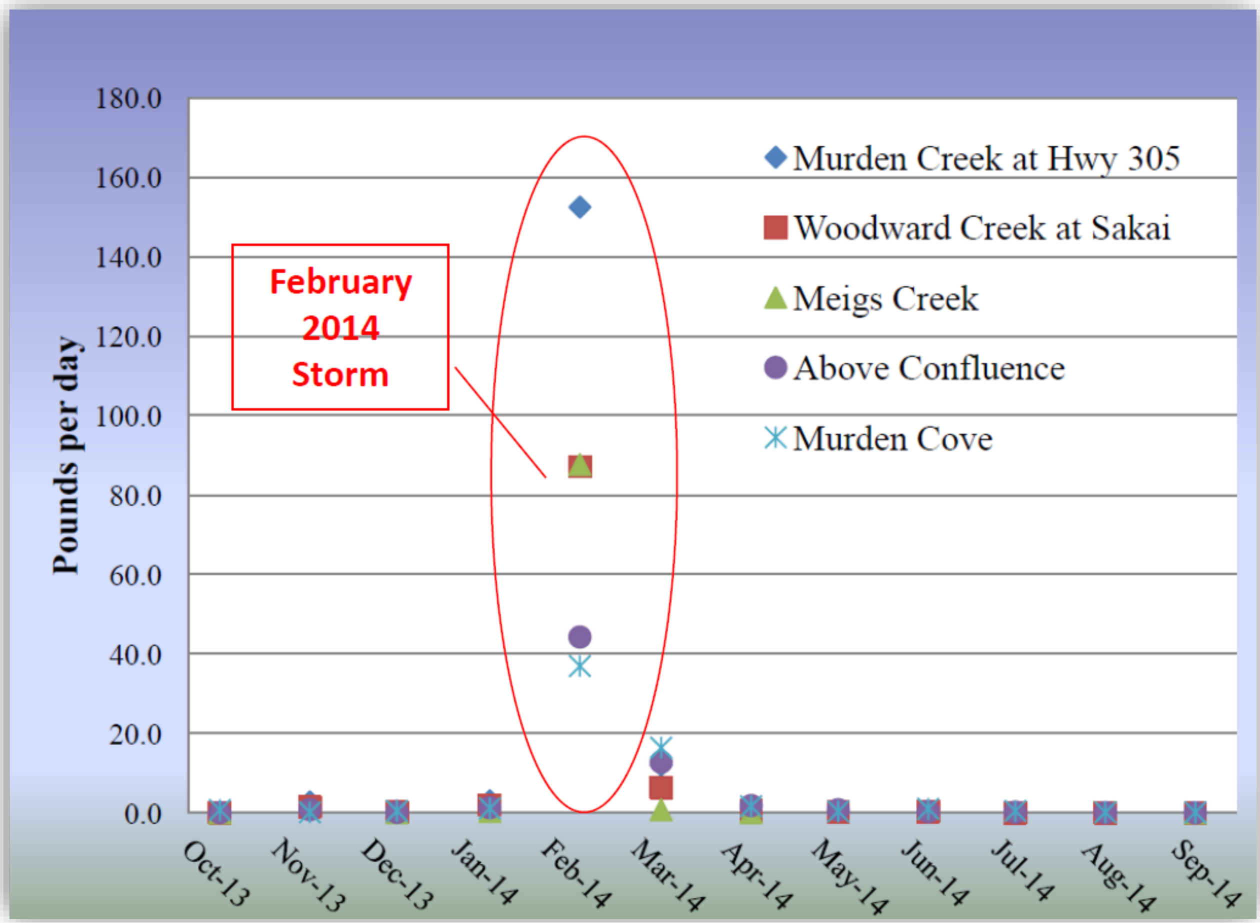


Figure 18. February 2014 Storm Event Instantaneous Nitrate Loads

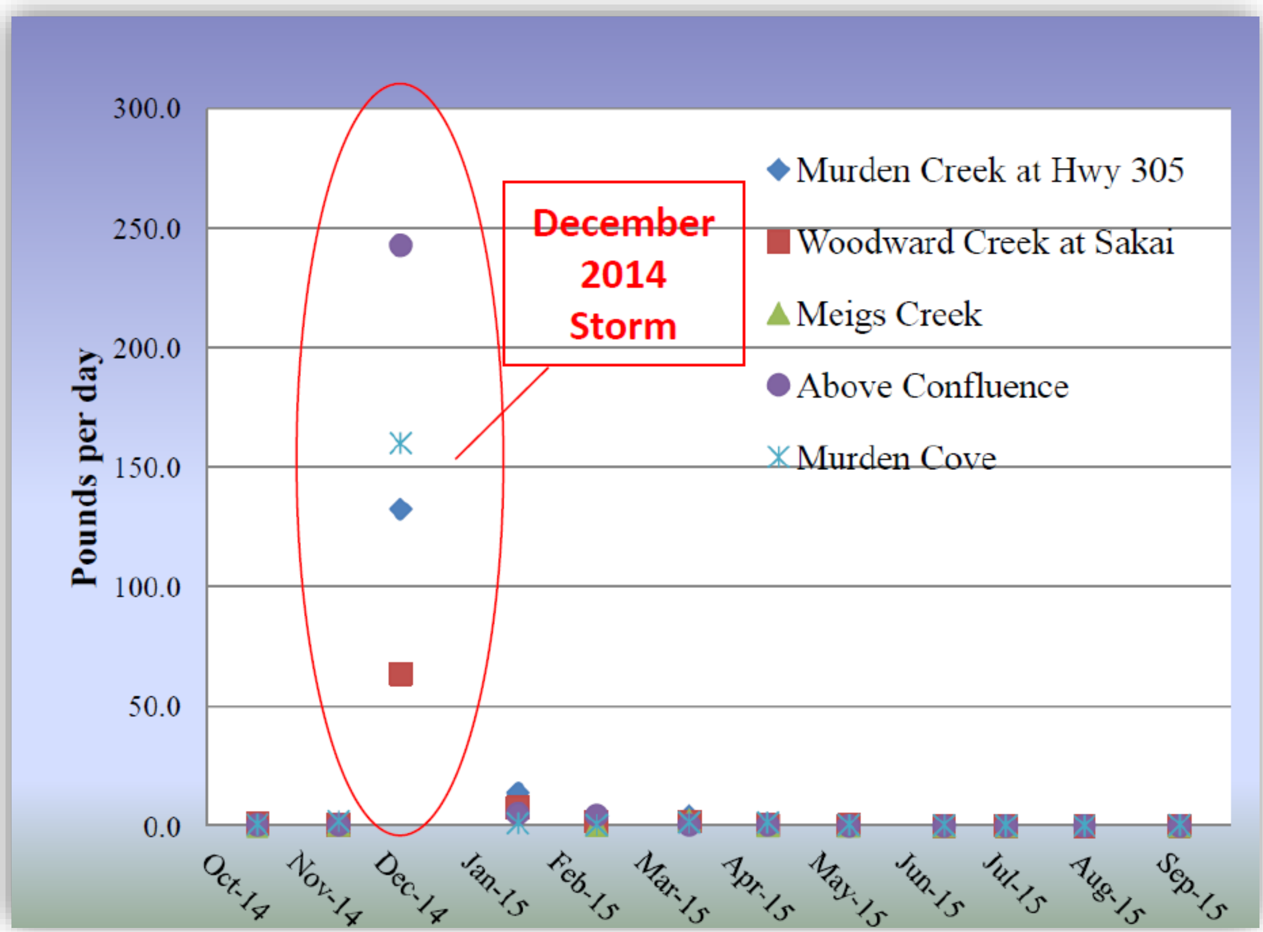


Figure 19. December 2014 Storm Event Instantaneous Nitrate Loads

2.2.4.2.2 Ammonia

Unlike nitrate, ammonia concentrations and mass percentages were higher in streams and cove over extended dry periods; however, this did not result in increased instantaneous loads, likely due to significantly less baseflow in the dry season.

Baseflow ammonia loads at the mouth of Murden Creek in the cove did not vary significantly over the course of the project, ranging from approximately 0 to 2.0 lbs/dy. However, loads at this location were generally higher than stream baseflow loads during the dry season (Figures 20 and 21).

Baseflow ammonia loads in streams did not vary significantly either. Wet season loads were generally <0.4 lbs/dy and dry season loads ranged from 0 - 0.8 lbs/dy. WY2015 saw very minor increases up to 1.5 lbs/dy over the wet season and 1 lbs/dy in the dry season.

There were a few notable peaks in observed loads. The lower watershed (Murden Creek at Hwy 305) spiked to 1.5 lbs/dy in December 2013 and coincided with a small rain event (~1 inch of rainfall in the previous 72 hours) and a corresponding increase in flow (Appendix B and Figure 22). The lower watershed site load also spiked to 5.5 lbs/dy in February 2015. This coincided with the highest concentrations measured at this site, but no rainfall or increased flow. This was not observed at any of the other sites on that day.

The cause for this spike is unknown, but it was observed by field staff that high flows from heavy rain events in the previous months washed out a beaver dam on Meig's Creek immediately above the confluence with the mainstem, releasing ponded water from behind the dam. The lower watershed site is the only stream site downstream of that location, and this may explain the observed phenomenon.

In previous discussion, it was noted that the lower watershed site at Hwy 305 did not have the highest concentrations in ammonia. However, it appears to be carrying the biggest loads (greatest mass). Again, it is important to consider flow when assessing and prioritizing stream segments or reaches for investigation as the location with the highest concentration may not be carrying the biggest load.

The upper mid-watershed site at Woodward Creek and the cove also spiked in January, 2015, but this increase did not seem to coincide with a storm and high flow event (Figure 23).

Although flows increased dramatically in response to the two significant storm events, ammonia loads had a mixed response. During the February 2014 storm event, ammonia loads showed very little measurable response (Figure 22). During the December 2014 storm, the mid-watershed sites and the cove had very minor load increases between 5-10 lbs/dy (Figure 23). It was only the lower watershed at Hwy 305 that spiked to just over 30 lbs/dy. This was followed by a notable spike observed at the mouth of Murden Creek in the cove which increased to 55 lbs/dy the following month.

Although baseflow ammonia loads are similar in scope to nitrate loads and are significantly smaller in scope than nitrate loads during intense rain events, even small amounts of ammonia can be toxic. Therefore, it is not surprising that streams experience frequent exceedances of chronic criteria and the cove frequently exceeds the acute criteria.

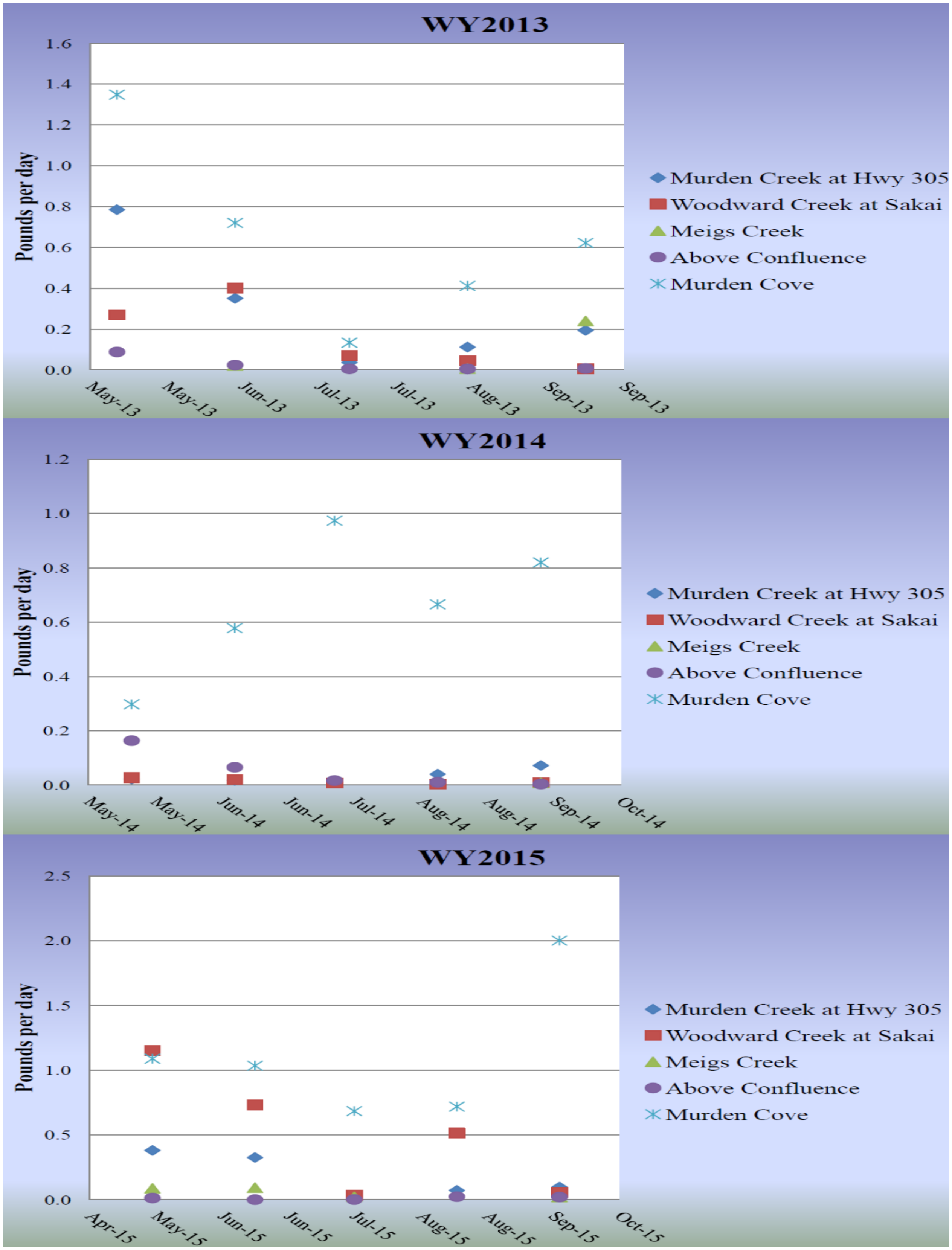


Figure 20. Dry Season Baseflow Instantaneous Ammonia Loads

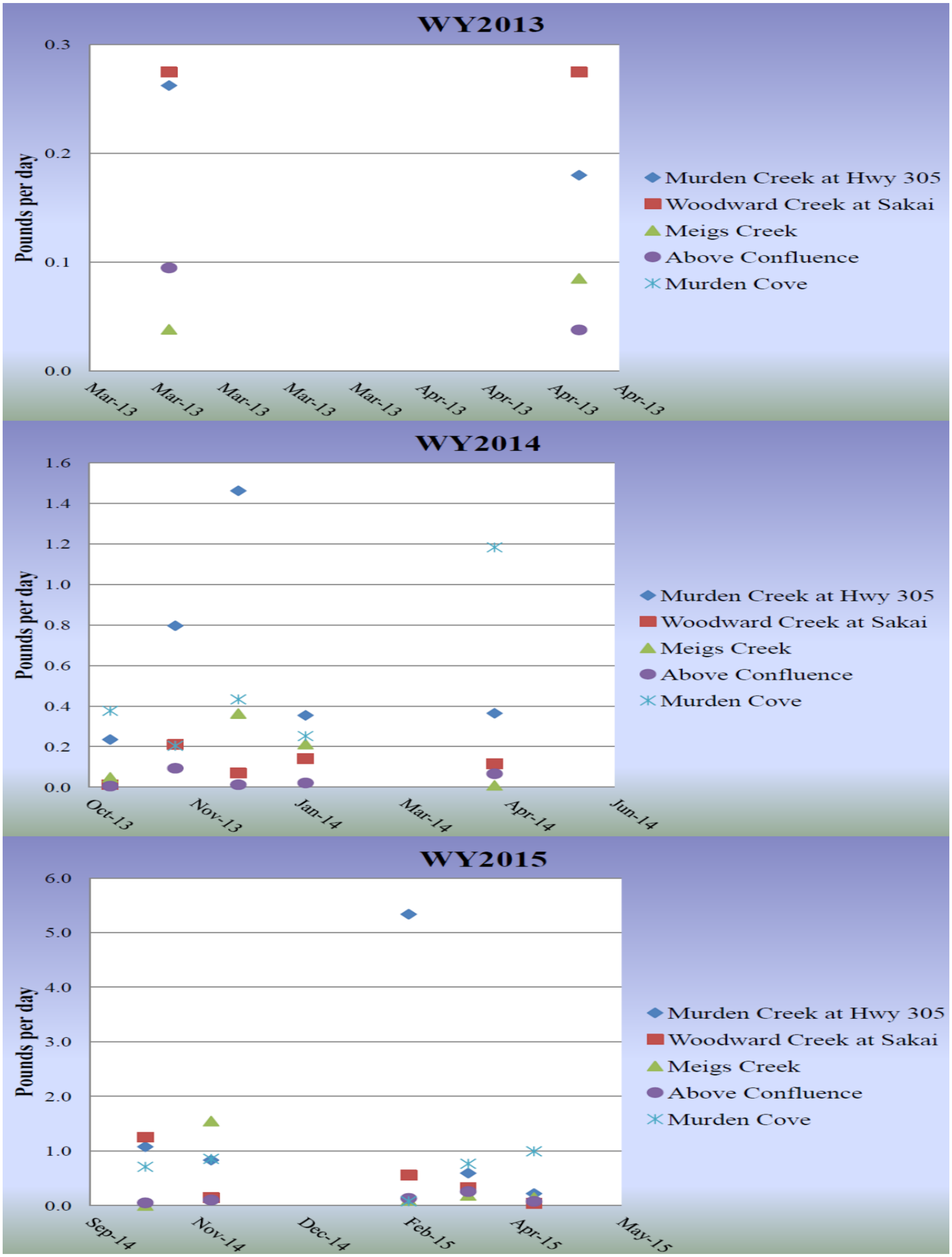


Figure 21. Wet Season Baseflow Instantaneous Ammonia Loads

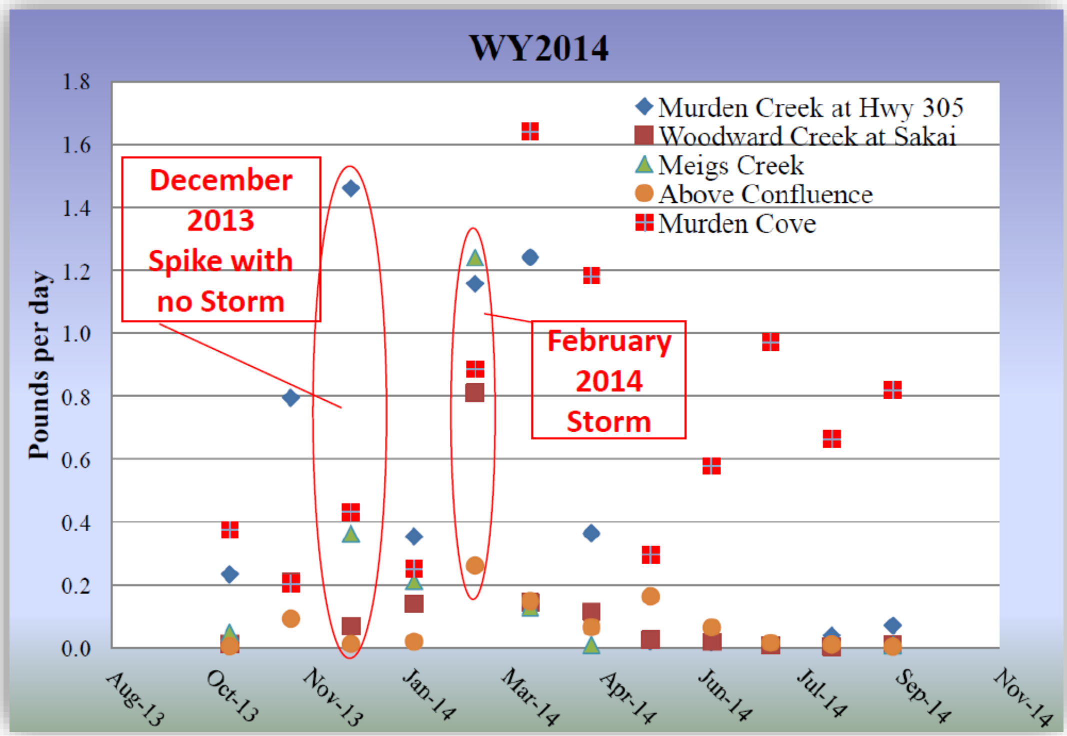


Figure 22. February 2014 Storm Event Instantaneous Ammonia Loads

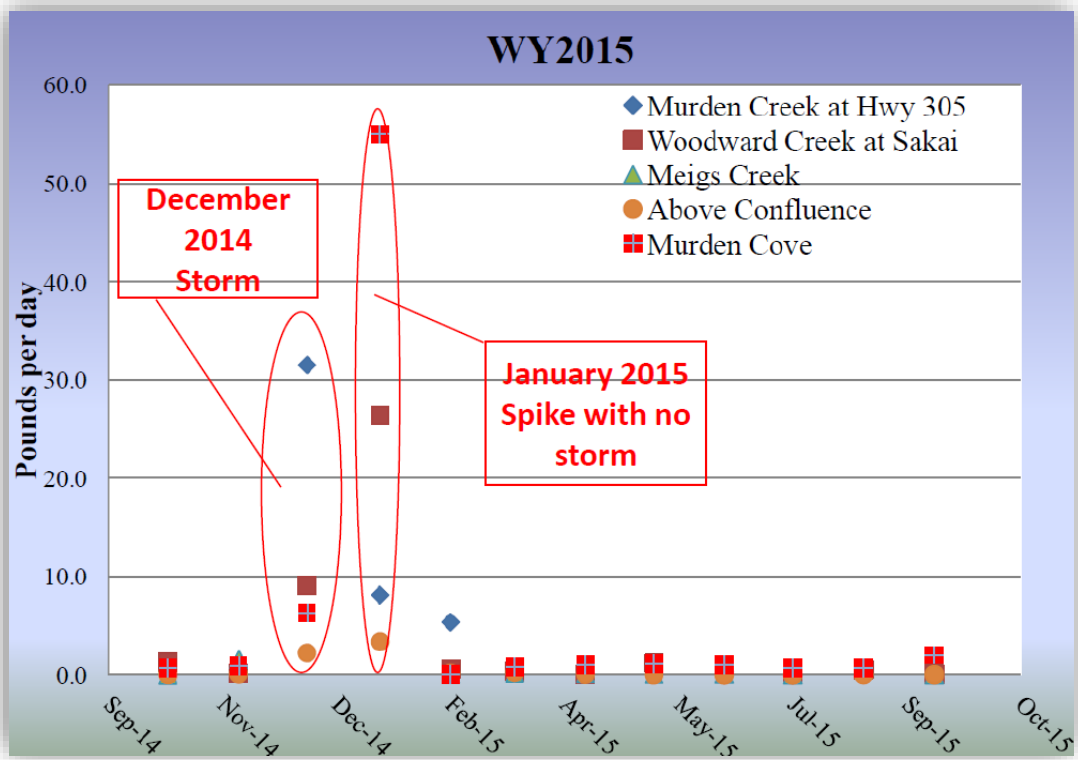


Figure 23. December 2014 Storm Event Instantaneous Ammonia Loads

2.2.4.3 Bacteria

Unlike chemical pollutants, bacteria are living organisms whose populations expand and contract in response to multiple factors in the environment (such as temperature and water salinity). This is the primary basis for the two-part criteria discussed in section 2.2.2.

Therefore, when estimating baseflow bacteria load for a waterbody, it is more common to use seasonal and annual geometric mean concentrations and a mean (average) baseflow, rather than the monthly instantaneous concentration and flow.

As discussed previously, the dry season is the most challenging for streams in terms of meeting criteria as concentrations are usually at their highest due to low flow (less dilution) and very warm temperatures which encourage bacterial growth. This is clearly evident in the dry season baseflow bacteria loads. Despite significantly less flow, dry season concentrations were so much greater than wet season concentrations that the dry season loads were significantly higher than wet season (Figures 24 and 25).

Over the course of the project, dry season loads in the mid-watershed ranged between 63 - 913 million colonies per day (mil col/dy). The lower watershed was significantly higher at 378 - 4,420 mil col/dy. Wet season baseflow loads in the mid-watershed were 58-302 mil col/dy and, again, higher in the lower watershed at 523 – 567 mil col/dy.

Loads at the mouth of Murden Creek in Murden Cove followed a similar trend with higher loads registered in the dry season. Dry season baseflow loads ranged from 375 – 3,056 mil col/dy and wet season loads ranged from 283 – 421 mil col/dy.

Annual (by water year) loads measured between 129 – 737 mil col/dy in the mid-watershed, 808-2,820 in the lower watershed, and 4.8-1,225 mil col/dy at the mouth of Murden Creek in the cove (Figure 26).

Storm event impacts to loading were primarily through increased flow. Due to these high flow events, loads spiked dramatically in stream sites and to a more moderate level in the cove.

Only one stream site (upper mid-watershed Woodward at Sakai) showed a significant increase in bacteria concentration during these events. This coupled with the increased flow caused loads to reach 152,249 mil col/dy during the February 2014 event compared to 6,263 – 16,177 mil col/dy at the other stream sites.

The mouth of Murden Creek at the cove showed a moderate response in load (1,961 mil col/dy) during the February 2014 event, but peaked dramatically both in concentration and flow during the December 2014 event, resulting in a load of 50,629 mil col/dy.

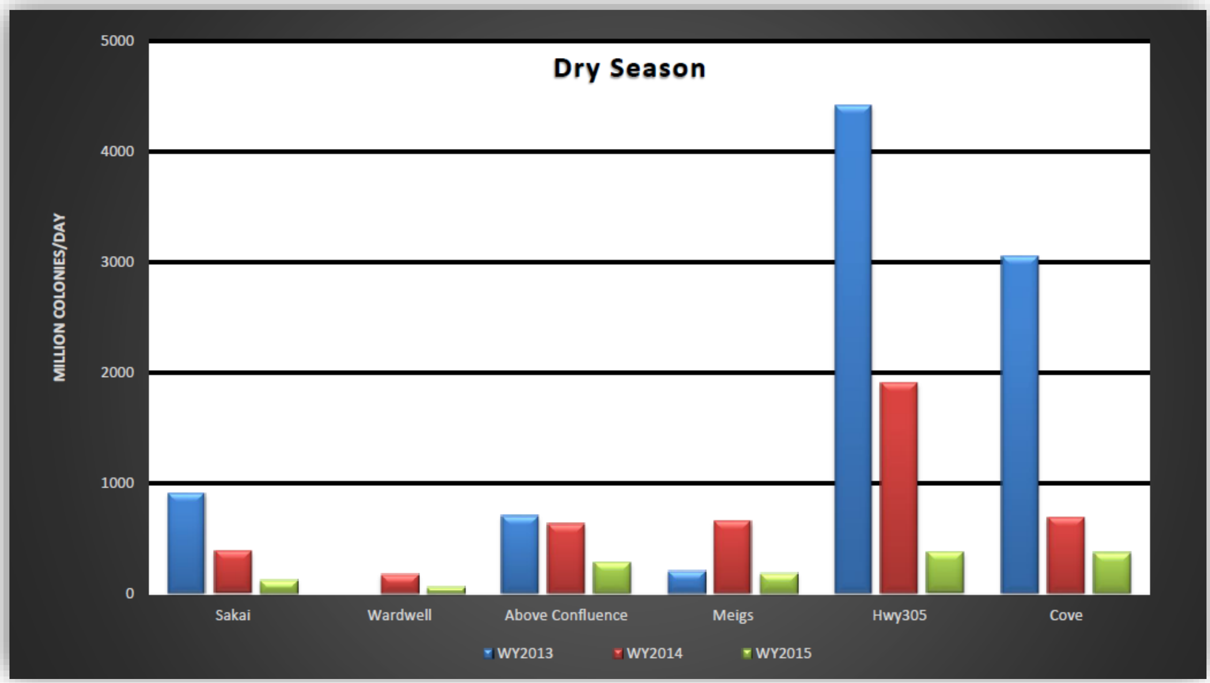


Figure 24. Dry Season Baseflow Mean Bacteria Loads by Water Year

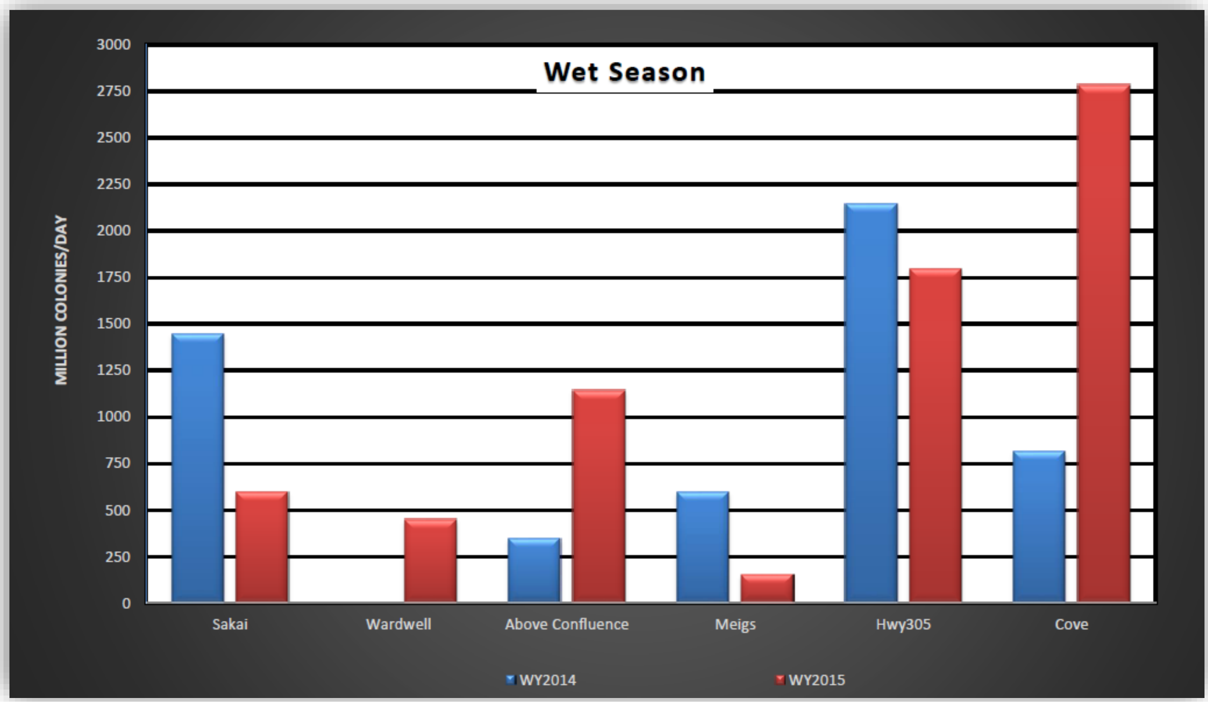


Figure 25. Wet Season Baseflow Mean Bacteria Loads by Water Year

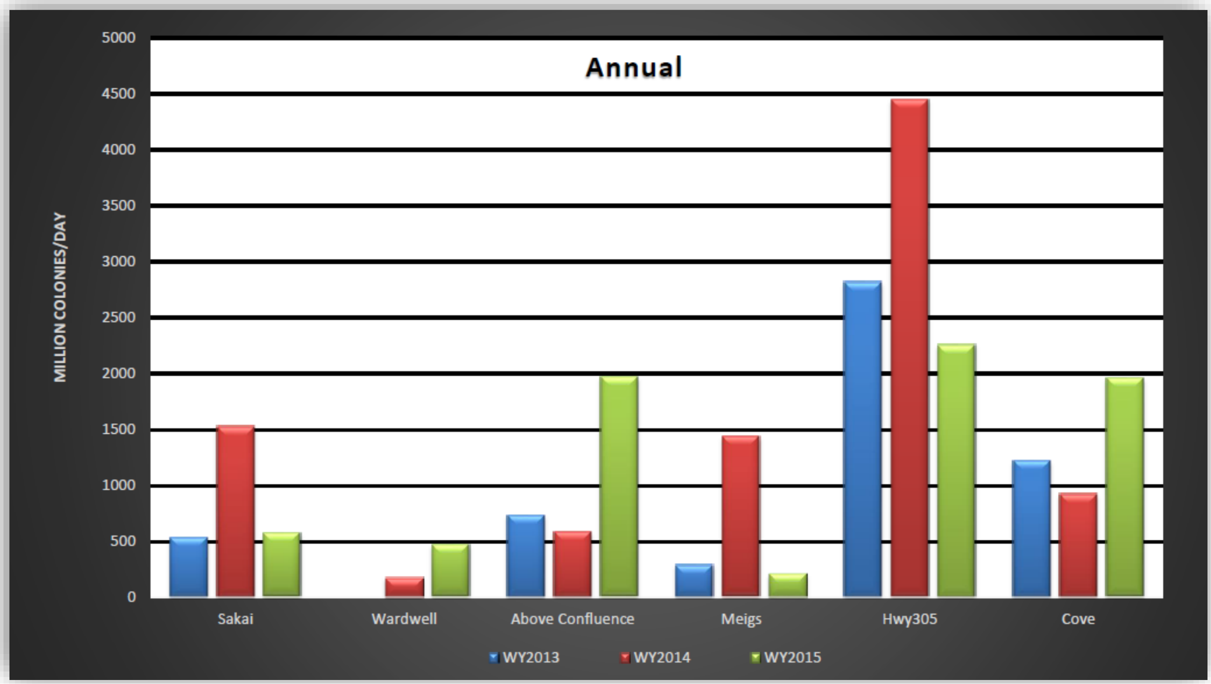


Figure 26. Annual Baseflow Mean Bacteria Loads by Water Year

3.0 ACHIEVEMENTS

The two primary objectives of this project were to define Murden Cove Watershed's water quality challenges and to identify and reduce sources of nutrients and bacteria in the watershed.

This project was successful in defining Murden Cove Watershed's water quality challenges by both examining water quality criteria and benchmark exceedances and detailing baseflow conditions as well as seasonal and storm runoff impacts on pollutant concentrations and loading in the watershed's primary drainage network – Murden Creek mainstem and tributaries, and in the cove at the mouth of Murden Creek (Section 2.0 – Findings).

Further, the partnership's focused source identification, technical assistance, and education and outreach, resulted in some significant reductions in bacteria and total phosphorus over the course of the project.

3.1 Bacteria

Fecal coliform bacteria is the one pollutant for which both Murden Creek and Murden Cove are declared impaired by Ecology. Though bacteria rarely impacts aquatic life, it (and the bloodborne pathogens and other pollutants such as pharmaceuticals, beauty products, and caffeine that are generally found with bacteria) can have serious consequences for human health either through primary contact such as swimming and wading or through the consumption of shellfish harvested from a contaminated area. Therefore, it was of primary importance to the partnership to find and eliminate sources of bacteria in the watershed.

3.1.1 Reduction in Average Concentration

Mean bacterial concentrations dropped significantly over the course of the project. During the critical dry season, most stream sites along the mainstem and the cove showed downward trends (Figure 6). Meig's Creek tributary increased dramatically in the second project year (WY2014) potentially due to improperly-managed manure found in close proximity to the stream. However, after prompt technical assistance, the issue was quickly resolved. This action is likely responsible for the dramatic decrease in Meig's Creek mean concentration in the last project year (WY2015). This improvement is significant as the WY2015 dry season saw extremely high temperatures and low flows (more growth/less dilution).

As the sampling site along the mainstem above the confluence with Meig's Creek had to be moved further upstream in WY2015, it is not possible to determine a dry season trend for this location.

Annual concentrations also showed promising downward trends at all sampling locations (Figure 7). Most significantly, the annual mean concentrations at two stream sites could not meet Part I of the criteria at the start of the project (mainstem above the confluence with Meig's Creek in the lower mid-watershed and Murden Creek at Hwy 305 in the lower watershed), but both met Part I by the end of the project.

3.1.2 Reduction in Percentage of Exceedances

A similar improving trend is evident in the decreasing percentage of monthly concentrations that exceeded Part II of the criteria (Figures 6 and 7). As discussed above, Meig's Creek concentrations spiked in WY2014, so the percentage of exceedance also increased. However, the percentage quickly decreased along with concentrations in WY2015 despite the extreme high temperatures and low flow.

All sites showed significant reductions in the percentage of Part II exceedances by the end of the project.

3.1.3 Reduction in Load

Reductions in pollutant concentrations are important from the standpoint of meeting a water quality standard or criteria. However, it is the reduction in *pollutant load* which is a true indicator of a successful reduction of the total mass of a pollutant in a waterbody.

Bacterial load trends during the critical dry season in watershed streams and the cove showed the same improvements observed in mean concentrations and percent exceedances. All sites showed significant reductions in bacterial loads during the dry season by the end of the project (Figure 24).

Trends in annual bacterial loads were more mixed (Figure 26). Woodward Creek at Sakai experienced a dramatic increase in annual load in WY2014, but quickly rebounded in WY2015. Only Meig's Creek and the lower watershed site (Murden Creek at Hwy 305) showed reductions in annual load by the end of the project.

3.2 Phosphorus

Phosphorus, the critical driver behind aquatic plant growth in freshwater (streams), also showed significant reductions over the course of the project.

3.2.1 Reduction in Concentration

In WY2013, Woodward Creek at Sakai, Murden Creek at Hwy 305, and Meig's Creek frequently exceeded EPA's benchmark of 0.1 mg/l. However, Woodward Creek at Sakai and Murden Creek at Hwy 305 saw significant reductions over the course of the project.

In WY2013, Woodward Creek at Sakai concentrations exceeded four times and exceedances ranged from 0.113 – 0.238 mg/l. By the second project year Woodward Creek had only one exceedance at 0.168 mg/l, and by the final project year had only one exceedance barely above the benchmark at 0.11 mg/l.

In WY2013, Murden Creek concentrations exceeded five times and exceedances ranged from 0.126 – 0.216 mg/l. By the second project year, Murden Creek had three exceedances that ranged from 0.106 – 0.135 mg/l, and by the final project year had only one exceedance barely above the benchmark at 0.13 mg/l.

3.2.2 Reduction in Load

Streams showed a moderate downward trend in baseflow total phosphorus load over the course of the project during both the wet and dry seasons (Figures 12 and 13). This is a notable achievement as WY2015 wet season was significantly wetter than usual and baseflows higher, but phosphorus load continued to decrease indicating an overall reduction in phosphorus in the streams. This agrees with the observed reductions in total phosphorus concentrations over the course of the project.

4.0 POTENTIAL NEXT STEPS

This project took important first steps in describing mid to lower watershed conditions and in reducing some of the pollutant loads impairing habitat and putting aquatic and human health at risk. However, project monitoring results highlighted continuing challenges and several areas for continued improvement.

4.1 Continuing Challenges

4.1.1 Bacteria

Despite promising downward trends in mean concentrations, percent exceedances, and loads over the course of the project, streams continued to fail Part II of the criteria (percentage of exceedances) on both a water year basis and during the critical dry season. During the critical dry season, Meig's Creek tributary and lower watershed stream sites continued to fail Part I of the criteria as well.

The Woodward Creek at Wardwell site was added to the project in WY2014 and the annual mean load at this location increased by the end of WY2015.

Lastly, despite promising downward trends in concentrations and percent exceedances, the cove at the mouth of Murden Creek continued to fail to meet both Parts I and II of the criteria and mean annual load increased by the end of the project.

4.1.2 Nutrients

Although total phosphorus concentrations and loads in streams showed moderate reductions over the course of the project, concentrations in the cove were still on the high end of the acceptable range, potentially impairing aquatic life diversity.

Unfortunately, there were no observed improvements in nitrogen loading in the watershed over the course of the project. Nitrogen speciation revealed that inorganic nitrogen, specifically nitrate and ammonia, continued to challenge the watershed streams and the cove. Concentrations of inorganic nitrogen were frequently near the high end of the acceptable range in the cove. Not only does this potentially impair aquatic life diversity, but it also creates a nutrient-rich environment for algal growth.

Lastly, streams continued to fail the chronic criteria for ammonia, and the cove frequently failed the acute criteria, putting aquatic life at risk.

4.1.3 Temperature and Dissolved Oxygen

Temperature and dissolved oxygen appeared to be driven by habitat-related stressors such as lack of canopy cover (shading) and low flows. These stressors were not targeted as part of this project; therefore, there were no improvements in these parameters over the course of the project. Project baseline monitoring indicated that they continued to fail aquatic life protection criteria in both streams and the cove, especially during the Core Summer Salmonid Habitat season.

4.2 Recommended Next Steps

In order to address these multiple continuing challenges in the watershed, it is recommended that a watershed management plan be developed through a similar community partnership. As part of that plan, the following work items should be considered at a minimum:

1. Additional baseline monitoring in the watershed to include the upper watershed which could include the following assessments:
   - Habitat survey to identify areas for restoration, enhancement, and conservation to improve temperature and dissolved oxygen
   - Fish utilization and productivity study
   - Sediment transport study
   - Human vs. animal bacterial study and/or contaminants of emerging concern studies to further identify and address human sources of bacteria and other bloodborne pathogens and human byproducts in the watershed. Some examples include:
     - Microbial Source Tracking (MST)
     - Integrative Diagnostic Stormwater Monitoring with Passive Sampling (USN, 2016) Note: This is a current ongoing pilot study by the U.S. Navy utilizing two sampling locations on the Island, including one in Murden Creek.
   - Nitrate source identification using isotope analysis of surface and groundwater to identify sources of inorganic nitrogen impacting the watershed to include septic systems, industrial sources, fertilizers, and areal deposition (Wernick, et.al., 1998) and (Wieban, et.al., 2012).
2. Identify and incentivize opportunities for low impact development (new and retrofit) not only to buffer stormwater runoff impacts during intense rain events, but to replenish shallow groundwater that sustains summertime flows (where feasible).
3. Study/incentivize water reuse and aquifer recharge protection/replenishment (where feasible).

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Appendix A: Partner Profiles

A.1 City of Bainbridge Island (Lead)

The City's Water Quality and Flow Monitoring Program's (WQFMP's) primary mission is to protect and restore the beneficial and designated uses of the Island's water resources. The WQFMP has been assessing the Island's surface water conditions since 2007.

The City not only provided training on the calibration and use of monitoring instruments and equipment, provided monitoring equipment, and coordinated monitoring efforts, but the City also served as the project hub by providing data compilation and analysis, data sharing, project effectiveness assessment, and project reporting (exception: grant reports and other deliverables were prepared and submitted by the individual grant holders). This allowed participants to work under their respective grants while, at the same time, contribute to the larger comprehensive watershed project.

The City conducted monthly water quality monitoring (including flow) at two project sites in addition to its long-term status and trends monitoring station in the watershed. The City also conducted annual stream macroinvertebrate sampling and one-time targeted storm event sampling in the watershed over the duration of the project.

A.2 Kitsap Public Health District

The Kitsap Public Health District's (KPHD's) Pollution Identification and Correction (PIC) program has demonstrated its capability for identifying and correcting nonpoint sources of pollution since 1996.

As Murden Cove provides critical shellfish habitat and provides waterfront access for Island residents, KPHD received a National Estuary Program Toxics and Nutrients Grant to address nutrient sources and bacteria sources in the Murden Cove Watershed.

KPDH efforts included an assessment of residential sources of nutrient pollution by routine water quality monitoring (three sites), an evaluation of land use practices including inspections of onsite sewage systems and the use of fertilizers, and the dissemination of information and resources to the public.

KPHD conducted outfall/drain point assessment in conjunction with the Bainbridge Island Watershed Council's (BIWC's) in-stream habitat survey whereby KPHD mapped, sampled, and assessed all flowing outfall/drain points along Murden Creek for bacteria, nutrients, physiochemistry, and flow. All elevated levels were investigated in conjunction with City and Kitsap Conservation District staff. Additional educational outreach efforts were coordinated with BIWC and Sonoji Sakai Intermediate School.

A.3 Sonoji Sakai Intermediate School and Islandwood

Sonoji Sakai Intermediate School (Sakai) sits adjacent to Woodward Creek, one of two primary tributaries in the Murden Creek drainage basin. Administration, faculty, and students of Sakai have long valued salmon and the quality of salmon habitat in Woodward Creek. They are self-appointed guardians of the stream, and signs of the high regard they hold for this connection to their environment and their aquatic neighbors are prevalent through dedicated curriculum, student projects, and the art work and architecture of the school itself.

For many years, Sakai students have studied and measured the water quality of Woodward Creek and released chum salmon fry every year. Upon learning of the status of the downstream water quality and aquatic habitat in Murden Creek and Murden Cove, the school proactively committed to the effort to identify the sources of pollutants causing the impairment and being an active part of the solution.

Sakai, in conjunction with IslandWood (an environmental institute on the Island), was awarded a 3M Eco Grant for monitoring equipment and curriculum development to conduct watershed monitoring and educational outreach in the Murden Cove Watershed. FarBank Enterprises also contributed money towards the project.

Sakai students and faculty developed and provided nutrient and bacteria focused educational outreach throughout the Murden Cove Watershed and surveyed watershed residents' understanding and behaviors. Of particular note, the students worked with the Bainbridge Island Watershed Council to design an interpretive sign to be displayed in the watershed.

Under the guidance of the City's WQFMP Final Monitoring Plan (COBI, 2008) and with initial training from City and Islandwood staff, Sakai students and faculty conducted monthly water quality monitoring at the upstream (upper mid-watershed) monitoring station on Woodward Creek located on the school grounds.

A.4 Bainbridge Island Watershed Council

The Bainbridge Island Watershed Council (BIWC) is an all-volunteer group of citizens committed to protecting Island watersheds and educating the community about the importance of watershed protection and restoration. The council's mission is to actively pursue projects and actions that will protect and improve the condition of Bainbridge Island's watersheds, shorelines, and related wildlife habitats through volunteer stewardship, educational outreach, and advising the City government on key issues.

BIWC's membership is strengthened by engineers, fish biologists, freshwater and marine water ecologists, and other environmental professionals as well as enthusiastic and caring citizens. The council has been conducting habitat surveys, fish counts, and watershed educational outreach projects for several years. Most notably, BIWC recently completed a successful salmon supplementation project in an Island stream in conjunction with the City and the Suquamish Tribe.

In addition to assisting the City's monitoring efforts and coordinating a stream walk with KPHD's streamside outfall/drain point survey in Murden Creek, BIWC developed and provided habitat assessment training to Sakai students and faculty as well as coordinated targeted nutrient and bacteria educational outreach efforts in the Murden Cove Watershed such as a Walk-Your-Watershed event and the design of a watershed interpretive sign featuring artwork and educational messages from Sakai students.

A.5 Kitsap Conservation District

The Kitsap Conservation District (KCD) is a non-regulatory agency that provides expert technical assistance in agricultural and livestock management. KCD also provides expert assistance and guidance in residential backyard management and rain gardens. KCD provides these services to Island landowners via an Interlocal Agreement with the City.

KCD has built a strong relationship with Island farmers and livestock owners, and served as the lead agency for addressing identified farm or livestock sources of nutrient and/or bacteria in the watershed. They also provided rain garden and agricultural-related educational outreach materials to augment Sakai, BIWC, and KPHD's efforts.

Appendix B: Nitrogen Speciation by Mass %

Site	Date	Concentration (mg/l)			Percent by Mass			Flow	Rainfall (in)		
		NO3-	TKN	NH3	%NO3-	%TKN	%NH3	(cfs)	24-hr Rain	48-hr Rain	72-hr Rain
SE16	3/26/2013	0.256	0.543	0.032	30.81	65.34	3.85	1.52	0.11	0.34	0.48
SE16	4/25/2013	0.193	0.746	0.030	19.92	76.99	3.10	1.11	0.00	0.00	0.00
SE16	5/29/2013	0.200	1.380	0.210	11.17	77.09	11.73	0.69	0.00	0.00	0.00
SE16	6/25/2013	0.195	0.684	0.140	19.14	67.12	13.74	0.46	0.09	0.16	0.16
SE16	7/24/2013	0.277	0.844	0.140	21.97	66.93	11.10	0.05	0.00	0.00	0.00
SE16	8/27/2013	0.310	0.741	0.190	24.98	59.71	15.31	0.11	0.00	0.00	0.00
SE16	9/24/2013	0.145	1.320	0.120	9.15	83.28	7.57	0.30	0.50	0.83	0.84
SE16	10/23/2013	0.000	1.210	0.220	0.00	84.62	15.38	0.20	0.00	0.00	0.00
SE16	11/21/2013	0.348	2.070	0.100	13.82	82.21	3.97	1.48	0.00	0.13	0.91
SE16	12/23/2013	0.114	1.530	0.300	5.86	78.70	15.43	0.90	0.15	0.26	0.36
SE16	1/21/2014	0.705	2.470	0.081	21.65	75.86	2.49	0.81	0.00	0.00	0.00
SE16	2/19/2014	1.710	1.040	0.013	61.89	37.64	0.47	16.53	0.66	0.78	2.14
SE16	3/19/2014	0.589	0.617	0.061	46.49	48.70	4.81	3.78	0.01	0.01	0.92
SE16	4/16/2014	0.199	1.110	0.076	14.37	80.14	5.49	0.89	0.00	0.00	0.00
SE16	5/20/2014	0.190	0.607	0.012	23.49	75.03	1.48	0.34	0.01	0.41	0.41
SE16	6/17/2014	0.181	0.589	0.000	23.51	76.49	0.00	0.29	0.06	0.72	0.73
SE16	7/16/2014	0.290	0.438	0.070	36.34	54.89	8.77	0.03	0.00	0.00	0.00
SE16	8/21/2014	0.178	0.716	0.247	15.60	62.75	21.65	0.03	0.00	0.00	0.00
SE16	9/23/2014	0.112	0.533	0.120	14.64	69.67	15.69	0.11	0.01	0.01	0.01
SE16	10/21/2014	0.129	1.560	0.224	6.74	81.55	11.71	0.89	0.18	0.18	0.47
SE16	11/19/2014	0.262	0.977	0.204	18.16	67.71	14.14	0.76	0.00	0.00	0.00
SE16	12/11/2014	1.420	1.220	0.338	47.68	40.97	11.35	17.29	0.96	1.53	2.17
SE16	1/22/2015	0.872	0.568	0.511	44.70	29.11	26.19	2.94	0.01	0.02	0.04
SE16	2/19/2015	0.461	1.040	0.623	21.70	48.96	29.33	1.59	0.00	0.00	0.00
SE16	3/24/2015	0.270	0.720	0.040	26.21	69.90	3.88	2.75	0.20	0.25	0.25
SE16	4/21/2015	0.170	0.600	0.050	20.73	73.17	6.10	0.82	0.00	0.00	0.00
SE16	5/20/2015	0.180	0.860	0.230	14.17	67.72	18.11	0.31	0.00	0.00	0.00
SE16	6/23/2015	0.200	0.510	0.500	16.53	42.15	41.32	0.12	0.00	0.00	0.00
SE16	7/15/2015	0.300	0.610	0.040	31.58	64.21	4.21	0.06	0.00	0.00	0.00
SE16	8/12/2015	0.240	0.770	0.220	19.51	62.60	17.89	0.06	0.00	0.01	0.01
SE16	9/15/2015	0.170	0.470	0.130	22.08	61.04	16.88	0.14	0.00	0.02	0.02
SE17	3/26/2013	0.326	0.577	0.057	33.96	60.10	5.94	0.89	0.11	0.34	0.48
SE17	4/25/2013	0.230	0.570	0.080	26.14	64.77	9.09	0.64	0.00	0.00	0.00
SE17	5/29/2013	0.172	1.280	0.050	11.45	85.22	3.33	1.00	0.00	0.00	0.00
SE17	6/25/2013	0.208	0.521	0.240	21.47	53.77	24.77	0.31	0.09	0.16	0.16
SE17	7/24/2013	0.243	0.822	0.150	20.00	67.65	12.35	---	0.00	0.00	0.00
SE17	8/27/2013	0.328	0.696	0.150	27.94	59.28	12.78	---	0.00	0.00	0.00
SE17	9/24/2013	0.167	1.350	0.000	11.01	88.99	0.00	---	0.50	0.83	0.84
SE17	10/23/2013	0.140	0.949	0.160	11.21	75.98	12.81	0.01	0.00	0.00	0.00
SE17	11/21/2013	0.513	1.910	0.070	20.58	76.61	2.81	0.56	0.00	0.13	0.91
SE17	12/23/2013	0.189	1.670	0.060	9.85	87.02	3.13	0.22	0.15	0.26	0.36
SE17	1/21/2014	0.823	2.180	0.057	26.90	71.24	1.86	0.46	0.00	0.00	0.00
SE17	2/19/2014	1.610	1.310	0.015	54.86	44.63	0.51	10.04	0.66	0.78	2.14
SE17	3/19/2014	0.483	0.507	0.000	48.79	51.21	0.00	2.46	0.01	0.01	0.92
SE17	4/16/2014	0.206	0.884	0.040	18.23	78.23	3.54	0.53	0.00	0.00	0.00
SE17	5/20/2014	0.202	0.482	0.019	28.68	68.61	2.70	0.27	0.01	0.41	0.41
SE17	6/17/2014	0.192	0.706	0.000	21.38	78.62	0.00	0.34	0.06	0.72	0.73
SE17	7/16/2014	0.247	0.604	0.028	28.10	68.71	3.19	0.05	0.00	0.00	0.00
SE17	8/21/2014	0.156	0.425	0.000	26.85	73.15	0.00	0.05	0.00	0.00	0.00
SE17	9/23/2014	0.140	0.471	0.197	17.33	58.29	24.38	0.01	0.01	0.01	0.01
SE17	10/21/2014	0.172	0.999	0.218	12.38	71.92	15.69	1.07	0.18	0.18	0.47
SE17	11/19/2014	0.363	0.988	0.113	24.80	67.49	7.72	0.24	0.00	0.00	0.00
SE17	12/11/2014	1.650	1.320	0.236	51.47	41.17	7.36	7.15	0.96	1.53	2.17
SE17	1/22/2015	0.934	0.513	3.160	20.27	11.14	68.59	1.55	0.01	0.02	0.04
SE17	2/19/2015	0.533	0.795	0.174	35.49	52.93	11.58	0.59	0.00	0.00	0.00
SE17	3/24/2015	0.280	0.550	0.050	31.82	62.50	5.68	1.23	0.20	0.25	0.25
SE17	4/21/2015	0.170	0.420	0.020	27.87	68.85	3.28	0.36	0.00	0.00	0.00
SE17	5/20/2015	0.240	0.880	0.760	12.77	46.81	40.43	0.28	0.00	0.00	0.00
SE17	6/23/2015	0.180	0.600	1.320	8.57	28.57	62.86	0.10	0.00	0.00	0.00
SE17	7/15/2015	0.260	0.470	0.190	28.26	51.09	20.65	0.03	0.00	0.00	0.00
SE17	8/12/2015	0.190	0.970	1.490	7.17	36.60	56.23	0.06	0.00	0.01	0.01
SE17	9/15/2015	0.180	0.520	0.070	23.38	67.53	9.09	0.15	0.00	0.02	0.02
SE83	3/26/2013	0.052	0.851	0.027	5.59	91.51	2.90	0.26	0.11	0.34	0.48
SE83	4/29/2013	0.018	1.132	0.030	1.53	95.93	2.54	0.53	0.00	0.00	0.00

Site	Date	Concentration (mg/l)			Percent by Mass			Flow	Rainfall (in)		
		NO3-	TKN	NH3	%NO3-	%TKN	%NH3	(cfs)	24-hr Rain	48-hr Rain	72-hr Rain
SE83	5/22/2013	0.027	1.453	0.070	1.74	93.74	4.52	---	0.69	0.69	0.69
SE83	6/25/2013	0.015	1.415	0.056	1.01	95.22	3.77	0.07	0.09	0.16	0.16
SE83	7/25/2013	0.173	1.027	0.081	13.51	80.17	6.32	---	0.00	0.00	0.00
SE83	8/16/2013	0.216	1.134	0.021	15.75	82.71	1.53	0.05	0.03	0.90	0.90
SE83	9/18/2013	0.022	1.578	0.229	1.20	86.28	12.52	0.19	0.00	0.04	0.26
SE83	10/15/2013	0.042	2.068	0.080	1.92	94.43	3.65	0.11	0.00	0.01	0.06
SE83	11/14/2013	0.016	1.884	0.013	0.84	98.48	0.68	---	0.00	0.16	0.16
SE83	12/18/2013	0.016	2.514	0.084	0.61	96.17	3.21	0.80	0.00	0.01	0.08
SE83	1/21/2014	0.118	1.262	0.066	8.16	87.28	4.56	0.60	0.00	0.00	0.00
SE83	2/20/2014	1.270	1.120	0.018	52.74	46.51	0.75	12.80	0.02	0.68	0.80
SE83	3/19/2014	0.113	0.743	0.019	12.91	84.91	2.17	1.27	0.01	0.01	0.92
SE83	4/16/2014	0.024	1.276	0.022	1.82	96.52	1.66	0.07	0.00	0.00	0.00
SE83	5/20/2014	0.251	0.809	0.039	22.84	73.61	3.55	---	0.01	0.41	0.41
SE83	6/17/2014	0.197	0.045	0.041	69.61	15.90	14.49	---	0.06	0.72	0.73
SE83	7/16/2014	0.072	1.518	0.176	4.08	85.96	9.97	---	0.00	0.00	0.00
SE83	8/21/2014	0.181	0.455	0.037	26.89	67.61	5.50	---	0.00	0.00	0.00
SE83	9/23/2014	0.107	0.318	0.019	24.10	71.62	4.28	0.08	0.01	0.01	0.01
SE83	10/21/2014	0.108	0.848	0.000	11.30	88.70	0.00	0.02	0.18	0.18	0.47
SE83	11/19/2014	0.206	1.614	0.680	8.24	64.56	27.20	0.42	0.00	0.00	0.00
SE83	12/11/2014	0.716	1.194	0.026	36.98	61.67	1.34	---	0.96	1.53	2.17
SE83	1/22/2015	0.273	0.698	0.633	17.02	43.52	39.46	---	0.01	0.02	0.04
SE83	2/19/2015	0.170	3.030	0.050	5.23	93.23	1.54	0.35	0.00	0.00	0.00
SE83	3/24/2015	0.400	0.690	0.030	35.71	61.61	2.68	1.16	0.20	0.25	0.25
SE83	4/21/2015	0.080	0.900	0.060	7.69	86.54	5.77	0.46	0.00	0.00	0.00
SE83	5/20/2015	0.060	0.890	0.090	5.77	85.58	8.65	0.18	0.00	0.00	0.00
SE83	6/23/2015	0.090	0.990	0.180	7.14	78.57	14.29	0.10	0.00	0.00	0.00
SE83	7/15/2015	0.210	0.680	0.160	20.00	64.76	15.24	0.03	0.00	0.00	0.00
SE83	8/12/2015	0.170	2.570	0.250	5.69	85.95	8.36	---	0.00	0.01	0.01
SE83	9/15/2015	0.130	0.600	0.090	15.85	73.17	10.98	0.04	0.00	0.02	0.02
SE84	3/26/2013	0.263	0.568	0.014	31.12	67.22	1.66	1.26	0.11	0.34	0.48
SE84	4/29/2013	0.211	0.416	0.012	33.02	65.10	1.88	0.59	0.00	0.00	0.00
SE84	5/22/2013	0.226	0.643	0.019	25.45	72.41	2.14	0.86	0.69	0.69	0.69
SE84	6/25/2013	0.202	0.419	0.000	32.53	67.47	0.00	0.40	0.09	0.16	0.16
SE84	7/25/2013	0.236	0.322	0.000	42.29	57.71	0.00	0.09	0.00	0.00	0.00
SE84	8/16/2013	0.210	0.221	0.015	47.09	49.55	3.36	0.06	0.03	0.90	0.90
SE84	9/18/2013	0.152	0.377	0.012	28.10	69.69	2.22	0.11	0.00	0.04	0.26
SE84	10/15/2013	0.151	0.517	0.000	22.60	77.40	0.00	0.09	0.00	0.01	0.06
SE84	11/14/2013	0.100	0.681	0.000	12.80	87.20	0.00	1.58	0.00	0.16	0.16
SE84	12/18/2013	0.267	0.446	0.022	36.33	60.68	2.99	0.10	0.00	0.01	0.08
SE84	1/21/2014	1.150	0.610	0.018	64.68	34.31	1.01	0.22	0.00	0.00	0.00
SE84	2/20/2014	2.200	1.570	0.013	58.15	41.50	0.34	3.73	0.02	0.68	0.80
SE84	3/19/2014	0.944	0.896	0.011	51.00	48.41	0.59	2.51	0.01	0.01	0.92
SE84	4/16/2014	0.423	0.577	0.015	41.67	56.85	1.48	0.82	0.00	0.00	0.00
SE84	5/20/2014	0.220	0.980	0.044	17.68	78.78	3.54	0.69	0.01	0.41	0.41
SE84	6/17/2014	0.186	0.034	0.034	73.23	13.39	13.39	0.36	0.06	0.72	0.73
SE84	7/16/2014	0.257	0.428	0.020	36.45	60.71	2.84	0.16	0.00	0.00	0.00
SE84	8/21/2014	0.195	0.422	0.024	30.42	65.83	3.74	0.08	0.00	0.00	0.00
SE84	9/23/2014	0.107	0.286	0.019	25.97	69.42	4.61	0.04	0.01	0.01	0.01
SE84	10/21/2014	0.109	1.131	0.000	8.79	91.21	0.00	0.87	0.18	0.18	0.47
SE84	11/19/2014	0.270	1.240	0.057	17.23	79.13	3.64	0.34	0.00	0.00	0.00
SE84	12/11/2014	2.310	1.520	0.021	59.98	39.47	0.55	19.50	0.96	1.53	2.17
SE84	1/22/2015	0.893	0.561	0.186	54.45	34.21	11.34	3.35	0.01	0.02	0.04
SE84	2/19/2015	0.630	0.730	0.020	45.65	52.90	1.45	1.24	0.00	0.00	0.00
SE84	3/24/2015	0.000	0.610	0.030	0.00	95.31	4.69	1.60	0.20	0.25	0.25
SE84	4/21/2015	0.250	0.420	0.040	35.21	59.15	5.63	0.37	0.00	0.00	0.00
SE84	5/20/2015	0.170	0.340	0.020	32.08	64.15	3.77	0.13	0.00	0.00	0.00
SE84	6/23/2015	0.220	0.230	0.010	47.83	50.00	2.17	0.03	0.00	0.00	0.00
SE84	7/15/2015	0.210	0.470	0.000	30.88	69.12	0.00	0.03	0.00	0.00	0.00
SE84	8/12/2015	0.160	0.290	0.050	32.00	58.00	10.00	0.09	0.00	0.01	0.01
SE84	9/15/2015	0.130	0.340	0.040	25.49	66.67	7.84	0.10	0.00	0.02	0.02

--- = Not measured or too low to measure.

Sites: SE16 = Lower watershed (Murden Creek at Hwy 305); SE17 = Upper mid-watershed (Woodward Creek at Sakai); SE83 = Meig's Creek; SE84 = Lower mid-watershed (mainstem above confluence)