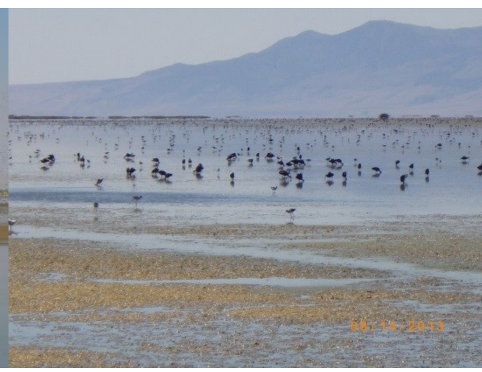
2011-2013 AMBIENT CONDITIONS FROM BASELINE MONITORING

** DRAFT FOR REVIEW **



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1. PROJECT BACKGROUND

This report provides a summary of the main components of the open water portion of the Willard Spur ecosystem, as part of a site-specific research project managed by the Utah Division of Water Quality (DWQ), 'Development of Water Quality Standards for Willard Spur'. The overall objective of the Willard Spur project was to address the central question posed by the Water Quality Board: *What water quality standards are appropriately protective of beneficial uses of Willard Spur waters as they related to the proposed POTW discharge?* The Water Quality Board directed DWQ to develop a study design to establish defensible protections for the beneficial uses of Willard Spur and sustain the natural resources of Great Salt Lake (GSL) and adjacent wetlands.

Developing a firm understanding of the baseline conditions of this ecosystem is critical to establishing defensible protections, such as development of numeric criteria, antidegradation policies, or changes to beneficial use classes. However, very little information describing the physical, chemical and biological characteristics of Willard Spur existed prior to the initiation of monitoring activities in 2011.

Through a series of technical and policy discussions, the Willard Spur Science Panel and support staff from DWQ developed a sampling approach and monitoring plans for data collection and analysis over the 2011 through 2013 period. Key characteristics of the Spur were identified: water chemistry (particularly nutrients and salinity), submerged aquatic vegetation (SAV), aquatic macroinvertebrate communities, and soil / sediment chemistry. This report summarizes some key elements of the open water portions of Willard Spur, while additional reports provide more in depth analysis of the hydrology, nutrient loading, and avian and macroinvertebrate communities.

The unique features of Willard Spur were identified early on. The dynamic hydrology of the Spur is expressed both seasonally and interannually, where water levels are controlled by the balance between the surface elevation of Great Salt Lake, and precipitation patterns and water development practices within the contributing watersheds of Bear River and Weber River, the two largest surface water inflows to the Spur. When water levels are sufficiently high (approximately 4200.5 feet above sea level), Willard Spur is hydrologically connected to Bear River Bay and both water as well as dissolved and suspended constituents can flow through the system to GSL. However, when waters recede below this elevation, waters in the Spur become 'hydrologically isolated' from Bear River Bay. Once isolated, the waters of Willard Spur continue to get smaller, saltier, and hotter. The observed interannually variability in water supply to Willard Spur during the 2011 to 2013 period provided an opportunity to examine hydrologic, chemical and biological interactions over a broad range of conditions.

The following section briefly describes the data analysis approach used in this report.

1.1 Project Objectives

1.1.1 DATA ANALYSIS: EFFECT OF INTERANNUAL HYDROLOGIC VARIATION

Monitoring data over the growing seasons of 2011-2013 were used to identify and characterize temporal (seasonal and interannual) and spatial patterns among chemical and biological parameters. Due to the wide range in water levels encountered during this period, four sites had sufficient data intensity (at least monthly measurements for most years) and were reasonable dispersed enough to serve as key monitoring sites. Key questions involved the shape and timing of seasonal patterns (if present), comparison of these seasonal patterns among high and low water years, and comparison of seasonal or annual patterns along the east to west flow gradient.

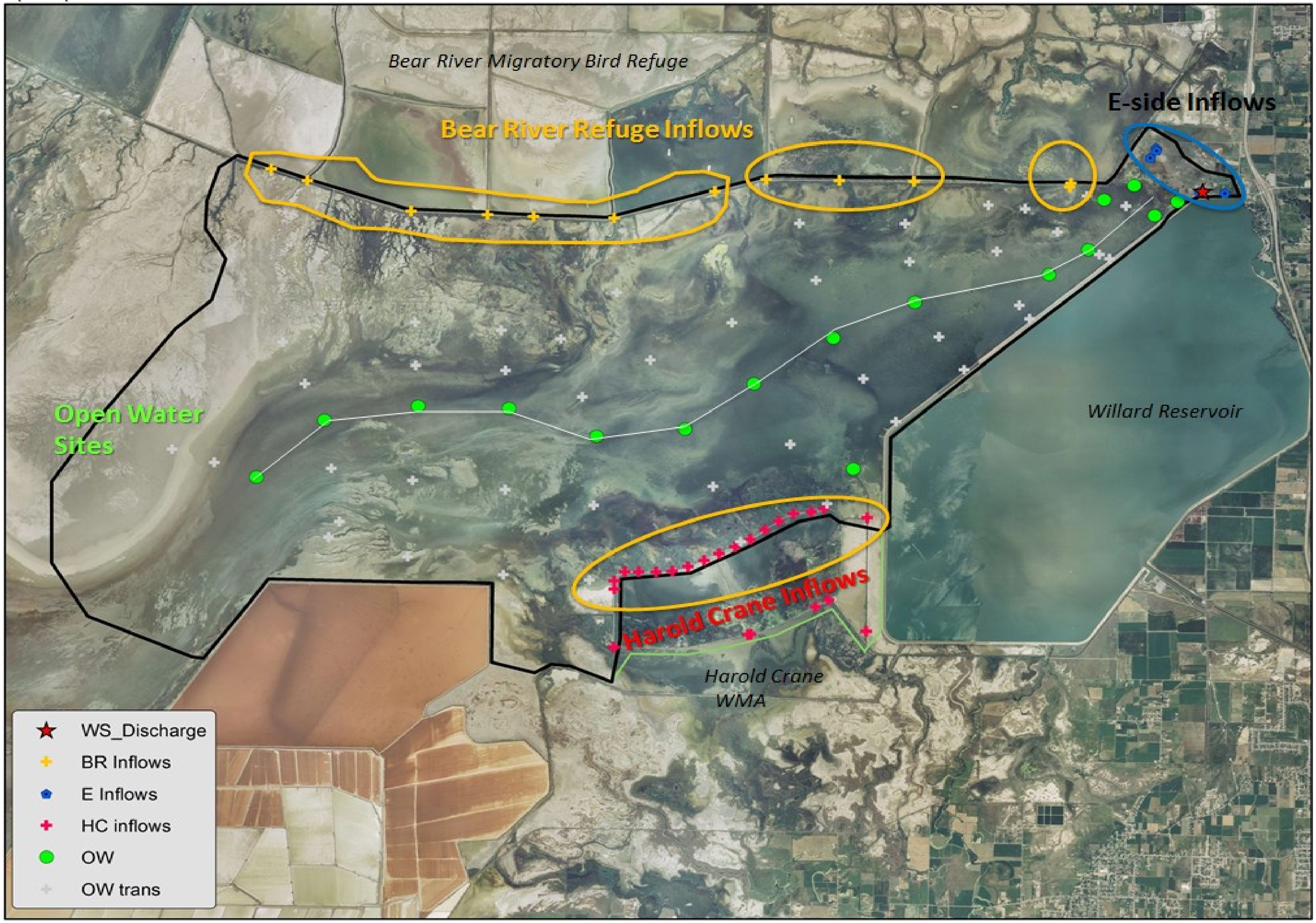
1.1.2 Data Analysis: Effect of Hydrologic Connectivity

A report on the hydrology of Willard Spur (CH2M Hill, 2015) provided detailed information on the duration and timing of periods of hydrologic connectivity versus isolation during the monitoring period. This information was used to separate the monitoring dataset into two classes: connected and isolated. The distribution of data for key variables were compared between the two classes to get a sense of which aspects of Willard Spur's open waters were most sensitive to these differences. It is without question that the transition from connected to isolated hydrology is gradual, and not a discrete event; however, this analysis serves as a sound starting point for identifying potential associations between hydrologic flow and chemical / biological variables across the Spur.

1.1.3 Data Analysis: Relationships Between Drivers and Biological Reponses

Building on the previous analyses, a comprehensive set of pairwise correlations was performed in order to quantify the degree of linear associations among variables and to screen for sets of correlated variables that need to be taken into account. For example, several sets of metrics describing the performance (or health) of submerged aquatic vegetation were calculated – it is important to understand whether each variable is largely telling the same story, or if there are important differences in variable response when compared to other variables. The Pearson correlation method was used. While this method has several limitations, the correlation coefficient (r) is more straightforward to interpret than non-parametric methods. The dataset was split into three main groups: physical and chemical components of waters, SAV metrics, and macroinvertebrate metrics.

Lastly, potential relationships (or associations) between 'response' variables and other key variables, such as water depth and total nutrient concentrations, were compared between connected versus isolated hydrologic conditions. The objective was to examine whether the shape of potential relationships differed based on the hydrologic state of the Spur.



Map 1. Monitoring locations for open water sampling and significant inflow areas to Willard Spur.

2. BROAD MEASURES OF WATER QUALITY: WATER CLARITY

The clarity of surface waters are a routine observation made by DWQ Water Quality Monitors. While this measure is somewhat subjective in terms of distinguishing turbid versus murky conditions, photographic evidence of water conditions over three years of field sampling revealed an apparent seasonal pattern of water clarity: (i) typically grayish or turbid waters in spring associated with sediment-laden runoff [Turbid]; (ii) clearing of waters as the growing season progressed, likely a consequence of increased particle retention from rapidly growing submerged aquatic vegetation (SAV) as well as a reduction in sediment content of inflows to Willlard Spur [Clear or Blue]; (iii) as summer progresses, increasing water temperatures can contribute to faster turnover of nutrients (cycling or spiraling) and support rapid growth of algae within the water column (phytoplankton), on SAV (epiphytes), or on surfaces (periphyton), with a concomitant increase in chlorophyll-a concentrations that may imbue a Green coloration to the waters [Green]. Green coloration may represent eutrophic conditions if these conditions produce large blooms or mats of free-floating or attached algae. Because this is an easily observable feature of shallow surface waters, we compared the prevalence of the Turbid, Blue and Green water phases over time (Figure 3.1).

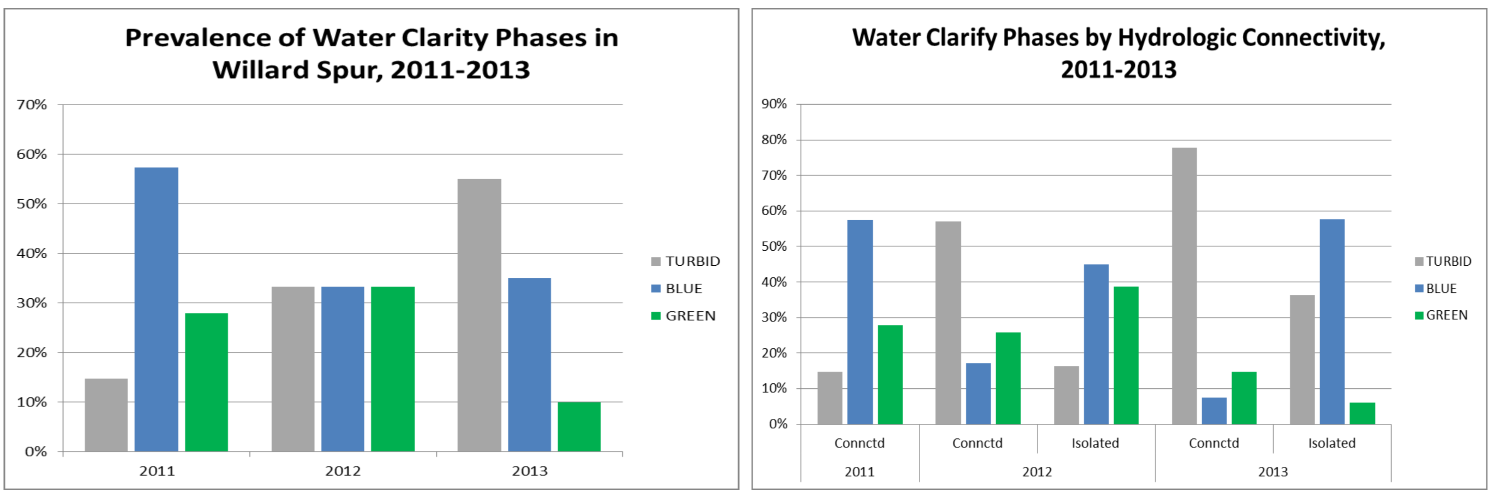


Figure 1. (Left) Proportion of Water Clarity field observations based on Turbid, Blue or Green water phases. (Right) Proportion of Water Clarity Phases by Hydrologic Connectivity.

The year 2011 was considered a relatively wet year (CH2M, 2015 [Hydrology Report]), while 2012 was nearer to normal conditions and 2013 was dominated by moderate to severe drought conditions. In line with hydrology, the Blue phase dominated the 2011 'wet' year, while Turbid or murky conditions dominated the 2013 'dry' year (Figure 1). The phases were equally distributed during the 2012 'normal' year. While these results are not a quantitative assessment, water clarity phases may provide a useful context to discuss and interpret the considerable amount of data that was generated during this project. Interestingly, the distribution of water clarity phases also differed among periods of time when Willard Spur was hydrologically connected to Bear River Bay (CH2M, 2015 [Hydrology Report]). As shown in Figure 1 (right), the Turbid phase dominated conditions when Willard Spur was hydrologically connected to Bear River Bay, while the Blue and Green phases were more common when Willard Spur was hydrologically isolated. Similarly, the Turbid phase again dominates the hydrologically connected phase of 2013, while the Blue phase dominates after Willard Spur becomes isolated. Several elements of ecosystem response contribute to this coarse classification of water clarity, including the quantity and quality of suspended particulates within contributing inflows, environmental conditions conducive to rapid algal growth and other disturbances to the soil-water interface within the Willard Spur wetland. A more in depth look at temporal changes to water chemistry after Willard Spur becomes isolated are presented below (Section 4).

Building on this basic pattern, potential relationships between the Water Clarity phases and some key water quality parameters are explored below. The Turbid phase appears to be associated with greater TSS and lower TVS/TSS ratios (i.e. more mineral solids suspended in the water column) compared to the Blue or Green water phases. While there were substantial differences among sampling years, TSS concentrations were greater in Turbid vs. Blue water conditions, but the Green phase was intermediate (Figure 2). Interestingly, laboratory-based turbidity measurements were well-correlated with TSS ($r^2 = 0.91$). The relative contribution of organic matter (volatile solids) of the suspended solids, measured as the TVS:TSS ratio, were lowest in Turbid waters (22% OM) versus Blue waters (36%); the Green phase was intermediate (29%). As such, the Turbid phase could be

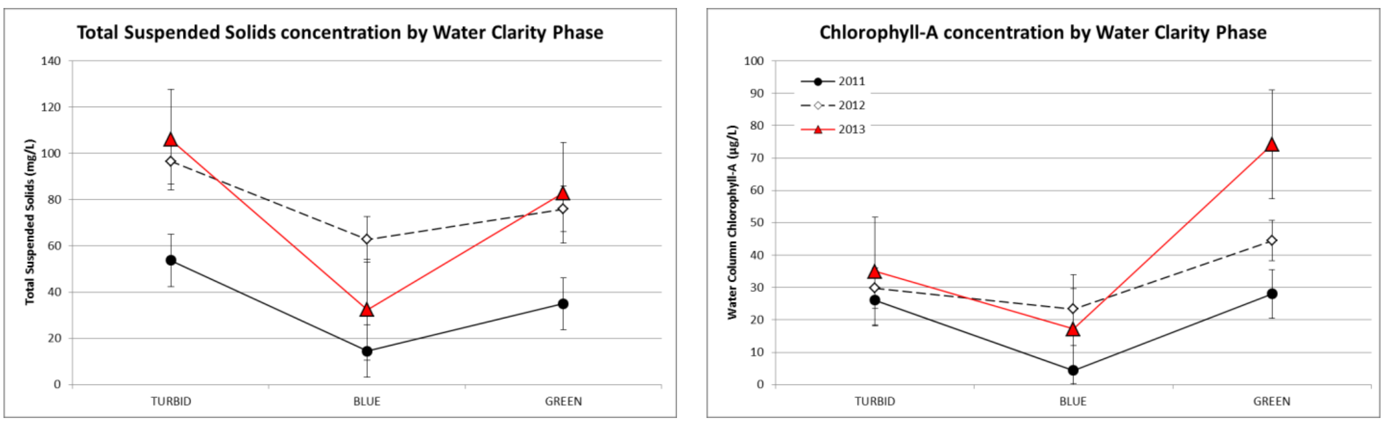


Figure 2. (Left) Mean Total Suspended Solids and (right) Chlorophyll-A concentrations by Water Clarity Phase and Sampling Year.

characterized by high TSS concentrations with low TVS:TSS ratios. A distinct pattern was seen in chlorophyll-A concentrations, where values were highest in Green phase (48.9 ug/L) compared to Turbid (30.3 ug/L) and Blue phase (15.0 ug/L) waters (**Error! Reference source not found.**). Interestingly, 2011 had lower overall chlorophyll-a concentrations than 2012 or 2013, possibly a consequence of the large inflows of cool water throughout the year.

3. Physical, Chemical, and Biological Characteristics of Open Water portions of Willard Spur

3.1 Temporal Variation of Key Monitoring Sites

Data were collected from approximately 70 monitoring locations during the 2011-2013 period. Because of resource constraints and the ever-changing hydrologic conditions within the Spur, not all parameters were collected at all sites for all monitoring events. Consequently, twenty two (22) sites were considered representative of open water conditions within Willard Spur, while the remaining 48 sites represented various inflows to Willard Spur or were part of annual synoptic surveys. Four sets of key monitoring locations (Sites) were used to examine temporal patterns in water quality during the 2011-2013 monitoring period. These sites were chosen because they were sampled throughout the baseline monitoring period and because they represent a nearly 8-mile longitudinal span across Willard Spur. The goal here was to use a consistent set of sites to examine how the baseline conditions of the Willard Spur ecosystem varied over time, in terms of both seasonal progressions (phenology) as well as any differences in wet versus dry years. The table below summarizes some details about the key monitoring sites, in terms of sampling intensity and proximate location within Willard Spur.

Table 1. Key Monitoring Sites in Willard Spur, 2011-2013

	Key Monitoring Location	Site Name	MLID	Distance from Inflow (km / mi)	Number of Sampling Events *			Mean Water Depth (2011 / 2013) (cm)
					2011	2012	2013	
1	Eastside Inflows	OUT-WB-TAILRACE	5984645	0.94 / 0.58	4	4	6	62.8 / 15.2
		OUTFALL-CNFL	5984640	1.31 / 0.81				59.5 / 12.3
2	Nearshore (WS-2)	**WS-2**	5984660	2.32 / 1.44	4	7	7	72.7 / 27.9
		WS-3	5984670	3.16 / 1.97				86.3 / 44.0
3	Middle Spur (WS-6)	OUT-HC-WMA-DD	5984695	8.22 / 5.11	4	8	9	49.7 / 11.4
		WS-6	5984700	8.82 / 5.48				82.3 / 48.3
4	Western Shoal	**WS-8**	5984720	11.84 / 7.36	4	6	7	56.0 / 28.3
-	Spur Outlet	WS-12	5984760	17.67 / 10.98	4	2	3	40.0 / 13.7

* Number of sampling events may vary due to lack of water availability or other site-access related constraints. Site Names in **bold** indicate the specific sites used as Key Monitoring Sites.

3.1.1 Physical and Chemical Characteristics of Open Water

- Water Depth

Water depths at Key Monitoring Sites ranged from over 100 cm to completely dry during the 2011-13 baseline monitoring period. There were clear interannual and seasonal differences in water depth among Key Monitoring Sites, particularly for 2011 versus 2012 and 2013 (Figure 3). Water depths were commonly 30 to 60 cm deeper in 2011 than in 2012 or 2013. Mean water depths were greatest near WS-3 and WS-6, and shallowest along the eastern margin at OUTFALL-CNFL. Willard Spur was nearly entirely dry in late summer of 2013 (DOY approximately 220 to 270), while in 2012 the central region of the Spur was at least partially inundated.

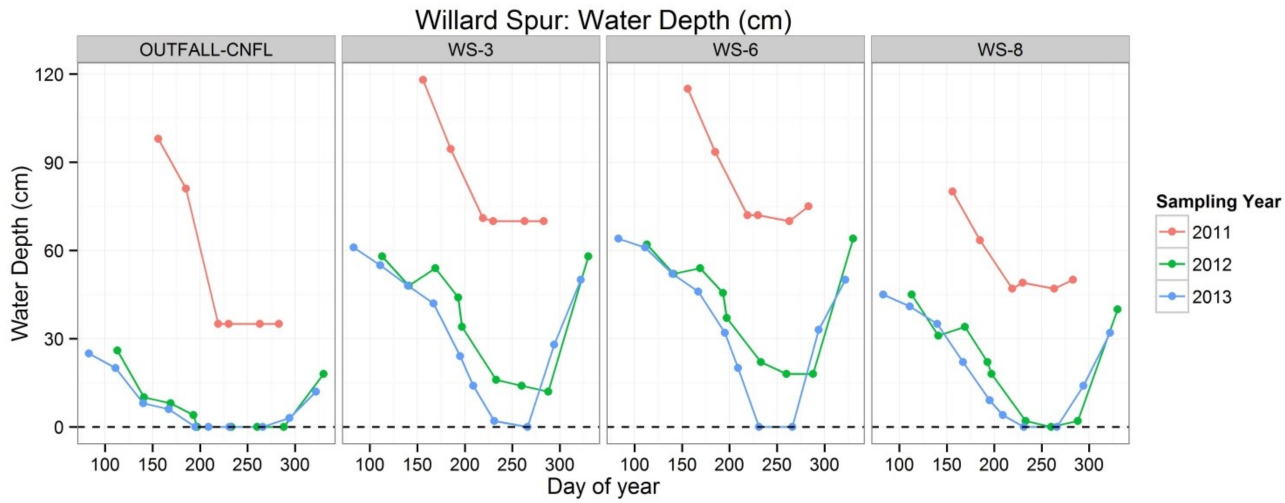


Figure 3. Depth of surface water for Key Monitoring Sites by Sampling Year.

- Water Temperature

Surface water temperatures for key monitoring sites exhibited strong seasonal variation, ranging from 10 °C in mid-spring to over 25 °C in mid- to late summer (day of year 180 to 220) and autumn cooling down to 5 °C in late October (Figure 4). Excessively warm temperatures (greater than 32 °C) were observed along the drying margins of the receding shoreline, particularly in 2012 and 2013 (data not shown).

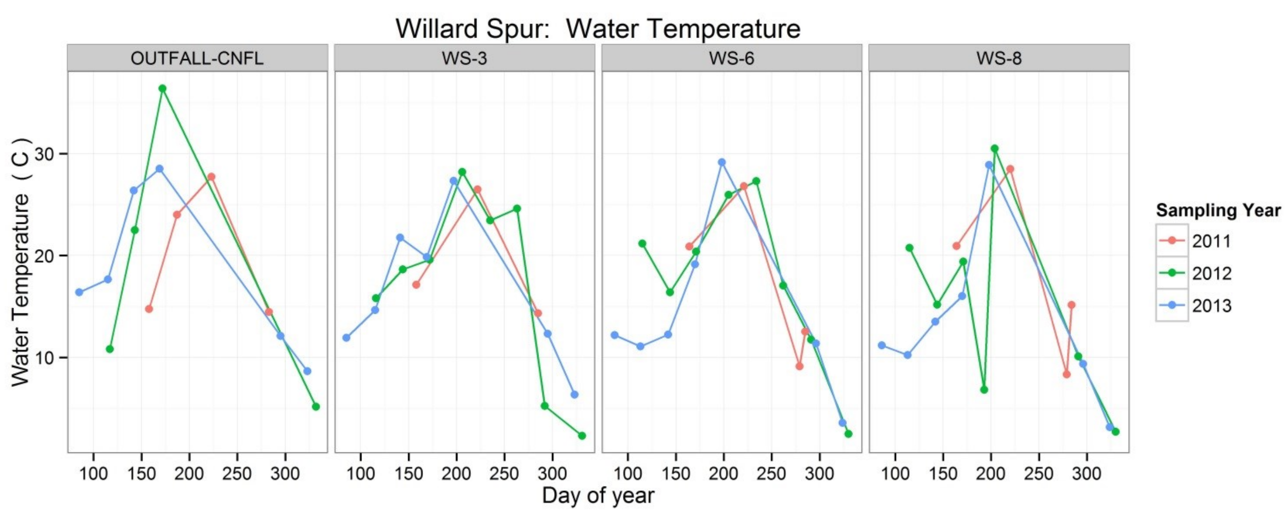


Figure 4. Water temperatures for Key Monitoring Sites by Sampling Year.

- Salinity

Salinity of open waters was determined from measurements of both conductivity (Specific Conductivity) as well as total salt concentration (as Total Dissolved Solutes), and were well-correlated with a mean slope-factor of 0.582 (Figure 5).

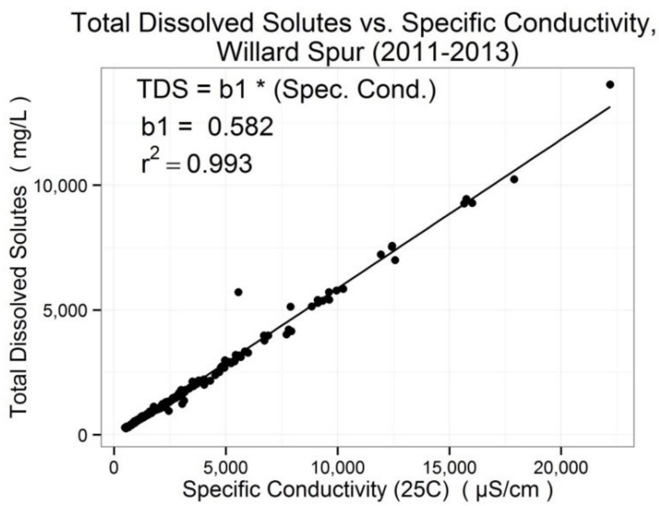


Figure 5. Relationship between Total Dissolved Solids and Specific Conductivity for Willard Spur surface waters over the 2011-2013 monitoring period.

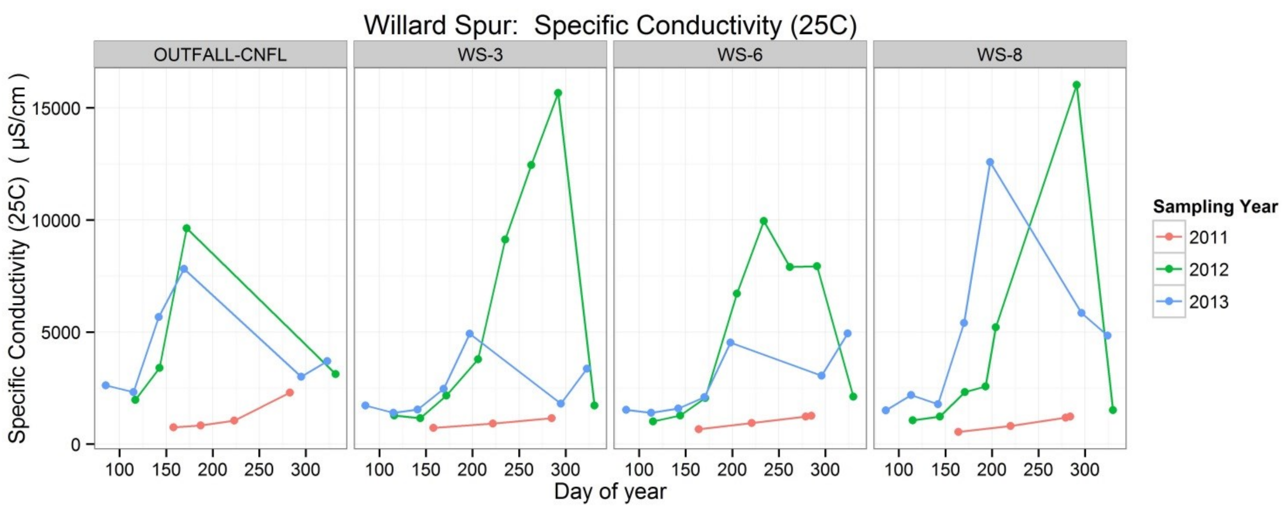


Figure 6. Specific Conductivity for surface waters of Key Monitoring Sites by Sampling Year.

There were clear differences in salinity, as Specific Conductivity, among and within monitoring years (Figure 6). As expected, the higher inflows in 2011 resulted in lower salinity (1084.6 µS/cm) compared to 2012 and 2013 (4672.2 and 3731.5 6 µS/cm, respectively). Higher salinities were observed in 2012 than 2013, largely due to very rapid and nearly complete loss of surface water in the Spur by early August in 2013, while open water conditions persisted in the deeper portions of the Spur in 2012.

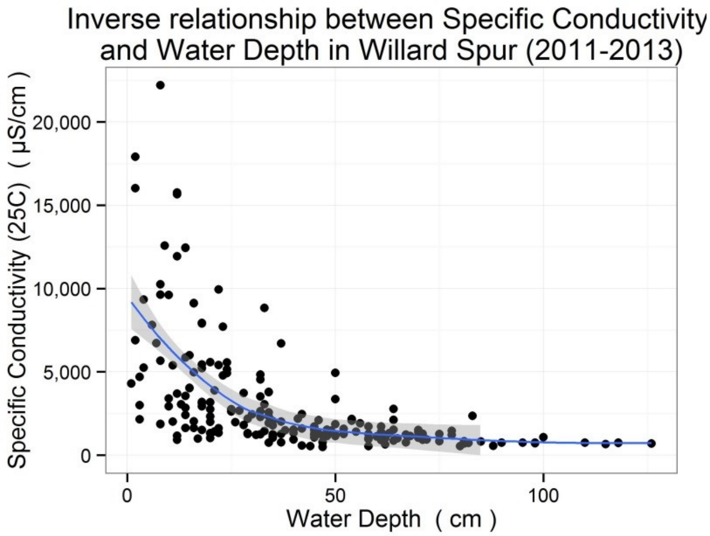


Figure 7. Relationship between Specific Conductivity and Water Depth for Willard Spur surface waters (2011-2013).

As expected, salinity increases strongly as water becomes shallower (Figure 7). The high degree of variation in specific conductivity at shallow water depths is likely driven by differences in the proximity of monitoring sites to surface water inflows. Areas near inflows would tend to remain fresher (lower specific conductivity), regardless of water depth, while progressive drying of open water sites via evaporation would increase salinity following an inverse power law.

- Suspended Solids

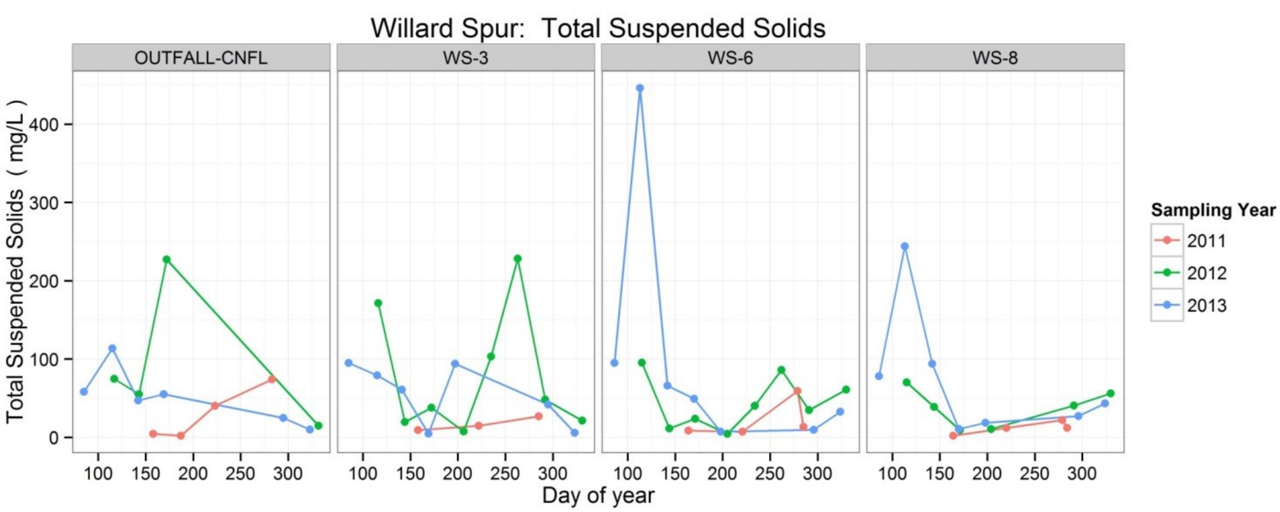


Figure 8. Total Suspended Solids concentrations for Key Monitoring Sites by Sampling Year.

Concentrations of total suspended solids (TSS) ranged from < 15 to over 100 mg/L at key monitoring sites during the 2011 to 2013 period (Figure 8). Generally, TSS appeared to be highest during the spring runoff period, and lower during summer. While early season TSS concentrations from key monitoring sites in spring of 2011 were incomplete, data from sites along the eastern third of the Spur ranged from 33 to over 200 mg/L. These results are consistent with the pattern of high TSS in spring associated with spring runoff, particularly associated with inflows from the Bear River Migratory Bird Refuge (average 278 mg/L in early 2011).

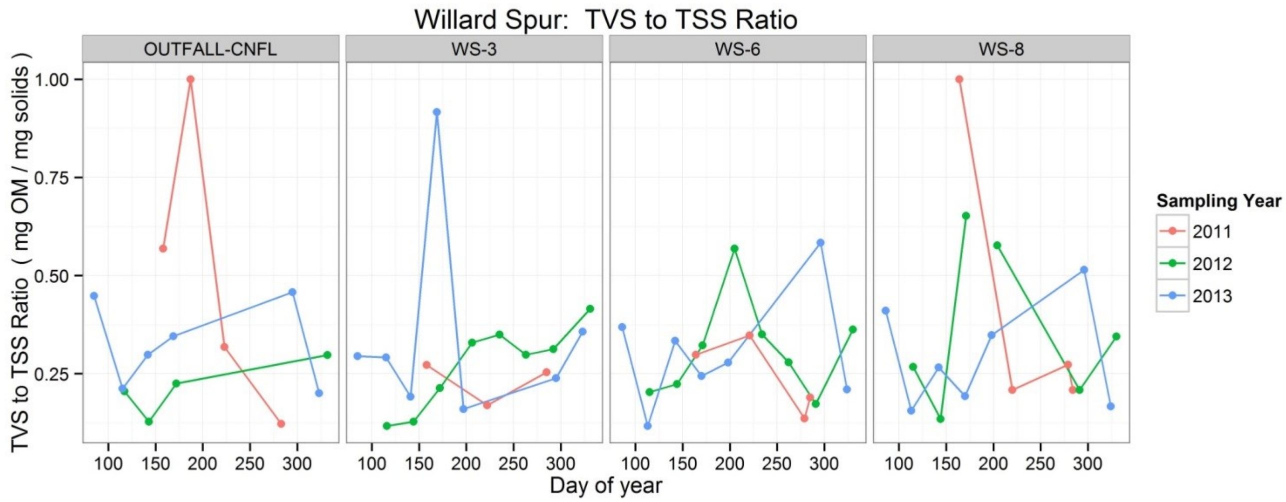


Figure 9. Total Volatile Solids to Total Suspended Solids Ratio (TVS:TSS) for Key Monitoring Sites by Sampling Year.

An important characteristic of suspended solids (particulates) is whether they are derived from organic matter versus from mineral solids within the contributing watershed; estimated by the TVS:TSS ratio (Figure 9). Unfortunately, this ratio is very sensitive at low TSS concentrations, resulting in considerable variation when data are plotted against sampling date. However, combining some adjacent sites and aggregating results by season yields a more robust view of how TVS:TSS ratios changed over time (Figure 10 (below)). While considerable variability remains, the spring season has lower TVS:TSS ratios (< 25%), indicative of greater mineral content of particulates compared to values in summer and autumn, where ratios can exceed 50% and which may be indicative of *in situ* sources of algal and SAV detritus.

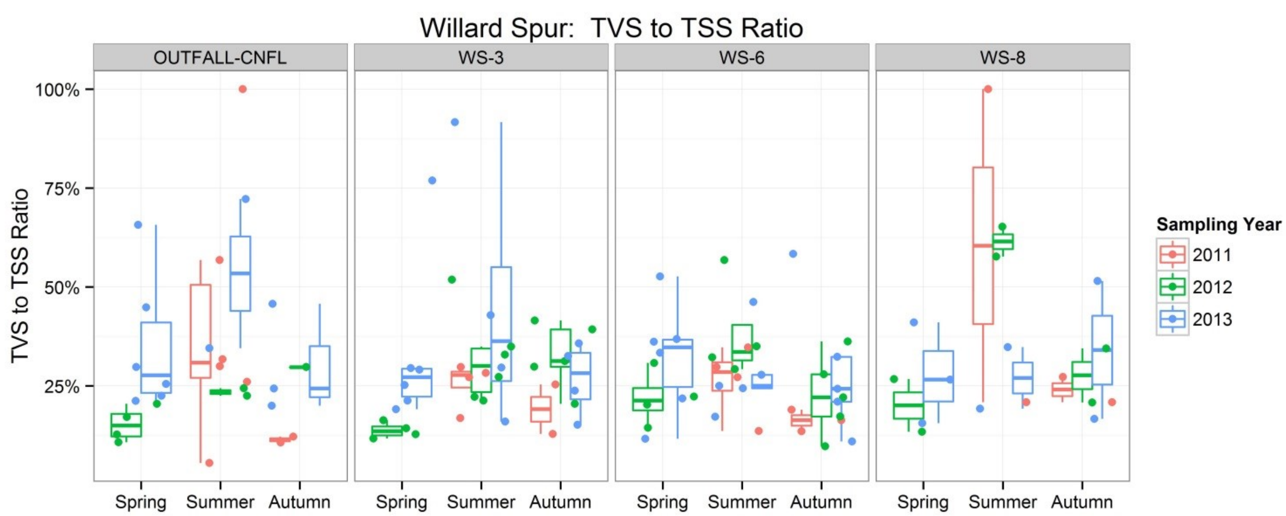


Figure 10. Seasonal distribution of TVS:TSS ratios for Key Monitoring Sites by Sampling Year.

- Chlorophyll-A

Chlorophyll-a concentrations were generally low in late-spring and increased as the summer season progressed (to day of year 270; late September) (Figure 11). Higher concentrations (> 50 µg/L) were observed in late summer of 2011 and 2012; note that the Spur was nearly entirely dry in August, 2013. In 2012 and 2013, early season (day of year 100 to 120) Chlorophyll-a concentrations exceeded 20 µg/L, but then declined rapidly. This pattern appears

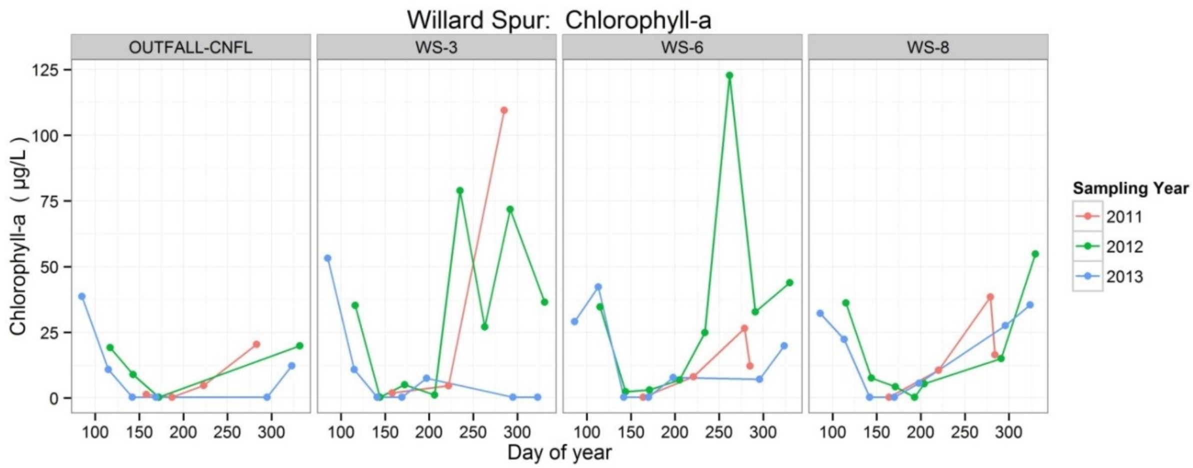


Figure 11. Chlorophyll-a concentrations for Key Monitoring Sites by Sampling Year.

consistent with the 'clearing' of the blue or clear water phase, where declining spring runoff flows combined with rapidly growing submerged aquatic vegetation (SAV) reduce particulate concentrations (Figure 8).

- Water Column pH

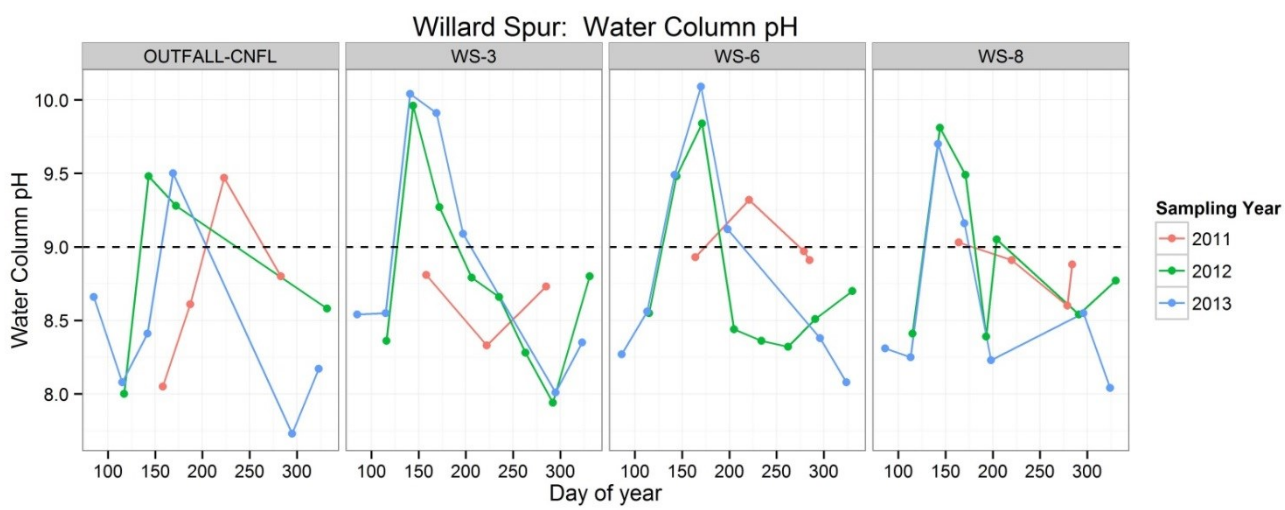


Figure 12. Water column pH for Key Monitoring Sites by Sampling Year.

The pH of the water column can be a sensitive indicator aquatic metabolism, since pH reflects a dynamic acid-base equilibrium between the effects of photosynthesis and respiration on the concentration of dissolved inorganic C species (as $CO_{2(aq)}$, H_2CO_3, HCO_3^-, and $CO_3^=$), and can have an important effect on the bioavailability and toxicity many compounds, including toxic metals and nutrients. Numeric criteria exist of pH for fresh and marine surface waters, but it remains unclear whether these values are appropriate for wetlands. Figure 12 (above) shows field measurements of pH for the key monitoring sites. While pH can vary substantially over a diel time scale, generally increasing during the day when rates of photosynthesis exceed respiration and concentrations of inorganic C are low, 90% of the measurements made in Willard Spur were between the daylight hours of 10:00 am and 4:40 pm. As such, these data are *not representative of daily average* pH values. The horizontal line in the above figure (at pH of 9.0) identifies the upper numeric criteria for freshwater, for reference. It is clear that highest pH values were observed in late-spring / early-summer, a time when rates of photosynthesis from algae and SAV are high, and generally declined as the summer progressed. High pH values have a particularly strong impact on the toxicity of ammonia, where a pH of 9.0 yields 36% of total dissolved ammonia in its toxic form and pH 9.5 results in 64% in the toxic form. The lower range of pH values near 8.0 are still in the range of alkaline waters, a consequence of the high concentrations of base cations Na^+, Ca^{2+}, and Mg^{2+} within the water column.

3.1.2 Major Ions

The surface waters in Willard Spur are largely dominated by Na-Cl and Mg-SO_4 ion groups. The major constituents of surface waters in Willard Spur were based on median concentrations in 2011 and include the anions: chloride (Cl^-), bicarbonate (HCO_3^-, estimated from total alkalinity), and sulfate ($SO_4^=$); and the cations: sodium (Na^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), and potassium (K^+). Na^+ and Cl^- were the dominant ions, accounting for 70 and 66% of cations and anions (as mole fractions), respectively. The remaining ions were distributed among total bicarbonate (determined from total alkalinity; 22%) and sulfate (12%) anions, and Mg^{2+}(15%), Ca^{2+} (12%), and K^+ (3%) cations. Observed concentrations of both Mg^{2+} and Ca^{2+} result in high levels of hardness to Willard Spur waters (see Figure 13 below), which can ameliorate the toxicity of some metals to aquatic organisms.

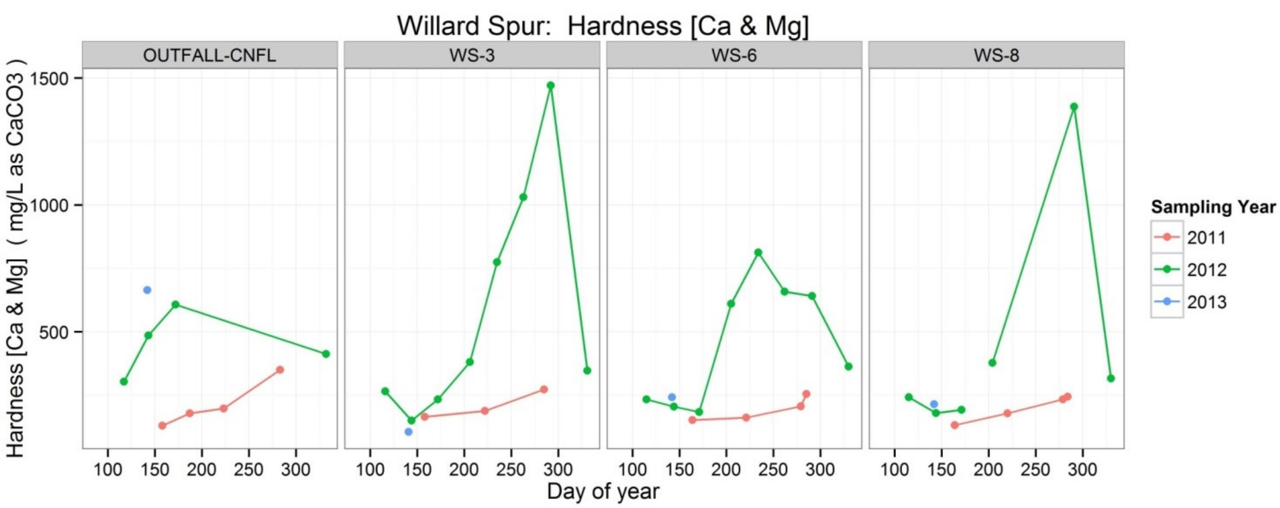


Figure 13. Surface water Hardness for Key Monitoring Sites by Sampling Year.

The following figures illustrate some broad patterns of natural variability across seasonal, interannual, and spatial scales.

Hardness and TDS tended to co-vary, increasing during the summer after the Spur became hydrologically isolated, and in drier vs. wetter years . Sodium and Chloride ions increase strongly across the growing season, likely as a consequence of evaporative water loss in summer. Magnesium and Calcium follow patterns similar to TDS and Hardness, as expected, however bicarbonate and sulfate anions were distinct. Sulfate concentrations generally increased seasonally, the two sites near the center of the Spur (WS-3 and WS-6) appeared to have lower concentrations than the two outlying sites (OUTFALL-CNFL and WS-8), however, the driver of this apparent pattern is unclear. In contrast, concentrations of bicarbonate tend to be highest in the spring and autumn, with a pronounced decline in early summer, particularly in the deeper open water sites WS-3, WS-6, and WS-8. This latter pattern appears to be inversely related to that for pH (Figure 12) and is likely related to the onset and decline of high growing season photosynthetic rates in the open water.

- Major Anions

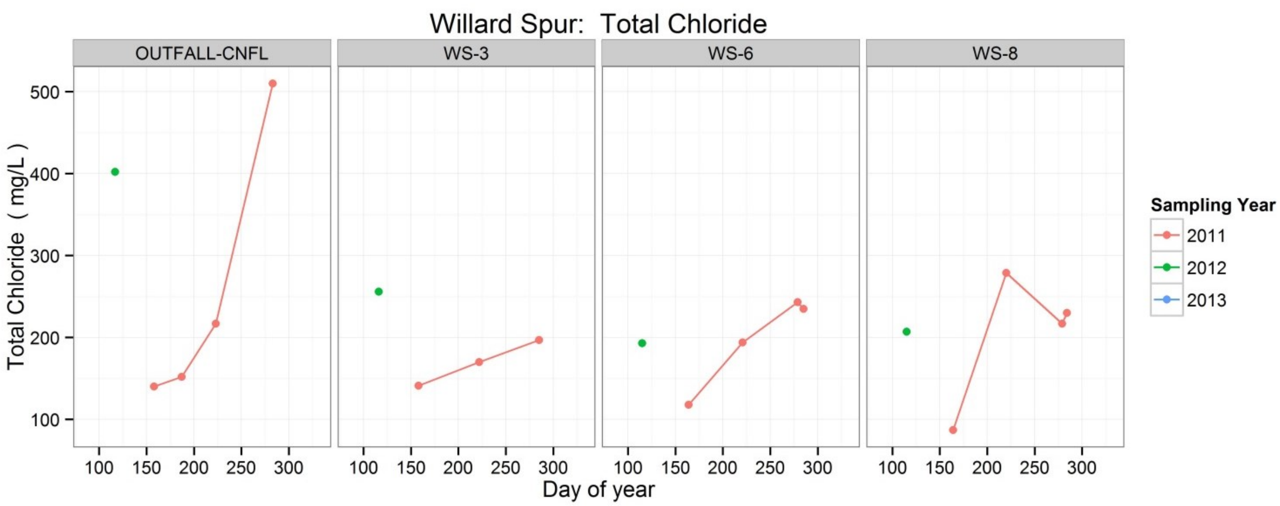


Figure 14. Surface water Total Chloride concentrations for Key Monitoring Sites by Sampling Year.

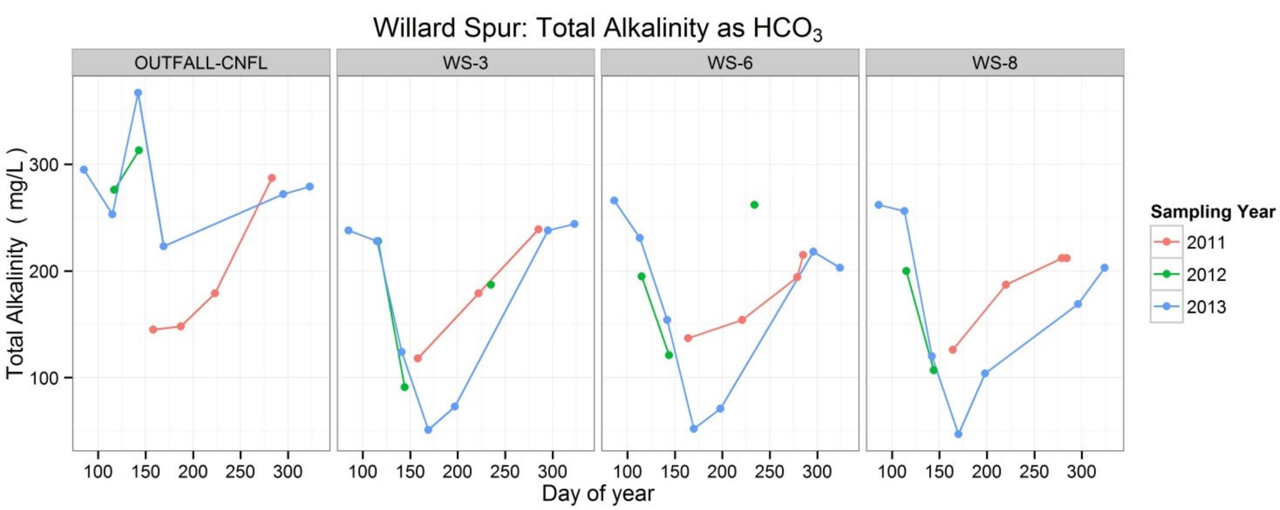


Figure 15. Total Alkalinity for Key Monitoring Sites by Sampling Year.

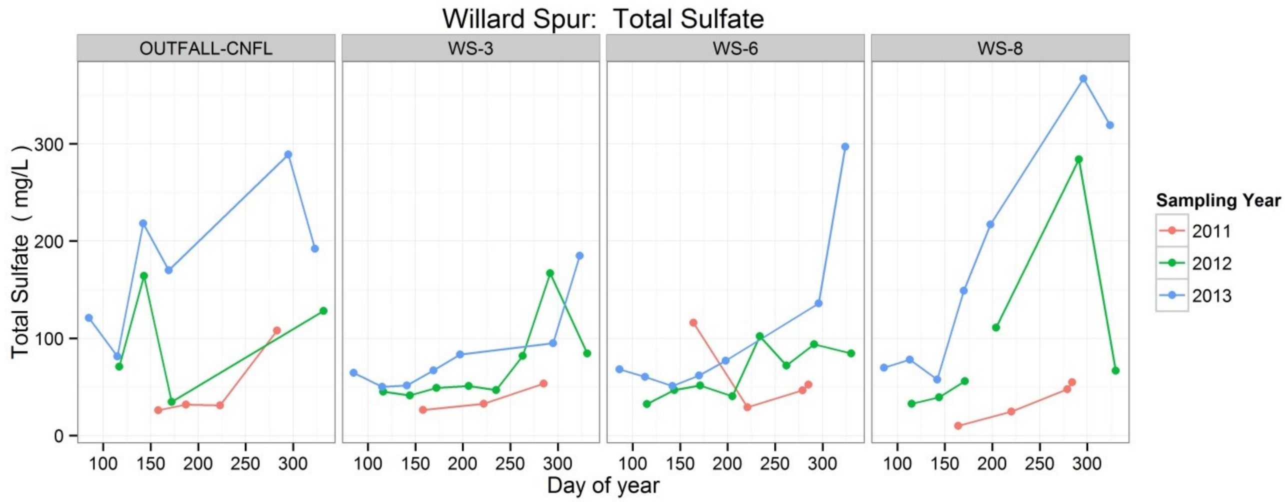


Figure 16. Total Sulfate for Key Monitoring Sites by Sampling Year

- Major Cations

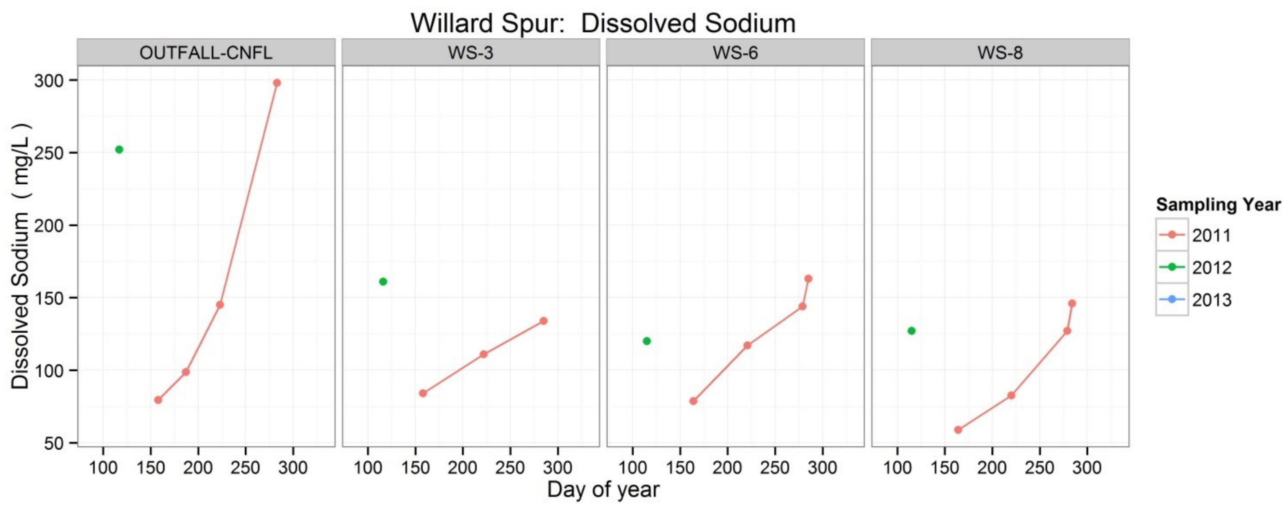


Figure 17. Dissolved Sodium concentrations for Key Monitoring Sites by Sampling Year.

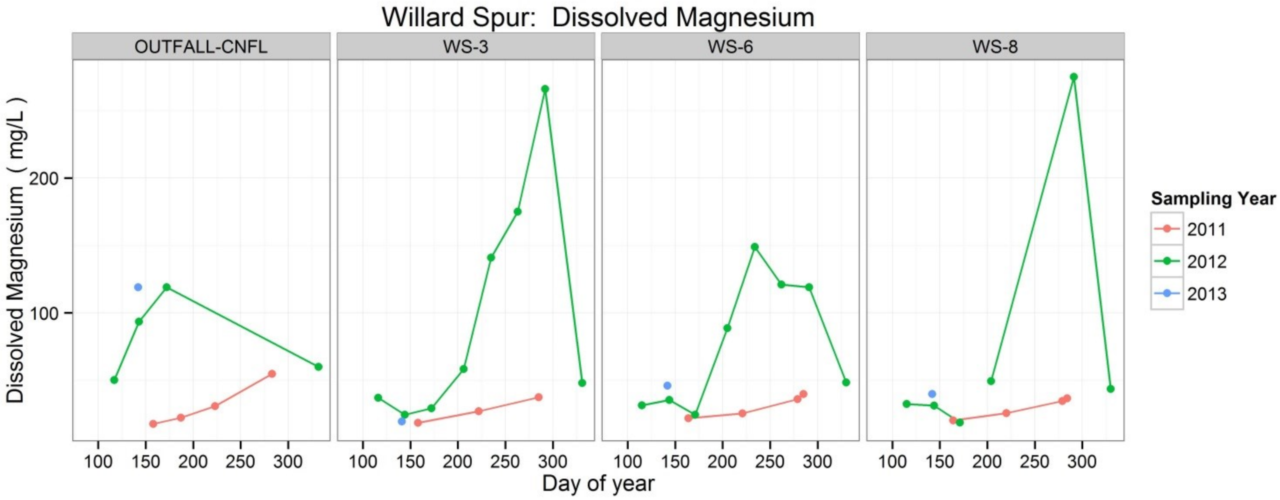


Figure 18. Dissolved Magnesium concentrations for Key Monitoring Sites by Sampling Year.

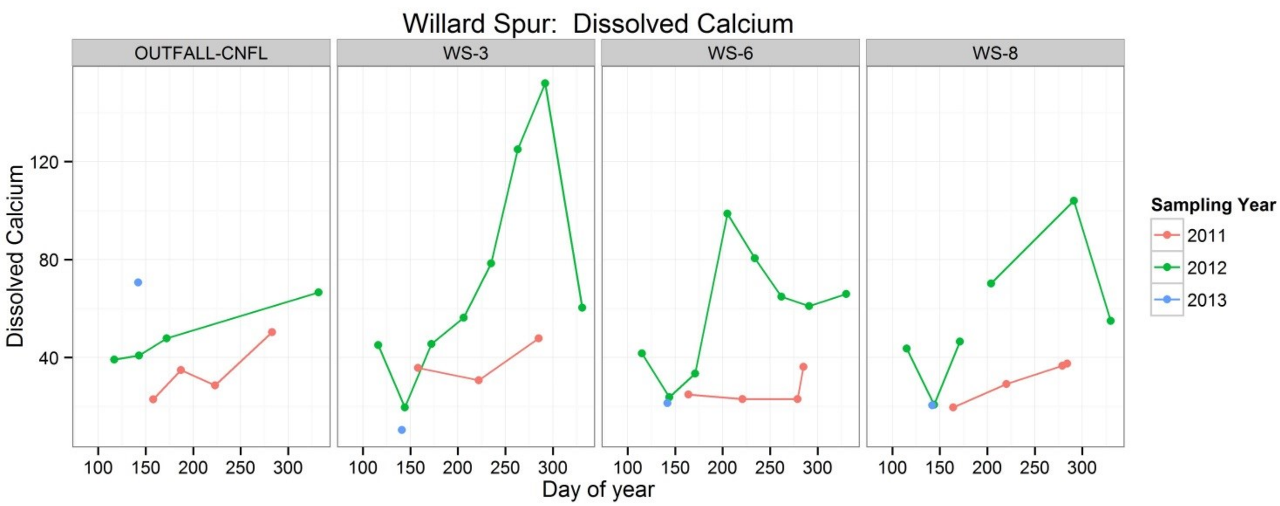


Figure 19. Dissolved Calcium concentrations for Key Monitoring Sites by Sampling Year.

3.1.3 Toxic Metals

Concentrations of dissolved metals were low in waters of Willard Spur. There were no exceedances for toxic metals, based on chronic or acute criteria for aquatic life use 3B or 3D (see Table 2 and Figure 20). However, three samples had dissolved Boron (B) concentrations that were greater than criteria for agricultural irrigation and stock watering uses (750 µg/L). This standard does not apply to Willard Spur waters; the values are provided as a screening measure only. Interestingly, the high Boron values were observed in the central portions of the Spur, within a few miles of inflows from the Harold Crane Waterfowl Management Area (WMA).

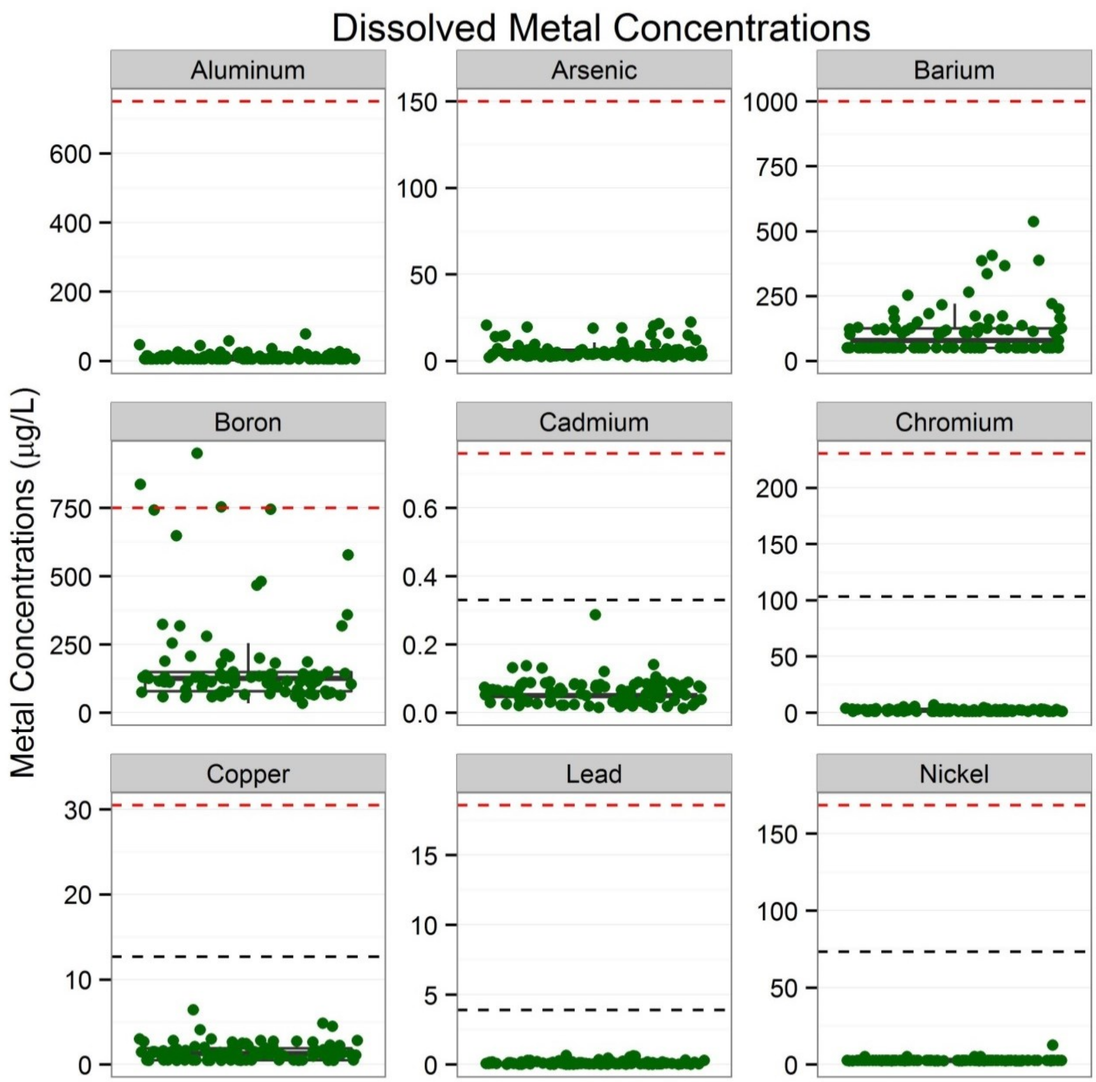


Figure 20. Distribution of Dissolved Metal concentrations from all Willard Spur sampling sites.

The above figure shows the distribution of dissolved metal concentrations from all Willard Spur sites for Al, As, Ba, B, Cd, Cr, Cu, Pb, and Ni. The dashed lines represent the 10th (black) and 90th (red) percentiles of numeric criteria, where the criteria are adjusted for water hardness.

These data were typically collected during summer in 2011-2013, when exposure of aquatic organisms to these pollutants would be greatest. While high levels of hardness (see TABLE) resulted in larger numeric criteria for some metals, substantial numbers of samples from 8 of 10 metals were below quantitation levels. As such, we feel that this determination of no exceedances is protective of the aquatic use.

Table 2. Summary statistics and benchmark criteria for water chemistry parameters of Willard Spur surface waters.

Parameter	Units	MRL *	Samples below MRL †	Percentiles					Range	Samples Exceeding	Benchmark	Comments
				10th	25th	Median	75th	90th				
Standard Water Quality Parameters												
Water Depth	cm	-	0 / 202	10	18	34	55	75	125			
Temperature	°C	-	0 / 209	5.24	12.18	17.89	23.88	27.67	27.69	27	27	
pH	--	-	0 / 209	8.07	8.33	8.66	9.05	9.49	3.2	0 / 56	6.5 / 9.0	
Specific Conductance	µS/cm	-	0 / 209	752	1,149	1,715	3,400	7,063	21,712			
Total Dissolved Solutes (TDS)	mg/L	-	0 / 208	400	626	952	1,898	4,056	13,774			
Dissolved O_2	mg/L	-	0 / 209	7.18	8.75	10.71	12.92	15.06	18.2	0	3	
Dissolved O_2	% sat.	-	0 / 209	86.7	102.4	123.8	164.2	198.5	300.3			
Chlorophyll-a	µg/L	0.35	40 / 211	0.35	2.2	17.6	32.8	59.7	304.7			
Hardness	mg $CaCO_3$/L	-	0 / 158	150	183	244	352	660	1590			
Major Anions and Cations												
Sulfate (SO_4)	mg/L	-	0 / 208	24.5	36.3	55.8	91.7	159.1	365.8			
Chloride (Cl)	mg/L	-	0 / 79	103.6	141	197	262	450	874.2			
Bicarbonate (from total alkalinity)	mg/L	-	0 / 159	103	135	194	231	263	337			
Sodium (Na)	mg/L	1	0 / 79	67.9	84.1	126	169	253.4	415			
Calcium (Ca)	mg/L	1	0 / 158	21.2	30.8	42.5	55.2	79.9	141.6			
Magnesium (Mg)	mg/L	1	0 / 158	19.8	25.0	34.9	48.5	122.5	303.3			
Potassium (K)	mg/L	1	0 / 97	5.9	8.5	114	15.8	43.5	82.5			
Nutrients and Organic Matter												
Ammonium (NH_4)	mg/L	0.03	0 / 211	0.0125	0.015	0.026	0.099	0.195	1.428	7	0.608	ALU, criterion corrected for pH and field Temperature (median criteria reported as benchmark)
Nitrate + Nitrite ($NO_3 + NO_2$)	mg/L	-	0 / 205	0.002	0.008	0.028	0.049	0.441	21.398	5	4.0	Benchmark is a pollution indicator for fishery-based ALU's.
Total Nitrogen (TN)	mg/L	-	0 / 211	0.41	0.53	0.81	1.51	2.87	22.0			
Total Organic N (TON)	mg/L	-	0 / 211	0.32	0.43	0.63	1.00	1.75	4.8			
Total Phosphorus (TP)	mg/L	-	0 / 211	0.037	0.05	0.085	0.150	0.254	0.747	157	0.05	Benchmark is a pollution indicator for fishery-based ALU's.
Dissolved Phosphorus (DP)	mg/L	-	0 / 157	0.02	0.036	0.048	0.076	0.147	0.59			
TN : TP ratio	g N : g P	-	0 / 211	3.81	6.5	10.8	17.2	26.9	171.4			
DN : DP ratio	g N : g P	-	0 / 157	6.45	9.73	14.4	25.1	45.9	165.2			
Trace Metals and Metalloids												
Aluminum (Al)	µg/L	10	52 / 97	5.0	5.0	5.0	14.0	22.7	72.2	0	750	For waters with pH > 7.0 and Hardness > 50, only the acute Al criteria applies for protection of aquatic life use (ALU)
Arsenic (As)	µg/L	1	0 / 97	2.6	3.2	3.9	6.4	14.6	20.4	0	150	Chronic ALU criteria
Barium (Ba)	µg/L	100	48 / 97	50.0	50.0	77.5	126.0	205.8	486.0	0	1000	Designated use class 1C (Domestic Source Water)
Boron (B)	µg/L	30	0 / 97	66.32	79.0	125.0	149.0	337.0	916.8	3	750	Designated use class 4 (Agriculture)
Cadmium (Cd)	µg/L	0.1	89 / 97	0.05	0.05	0.05	0.05	0.05	0.20	0	0.47	ALU, criterion corrected for hardness (median criteria reported as benchmark)
Copper (Cu)	µg/L	1	26 / 97	0.5	0.5	1.3	1.9	2.7	5.9	0	19.46	ALU, criterion corrected for hardness (median criteria reported as benchmark)
Chromium (Cr)	µg/L	2	46 / 97	1.0	1.0	2.0	2.7	3.2	5.8	0	153.7	ALU, criterion corrected for hardness (median criteria reported as benchmark)
Iron (Fe)	µg/L	20	128 / 158	10.0	10.0	10.0	10.0	22.7	93.0	0	1000	ALU
Manganese (Mn)	µg/L	5	114 / 158	2.5	2.5	2.5	5.0	16.3	132.5			No benchmark available
Nickel (Ni)	µg/L	1	92 / 97	2.5	2.5	2.5	2.5	2.5	10.0	0	110.6	ALU, criterion corrected for hardness (median criteria reported as benchmark)
Lead (Pb)	µg/L	0.1	58 / 97	0.05	0.05	0.05	0.14	0.25	0.6	0	6.83	ALU, criterion corrected for hardness (median criteria reported as benchmark)

* Missing values indicate that no minimum reporting level (MRL) was given for that analyte by the State Public Health Laboratory.
† Values reported as: # of Samples < MRL / Total # of samples.

3.1.4 NUTRIENTS

- Nitrogen

Total Nitrogen (TN) concentrations within the water column, averaged across all sites and over all sampling periods, were approximately 1.0 mg N/L (Figure 21). Most of this N was in dissolved and organic fractions.

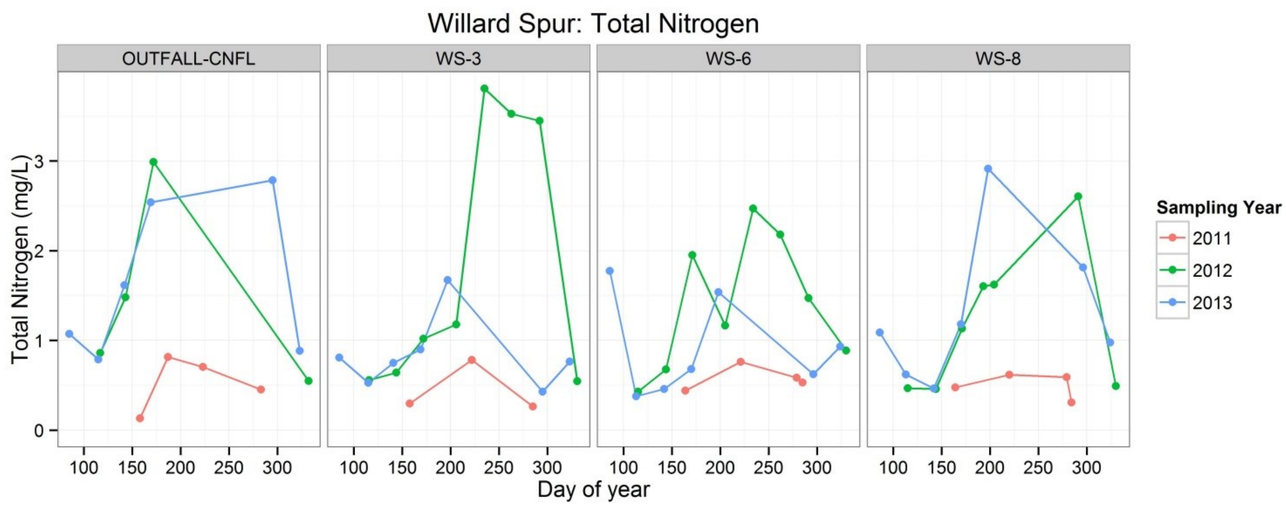


Figure 21. Total Nitrogen concentrations for Key Monitoring Sites by Sampling Year.

Differences in average TN among sites were not readily apparent, however concentrations were much greater during the drier years (2012 and 2013) than the wetter year (2011). In addition, TN increased during the growing season, particularly in 2012, reaching concentrations over 2.0 mg N/L before rapidly declining in autumn.

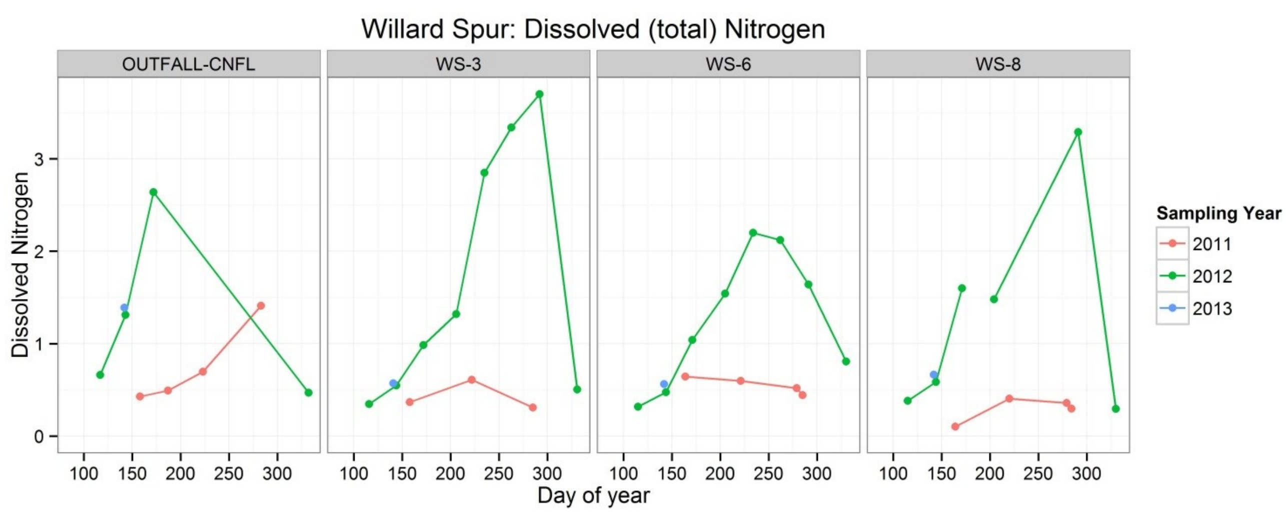


Figure 22. Dissolved Nitrogen concentrations for Key Monitoring Sites by Sampling Year.

Dissolved N (DN) concentrations (< 0.45 µm in size) followed a similar pattern as TN, where concentrations were higher in 2012 versus 2011, increased during the summer, and then declined rapidly in autumn (Figure 22). Based on these results, it appears that particulate forms of N, i.e. those greater than 0.45 µm represent only a small fraction of N within the water column of Willard Spur.

Inorganic forms of N (TIN, as total inorganic N), as ammonium (NH_4^+) and nitrate (as NO_2^- + NO_3^-), account for 6% to 33% of TN concentrations. On a seasonal basis, the proportion of TN in inorganic forms was greater at sites near Willard Spur inflows (17% to 33%; OUTFALL-CNFL and WS-6) than at more 'internal' sites (5 to 20%). We also observed episodic pulses of TIN (Figures 23 and 25), particularly at sites near inflows, that were much more pronounced than any apparent seasonal patterns. Interestingly, the seasonal summer-peak and autumn-decline

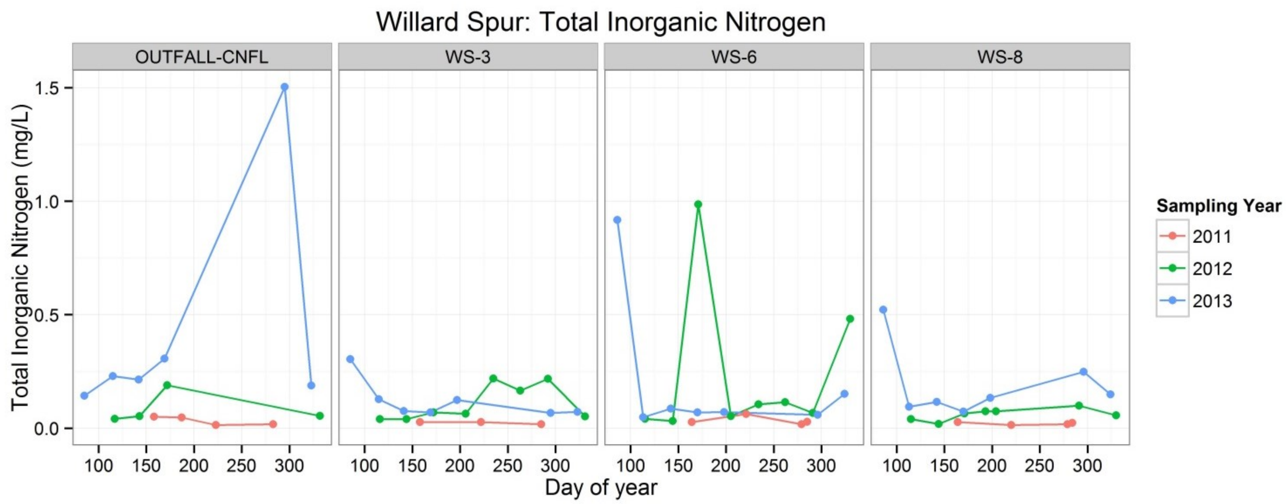


Figure 23. Total Inorganic Nitrogen concentrations for Key Monitoring Sites by Sampling Year.

patterns observed for TN and DN were largely the result of changes in organic N forms (Figure 24). The seasonal pattern is most evident in 2011 and are likely derived from the turnover of algal and aquatic vegetation biomass during the latter portions of the growing season, possibly as a result of accumulating environmental stress during low water conditions (e.g. shallow water depths, high temperatures and increasing salinity).

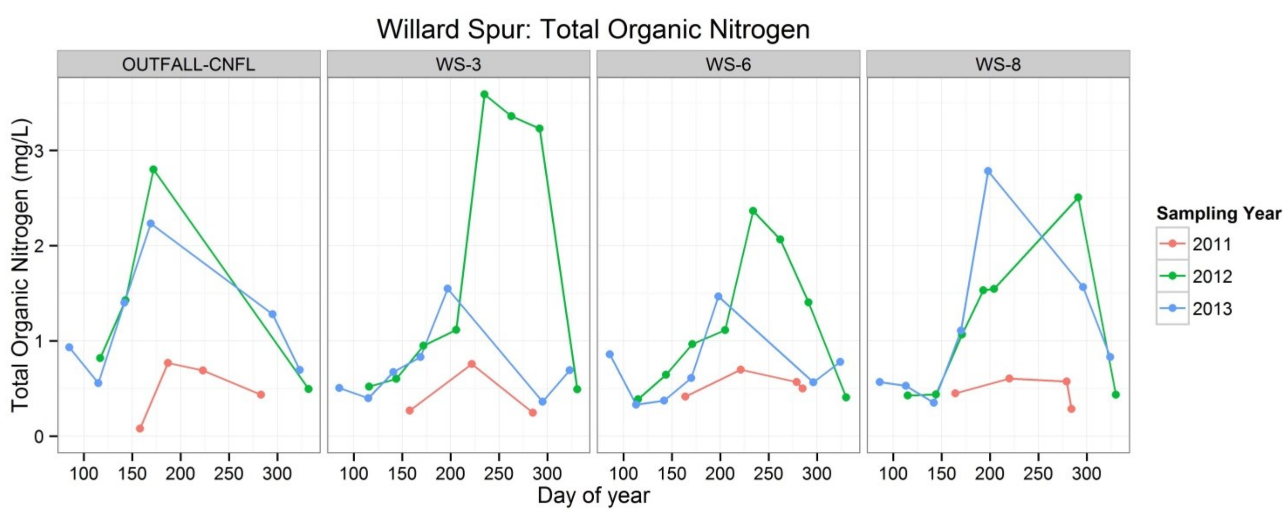


Figure 24. Total Organic Nitrogen concentrations for Key Monitoring Sites by Sampling Year.

As mentioned above, pulses in NH_4^+ and NO_3^- concentrations were rare (FIGURE, below). High values for inorganic N species (NH_4 and NO_3) were sporadic throughout the baseline monitoring period for key monitoring sites, and for all sampled sites (Figures 70 and 71 in Appendix). Data from all monitored sites shows that TIN spikes were relatively more common along the eastern inflows ("East Side") and near the inflow from Harold Crane WMA ("HC inflow"). Interestingly, most of these spikes were dominated by NO_3 rather than NH_4, and elevated concentrations do not appear to persist beyond the next monitoring station.

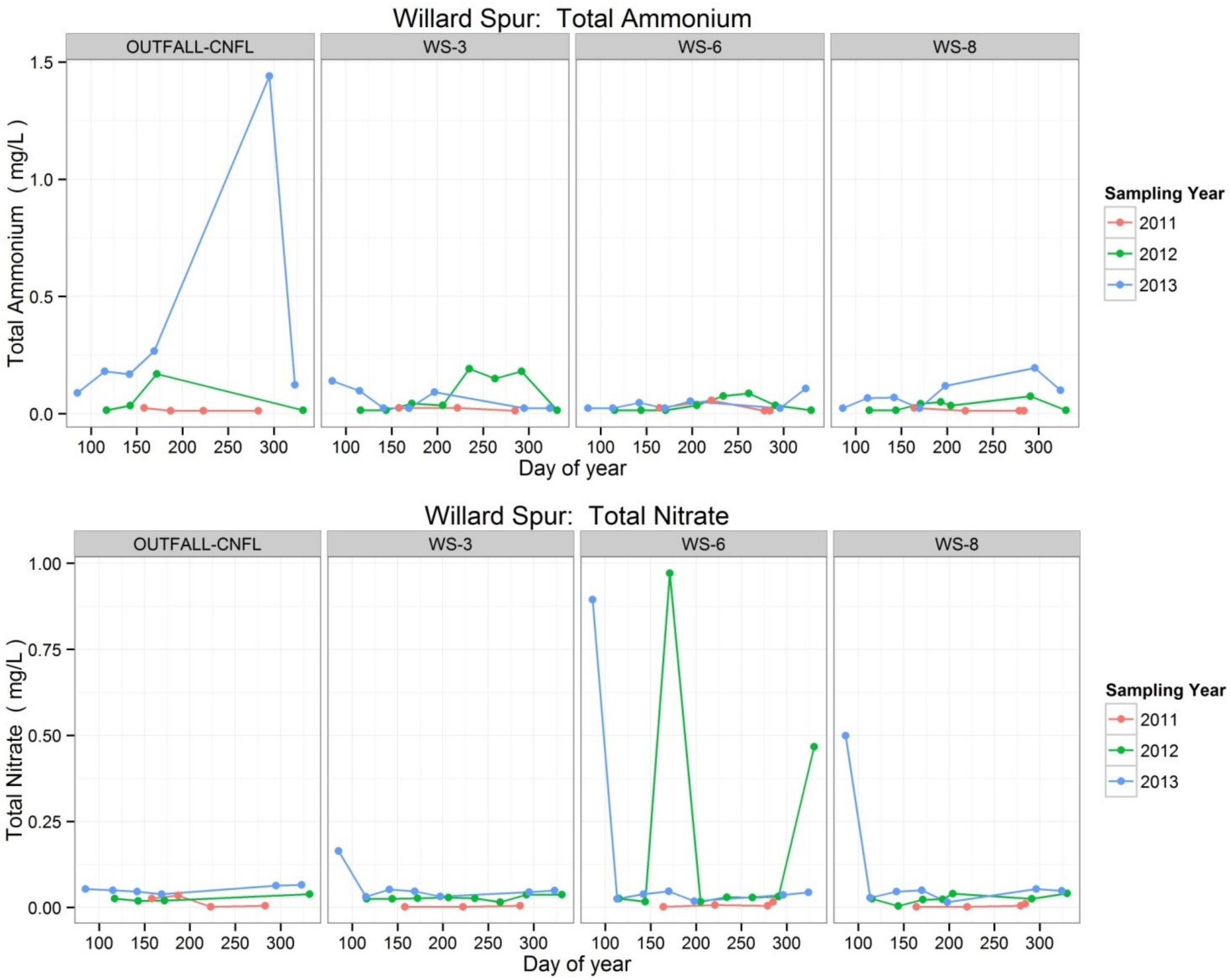


Figure 25 Total Ammonium (top) and Nitrate (bottom) concentrations for Key Monitoring Sites by Sampling Year

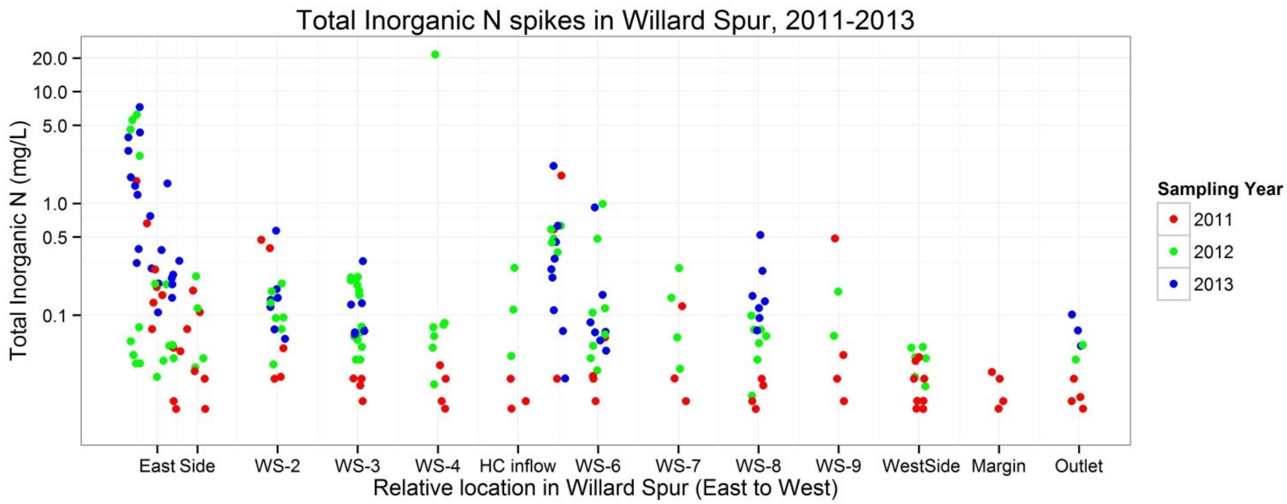


Figure 26. Distribution of Total Inorganic N concentrations across the Willard Spur project area by Sampling Year.

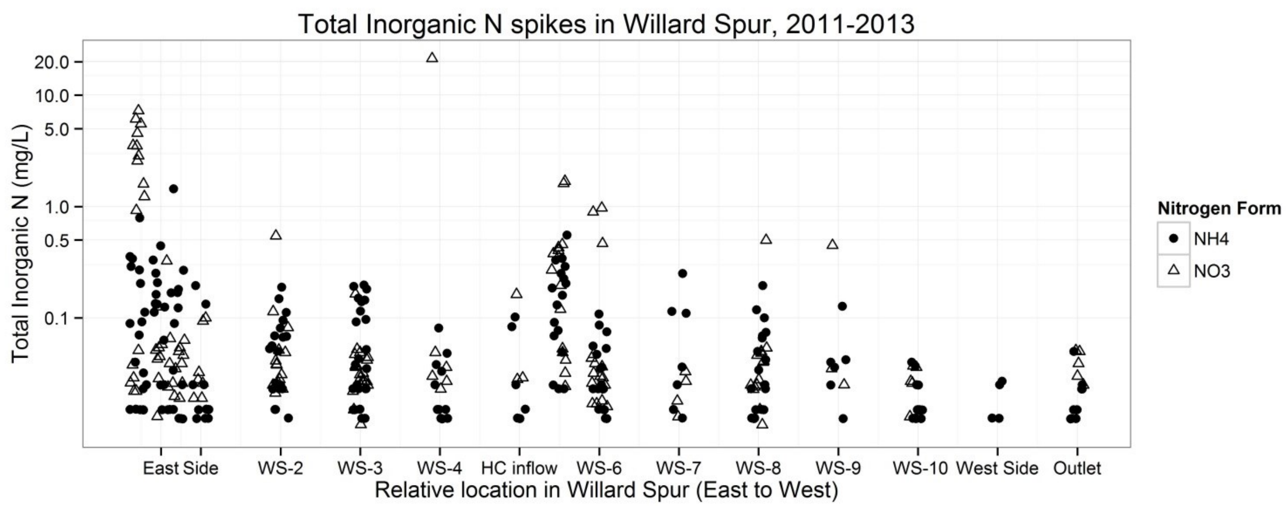


Figure 27. Distribution of Total Ammonium and Nitrate concentrations across the Willard Spur project area.

- Phosphorus

Average Total Phosphorus (TP) concentration within the water column, across all sites and over all sampling periods, was approximately 0.12 mg P/L (Figure 28). The dissolved P fraction (DP; < 0. 0.45 µm in size) ranged from 40 to over 80%, suggesting that particulate P loads from watershed sources were temporally variable but important sources of P. Seasonal patterns in TP were less clear than for TN, but generally suggest two periods of elevated TP concentrations: early- to mid-spring and early autumn, with lower concentrations during the summer. This pattern is consistent with P uptake and retention within the biomass of photosynthetic biota,

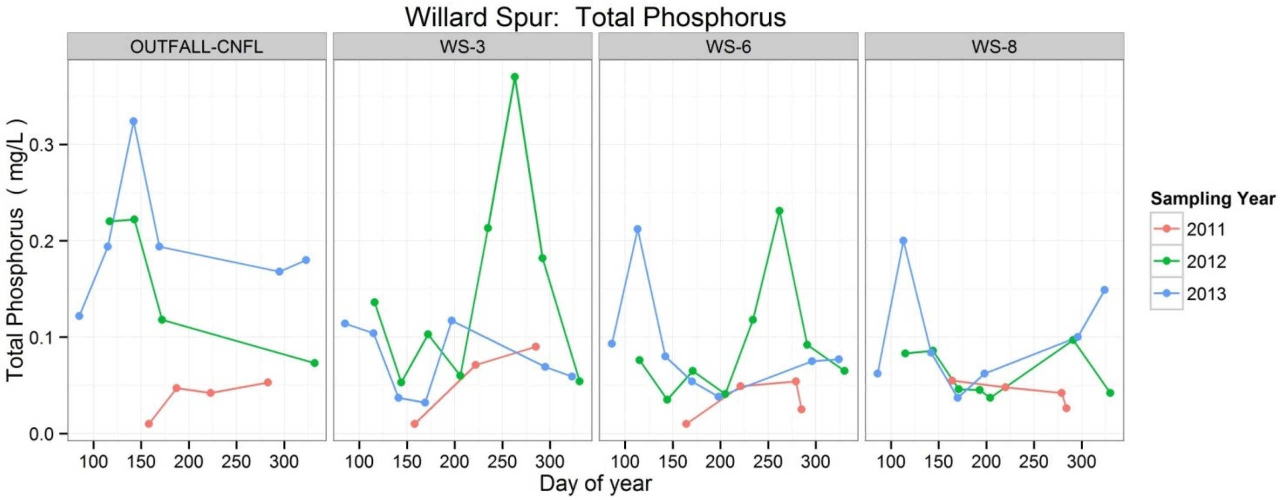


Figure 28. Total Phosphorus concentrations for Key Monitoring Sites by Sampling Year.

including SAV, attached epiphytes, and periphyton within the water column and on wetland soil surfaces.

Dissolved P displayed similar seasonal patterns as TP (Figure 29), except that early-season peaks in DP were generally only observed along the eastern margin of the Spur (OUTFALL-CNFL site). In addition to seasonal patterns, we also found that TP and DP concentrations, averaged over the entire monitoring period, decreased from east (OUTFALL-CNFL: 0.14 and 0.10 mg P/L for TP and DP) to west (WS-8: 0.07 and 0.035 mg P/L for TP and DP). This pattern is consistent with biotically-driven retention of bioavailable P in plant and algal biomass as well as physicochemical sorption associated with surface sediments and inorganic particulates.

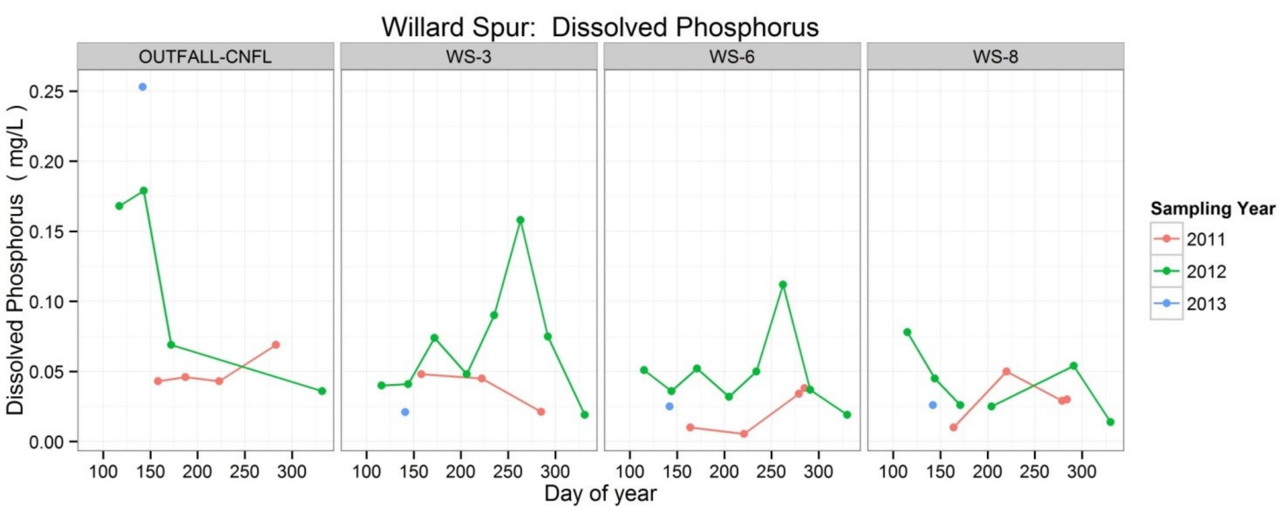


Figure 29. Dissolved Phosphorus concentrations for Key Monitoring Sites by Sampling Year.

- Water Column Nitrogen to Phosphorus Ratios

The ratio of N to P concentrations within the water column is commonly used to describe the balance between N and P availability of aquatic ecosystems, such as shallow lakes or regularly inundated wetlands like Willard Spur. Low or narrow N:P ratios suggest a limitation by N availability to growth of photosynthetic organisms, while high or wide N:P ratios, conversely, suggest a limitation by P availability. Reasonable breakpoints for N- versus P-limited growth, derived from N:P ratios of marine phytoplankton (16:1 N:P molar ratio), are < 8 and > 30 for N- and P-limitations, respectively; commonly referred to as the 'Redfield Range' (Moss et al., 2013). The following results for Willard Spur are presented as N:P mass ratios, equivalent to molar ratios x 0.45, where N-limited growth is expected for N:P mass rations < 3.6 and P-limited growth is expected for N:P > 13.6. Intermediate values may support the idea that algal growth is limited by both N and P availability.

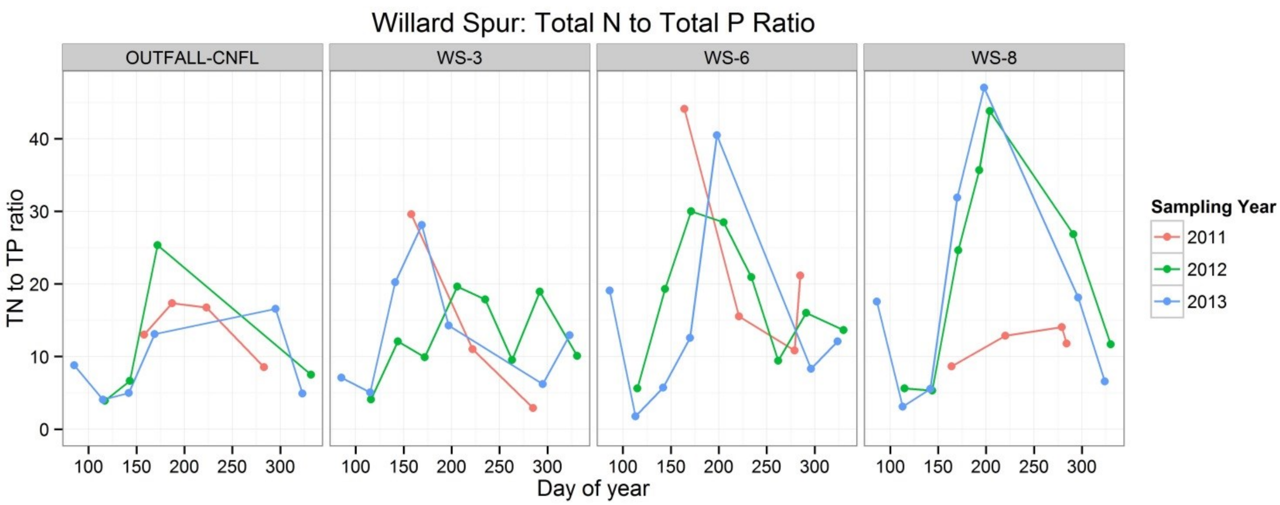


Figure 30. Total N to Total P ratios for Key Monitoring sites by Sampling Year.

There were marked seasonal patterns in TN:TP ratios (Figure 30), with values typically increasing in early- through late-summer (DOY 150 through 200), before declining in autumn, suggesting the development of a progressive P-limitation during the growing season. Values in late-spring were between 3 and 10:1 in all four key monitoring sites, while peak values in late-summer ranged from 20 to over 40:1. The highest N:P ratios were observed in the westernmost (downstream) sites (WS-6 and WS-8), largley as a consequence of lower TP concentrations compared to the more upstream sites. TN:TP ratios were usually similar among the wet (2011) vs. drier (2012 and 2013) years, even when TN and TP concentrations differed by year. One exception was for WS-8, where TN:TP ratios were much lower (approximately 10 to 15:1) in 2011 vs. 2012 and 2013.

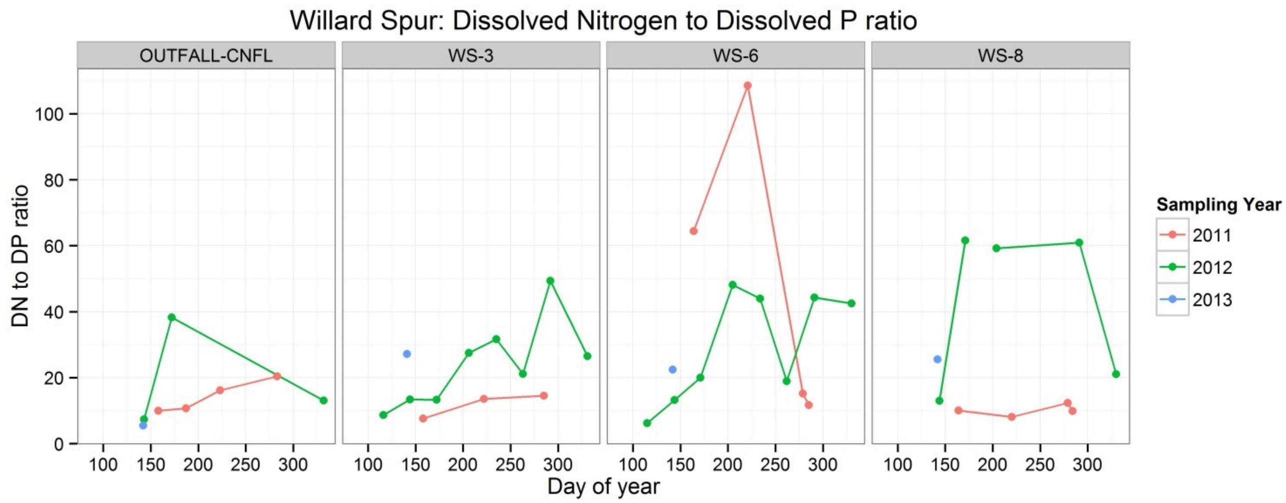


Figure 31. Dissolved N to P ratios for Key Monitoring Sites by Sampling Year.

Fewer observations for dissolved N:P ratios were recorded, due to sampling-related resource constraints. DN:DP ratios tended to increase over the growing season during the drier year (2011), similar to the seasonal TN:TP pattern, but the autumnal decrease was less apparent, particularly at WS-3 and WS-6 (Figure 31). The mechanisms controlling these patterns are not entirely clear. Declining P concentrations and increasing N:P ratios may be related to seasonal immobilization of soluble P by sorption onto precipitating $CaCO_3$ (calcite) during periods when pH values (and photosynthetic rates) were high. However, questions remain as to whether, if available P was immobilized by calcite-sorption during the summer, this sorbed-P was released back to the water column during the cooler autumn and winter months, transported as suspended flocc after the return of hydrologic connectivity with greater Bear River Bay, or stored more permanently in sediments.

3.1.5 Numeric Criteria and Pollution Indicators

This section compares water chemistry measurements against numeric criteria for warm water fishery (3B) and aquatic waterfowl life (3D) designated uses (see R317-2-7). Observed values for Willard Spur open water conditions are summarized in Table 2.

Indicators of toxic or degraded conditions were calculated as numeric criteria for NH_3 (undissociated ammonia) and as pollutant indicators NO_3 and Total P, as reported in UAC R317-2-7 for aquatic wildlife. There were seven (7) exceedances for Total Ammonia (NH_4-N), based on current numeric criteria for warm water aquatic life use with early life-stage fish present. These exceedences were due to a combination of higher NH_3 concentrations (above 80th percentile of observed NH_4^+ values), high pH (> 9.17), and warm temperatures (> 28.5 °C) (see Figure 32), and were observed within the eastern portion of the Spur.

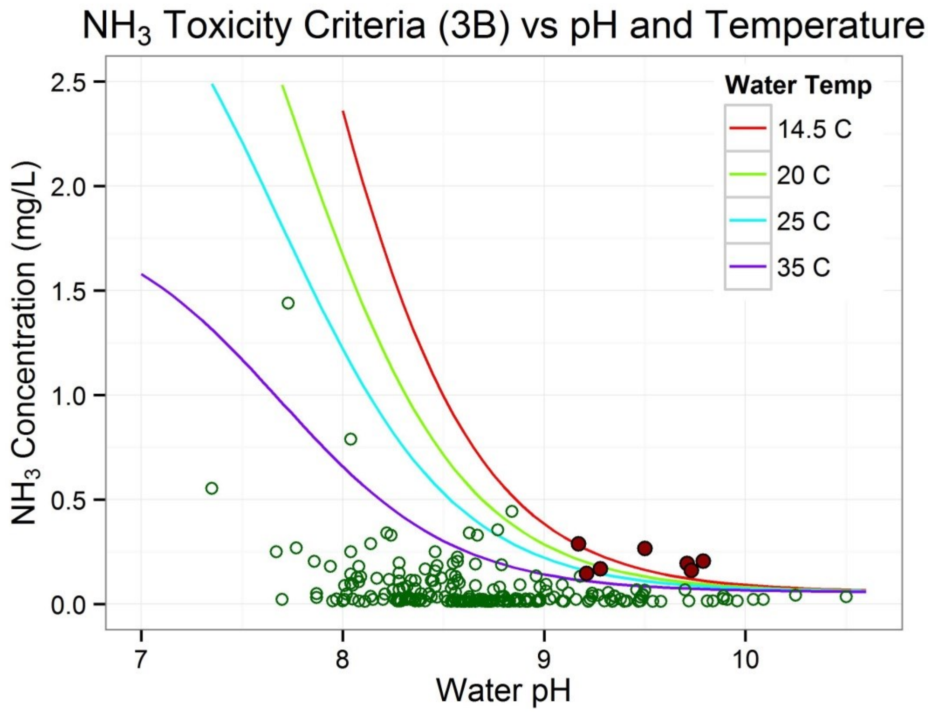


Figure 32. Relationship between Total Ammonium Concentrations and NH_3-Toxicity Criteria against water column pH.

We found no exceedences for low dissolved oxygen concentration (< 3 mg/L), but 2 samples had DO below 5 mg/L, while 56 samples had pH greater than 9.0. This is likely because instantaneous (grab sample) DO measurements taken during the daytime (10:00 am to 4:00 pm) and not over the entire diel cycle, where presumably high rates of photosynthesis result in increased DO and decreased CO_2 aqueous concentrations that drives pH upward.

We also observed that five (5) samples had NO_3^- concentrations greater than the of 4.0 mg NO_3-N/L pollutant indicator; four of these samples were from inside the Willard Bay (reservoir) Tailrace (monitoring location id 5984643). By contrast, the occurrence of high TP concentrations was widespread, where 157 of 211 samples had TP concentrations greater than the 0.05 mg P/L pollution indicator value.

3.2 Indicators of Aquatic Metabolism

Several chemical and biological indicators can be used to describe various aspects of aquatic metabolism, such as rates of photosynthesis and decomposition and the size of biomass pools within the aquatic system. These indicators include the concentration (and diel patterns) of dissolved oxygen (DO), water pH, chlorophyll a concentration, and measures of the availability of labile C such as the 5-day (carbonaceous) biochemical oxygen demand (BOD). Dissolved oxygen and BOD are presented here, while the other measures have been reported for Willard Spur in other sections of this document.

Dissolved oxygen concentrations are show below, as absolute concentrations (mg/L) (Figure 33) and as percent of saturation (Figure 34). Note that the dashed line in Figure 33 below represents the numeric criterion for minimum DO concentration for 3B and 3D aquatic wildlife beneficial use classes. All DO measurements were higher than the DO minimum concentration criterion of 3 mg/L, as expected, since measurements were taken between 10:30 and 16:00, when the diel DO curve is near its peak. While seasonal and interannual patterns are not clear from these

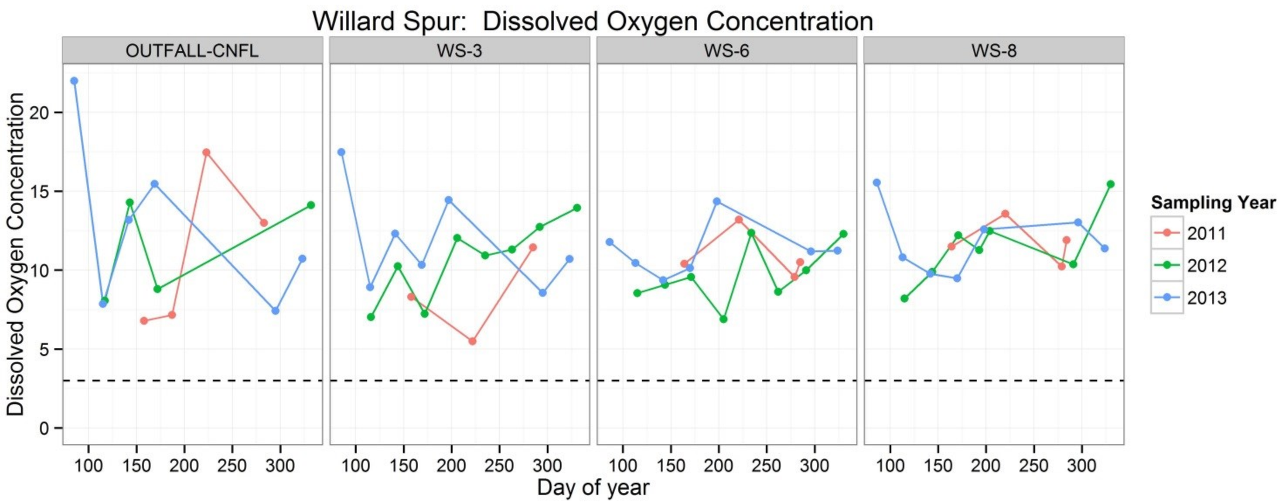


Figure 33. Dissolved Oxygen concentration for Key Monitoring Sites by Sampling Year.

data (daytime concentrations range from approximately 7 to over 15 mg/L), it appears that seasonal and interannual differences become more muted in western (WS-6 / WS-8) vs. eastern sites (WS-3 / Outfall-CNFL).

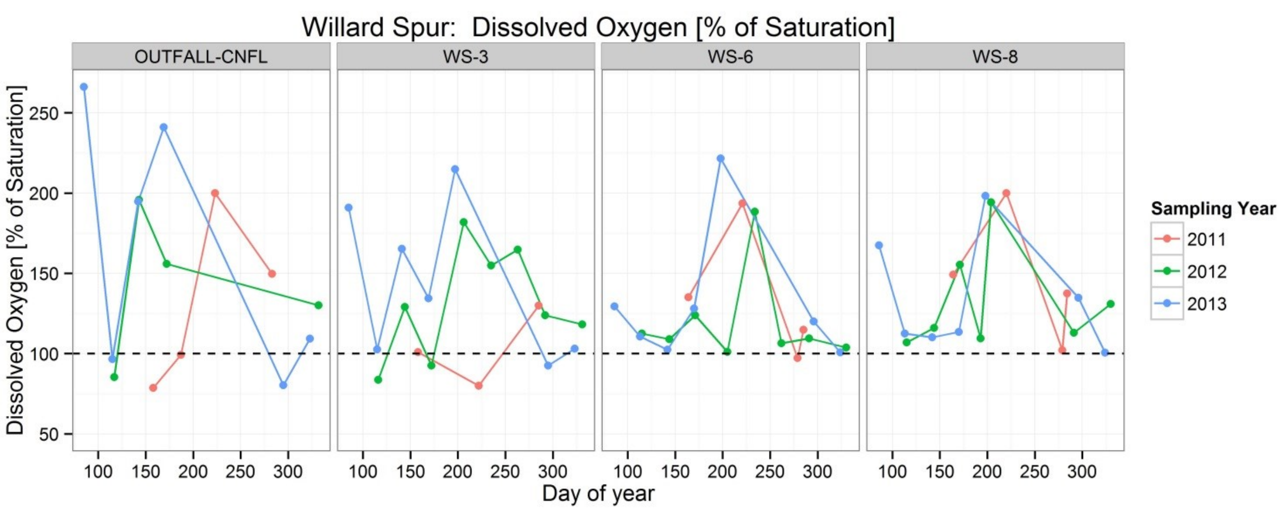


Figure 34. Dissolved Oxygen (% saturation) for Key Monitoring Sites by Sampling Year.

When DO concentrations were relativized to physical equilibrium (or saturated) conditions, daytime DO measurements (figure above) were nearly always >100% (over saturated) and displayed seasonal peaks in mid-summer. These data suggest that, under current conditions, there is no strong evidence for an imbalance between photosynthetic primary production and heterotrophic respiration within Willard Spur. However, DO values near 200% of saturation suggest that daytime photosynthesis rates are very high, typical of a productive shallow-aquatic ecosystem.

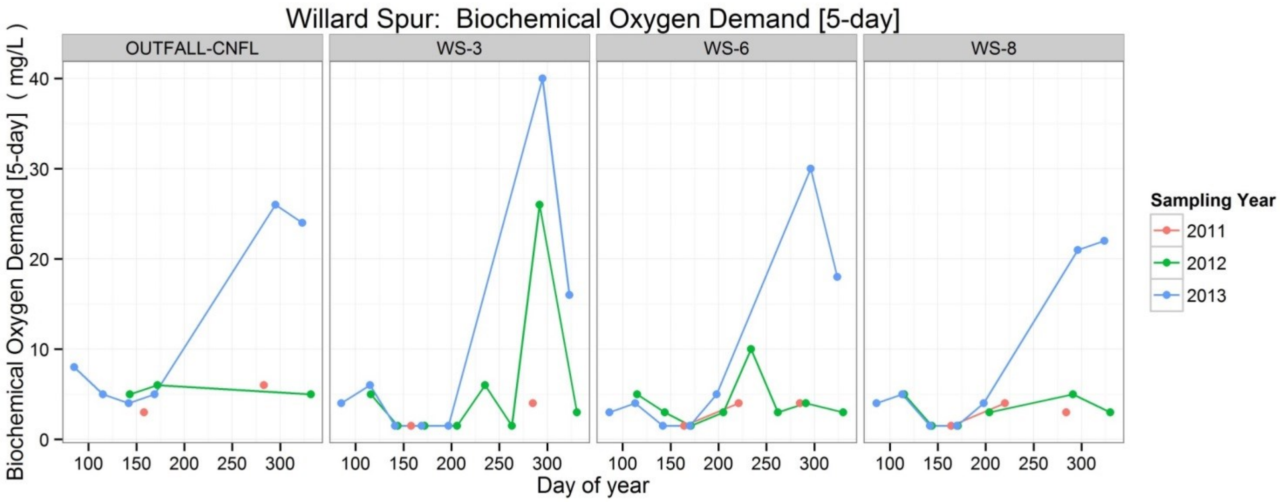


Figure 35. 5-day Biochemical Oxygen Demand for Key Monitoring Sites by Sampling Year.

Generally, 5-day BOD values were below minimum reporting levels of 3 mg/L, as expected for most natural wetlands with low effluent loads (Figure 35) (Kadlec and Wallace; Reddy [?]). However, late-season (DOY 270 to 320) BOD pulses were observed in 2012 and 2013, similar to the late-season pulses of TN (Figure 21), DN (Figure 22), and TON (Figure 24). These pulses are consistent with re-solubilization of partially decomposed detritus that was exposed and re-wetted in late summer of those years.

3.3 Open Water – Biological Responses

3.3.1 Submerged Aquatic Vegetation (SAV)

Submerged aquatic vegetation (SAV) is a key component of the Willard Spur ecosystem. SAV serves as important habitat for invertebrates and juvenile fish, and contributes to entrainment of suspended particles derived from surface water inflows or wind-induced wave action. Moreover, SAV and associated epiphytic growths (algae and heterotrophic biofilms) account for substantial quantities of primary production and nutrient uptake. Biomass accumulation and nutrient retention within SAV (and epiphytes) can provide at least temporary (i.e. seasonal) storage of available nutrients, before being released as detritus. While changes in species composition of plant communities are often an important part of wetland assessments, early monitoring efforts by DWQ collected only sparse data on species composition of the SAV community. A Willard Spur project report: *Response to Experimental Nutrient Additions* (Johnson et al. 2014) and a review of Willard Spur vegetation (Downard et al., 2014) describe common plant species found in the Spur and similar ecosystem types. DWQ observed *Stuckenia* sp. and *Myriophyllum sibiricum* in 2013 during a mesocosm nutrient uptake experiment (see Ostermiller et al., 2015).

Many questions remain with regard to the importance and the dynamics of SAV communities as an indicator of ecosystem health. DWQ will work to incorporate SAV community composition in future monitoring efforts. However, results on SAV cover and condition class (see Willard Spur SOPs for Vegetation) from Willard Spur can shed some light on seasonal patterns of SAV growth during the 2011-13 monitoring period.

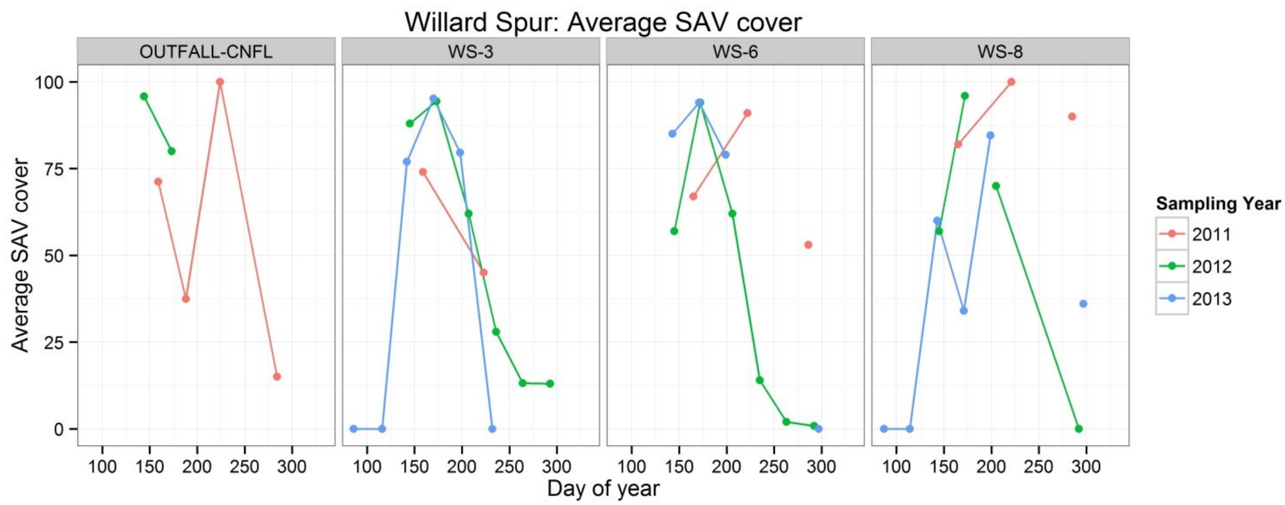


Figure 36. Average cover of Submerged Aquatic Vegetation (SAV) for Key Monitoring Sites by Sampling Year

The cover and condition class of SAV within open water portions of Willard Spur were determined from measurements collected along five 1-m^2 quadrats. Condition class describes the relative health of the SAV canopy, ranging from lush and vibrant growth (class 3) to the remains of a sparse and nearly senescent canopy (class 1). Additional details about SAV transect sampling is included in the SAV SOP (see Willard Spur project website).

The figure above (Figure 36) shows average SAV cover from transect measurements along the key monitoring sites, similar to previous figures of water chemistry (above). Unfortunately, occasional site-access and sampling issues reduced the sampling intensity among these sites, such that temporal patterns across Willard Spur are difficult to visualize, however, results from these measurements are provided as figures in the Appendix (Figures 72 to 76). Nonetheless, the figure highlights the seasonal peak in SAV cover in June during drier years. An expected period of rapid growth leading up to peak SAV cover appears to be coincident with an increase in water column pH (Figure 12) as well as a rapid decline in alkalinity (Figure 15). Wetter years (as 2011) may experience extended periods of SAV dominance throughout the open water portions of the Spur. In addition, a seasonal decline in cover (after day 200; late July) appears to be associated with the late-summer increase in TON (Figure 24).

Seasonal patterns of SAV cover, plotted across a broader range of sites highlight the distribution of SAV cover measurements over time (Figure 37 below). The extended period of high SAV cover in 2011 is clear, extending from June through August. In addition, drier years (2012 and 2013) exhibited earlier declines in SAV cover than 2011. Also note that for 2013, nearly the entire area of Willard Spur was dry during August and September.

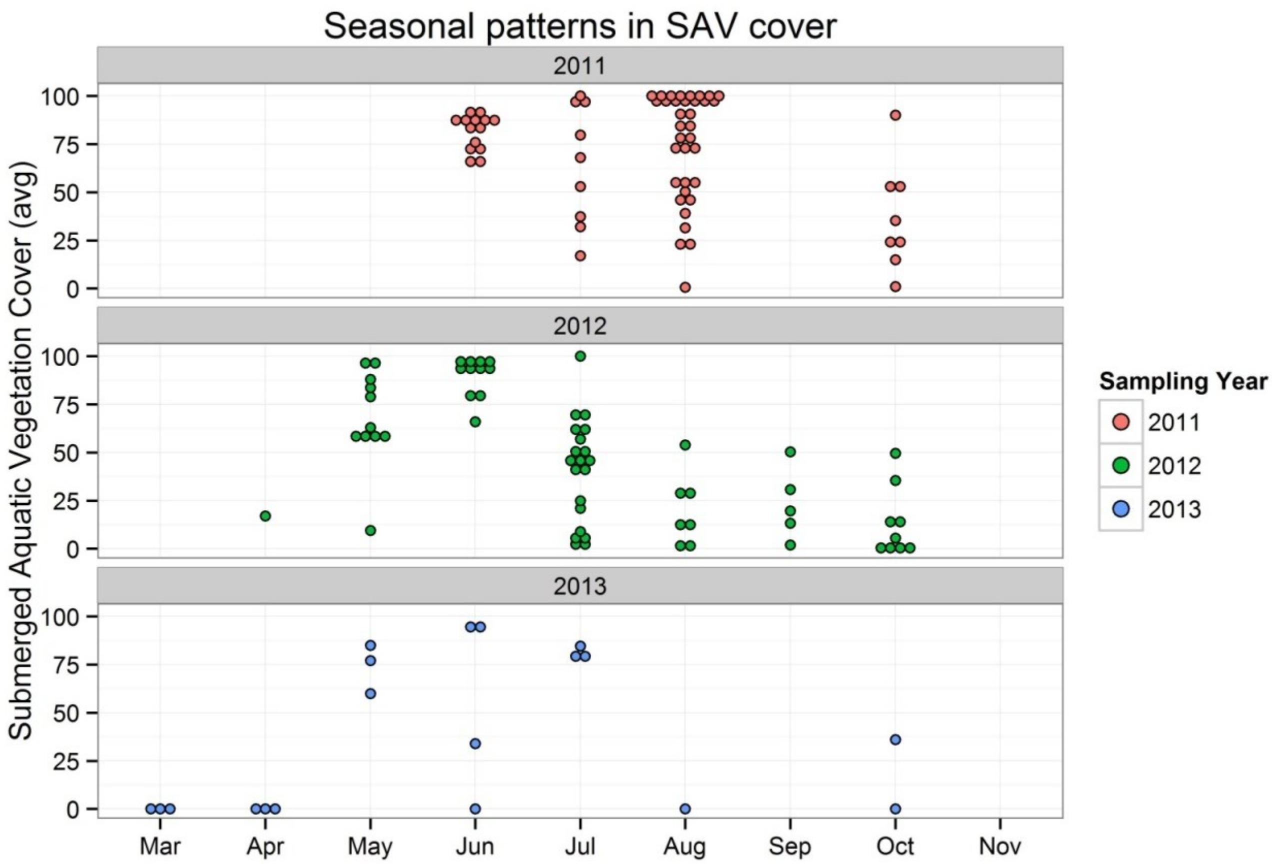


Figure 37. Distribution of SAV cover over the Willard Spur project area by Month and Sampling Year.

The following figures illustrate the spatial gradient in SAV cover, SAV condition class, and SAV biovolume for the 2011-2013 period. The figures show SAV measurements and monthly median values (larger circles) based on a larger collection of monitoring sites than the previous water chemistry figures.

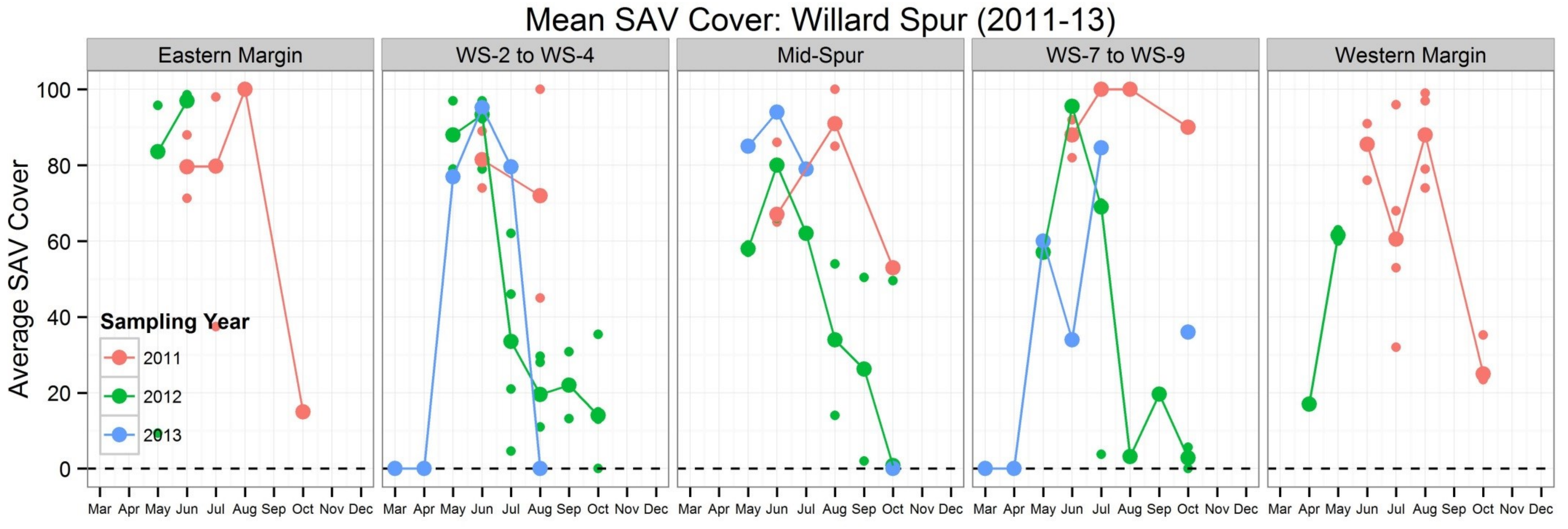


Figure 38. Mean SAV cover over the extended Willard Spur Monitoring Area by Sampling Year.

During the wetter year (2011) high SAV cover was observed throughout Willard Spur, and persisted into early-autumn (Figure 38). SAV cover appeared to peak earlier in dry (2012 and 2013) than wetter (2011) years., and was not as extensive.

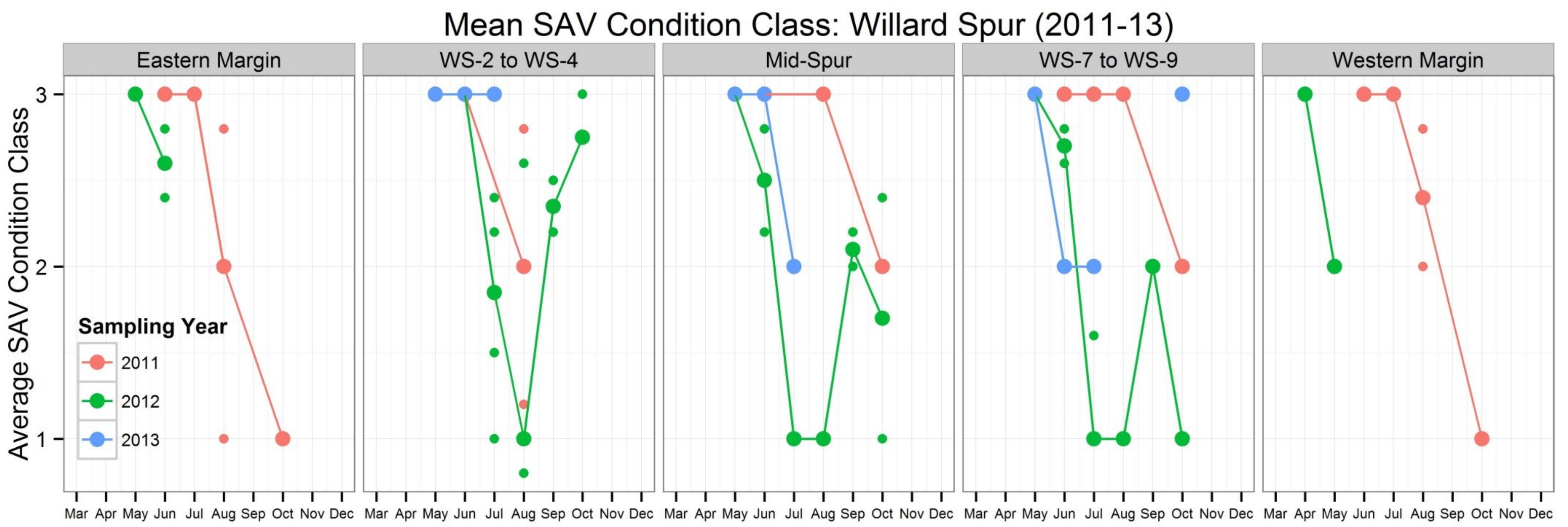


Figure 39. Mean SAV Condition Class over the extended Willard Spur Monitoring Area by Sampling Year.

The relative health of SAV (SAV Condition Class), based on categories ranging from vibrant and full canopies (class 3) to senescing with few branches and largely open canopy (class 1), is shown above (Figure 39). These patterns largely follow SAV cover, but a decrease in condition class precedes declining SAV cover.

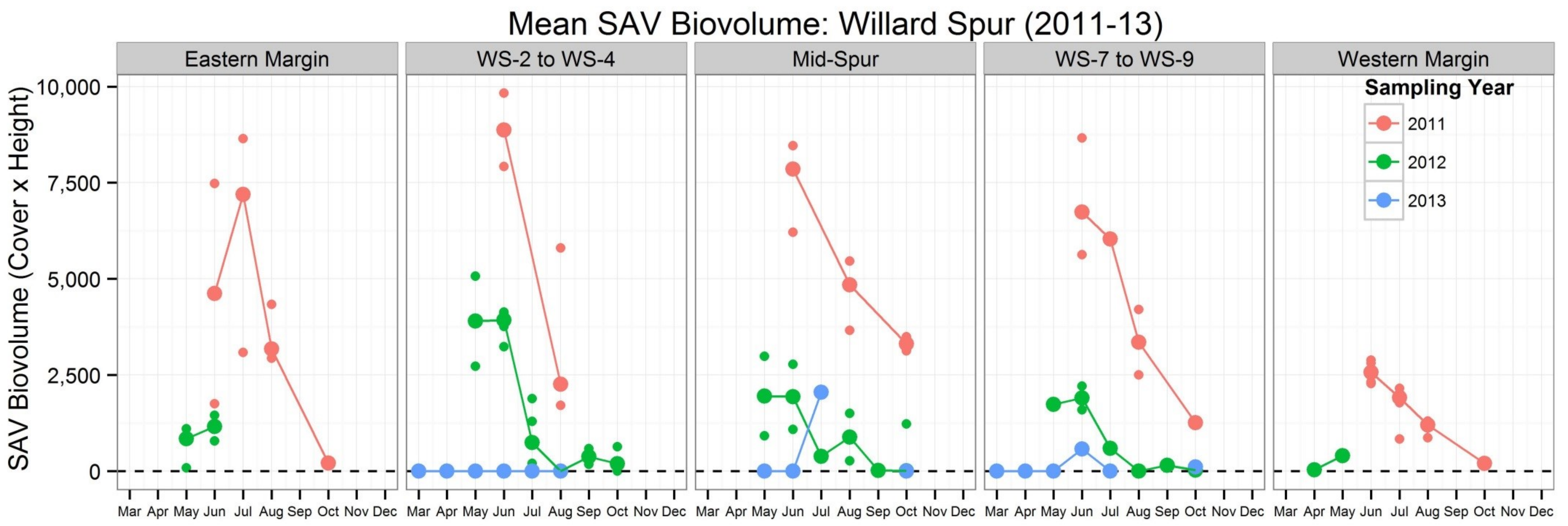


Figure 40. Mean SAV Biovolume over the extended Willard Spur Monitoring Area by Sampling Year.

SAV biovolume, calculated as cover times mean plant (canopy) height, highlight the strong dependence of SAV growth on water availability (Figure 40). While SAV cover appears to be comparable among wet and dry years, total SAV productivity (estimated by SAV biovolume) was severely reduced in the low water years. As such, the ability of SAV to effectively retain suspended sediments, influence dissolved nutrient concentrations, or serve as habitat for fish and macroinvertebrates is very dependent on the availability of water to Willard Spur. Additional figures that illustrate SAV metrics by monitoring location are included in the Appendix.

3.3.2 BENTHIC MACROINVERTEBRATES

The common macroinvertebrate taxa observed in Willard Spur are widely distributed throughout wetlands associated with Great Salt Lake (Gray, 2015). Thirty nine (39) taxa were recorded durign the 2011-2013 monitoring period, out of approximately 60 taxa collected by DWQ and identified by Dr. Larry Gray from nearby impounded and fringe wetlands since 2012. Samples were composited from 5 triplicate sweeps along a 100-m transect, and represent approximately 1.5 m^2 of area. The following results are based on work reported by Gray (2012, 2013, 2015) for the Willard Spur project, including invertebrate abundance (count of individuals per 1.5 m^2), the number of taxa observed in a (composite) sample, and two metrics that describe aspects of the macroinvertebrate community: (1) fraction of macroinvertebrate abundance (based on organism counts) derived from taxa strongly associated with vegetation (primarily SAV), as phytophilous macroinvertebrates (PMI); and (2) Simpson's diversity index (SI), derived from the probability that two randomly selected individuals are drawn from different taxa (as 1-D), such that higher SI values represent a greater degree of diversity. Broady, SI increases with taxa richness, and high PMI values is associated with healthy SAV (Gray, 2012).

The abundance of macroinvertebrates varied widely among the 216 samples associated with open water environments of the Spur. Eighty three (83, 38%) samples had abundances of < 200 individuals, the median abundance was 412 individuals per sample, and the 90th percentile was over 3,000 individuals. The eastern portion of the Spur had low macroinvertebrate abundance, possibly as a result of shallow water depths and frequent drying of sediments (Figure 41). Abundance was low in all key monitoring sites in 2011, possibly resulting from high inflows and low concentrations of detrital food sources (Gray, 2015). During the drier years, macroinvertebrate abundance peaked in late-summer / early-autumn in 2012 with an relative increase in the abundance of snails (*Stagnicola, Physella and Gyraulus*), and in late-spring in 2013 with an increase in chironomid (midge) larvae (*Chironomus* and sub-family Tanypodinae) (Gray, 2015).

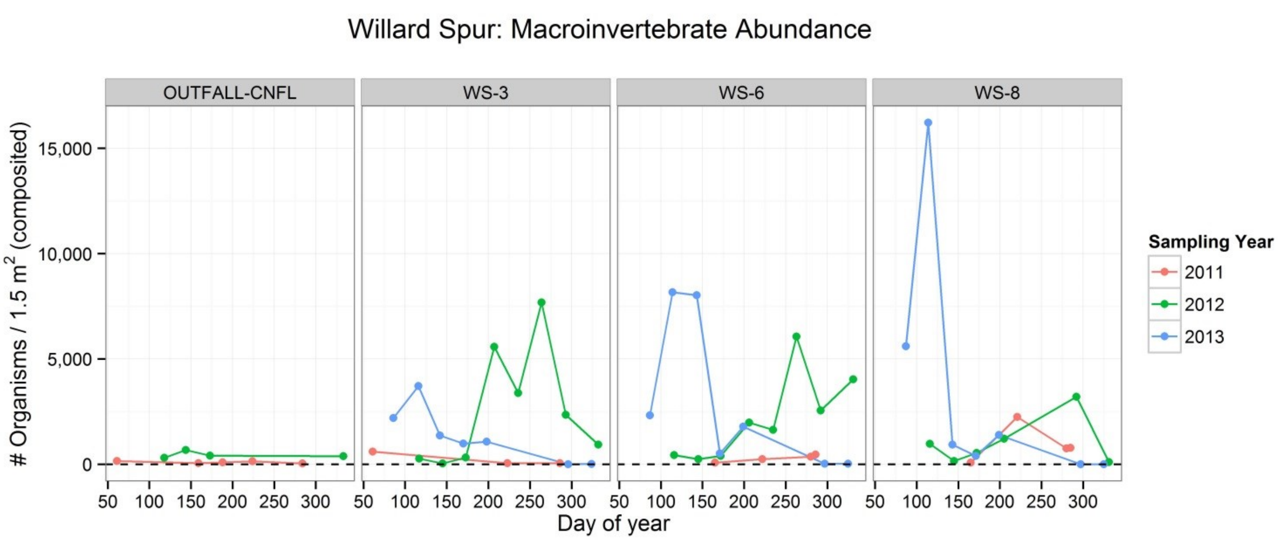


Figure 41. Macroinvertebrate abundance for Key Monitoring Sites by Sampling Year.

The number if macroinvertebrate taxa (or taxa richness) followed a recognizable pattern of increasing values through the summer and a rapid decline in autumn (Figure 42). There were few strong differences among years or across sites, except that 2011 taxa richness was commonly less than in 2012 and 2013 for sites east of WS-6.

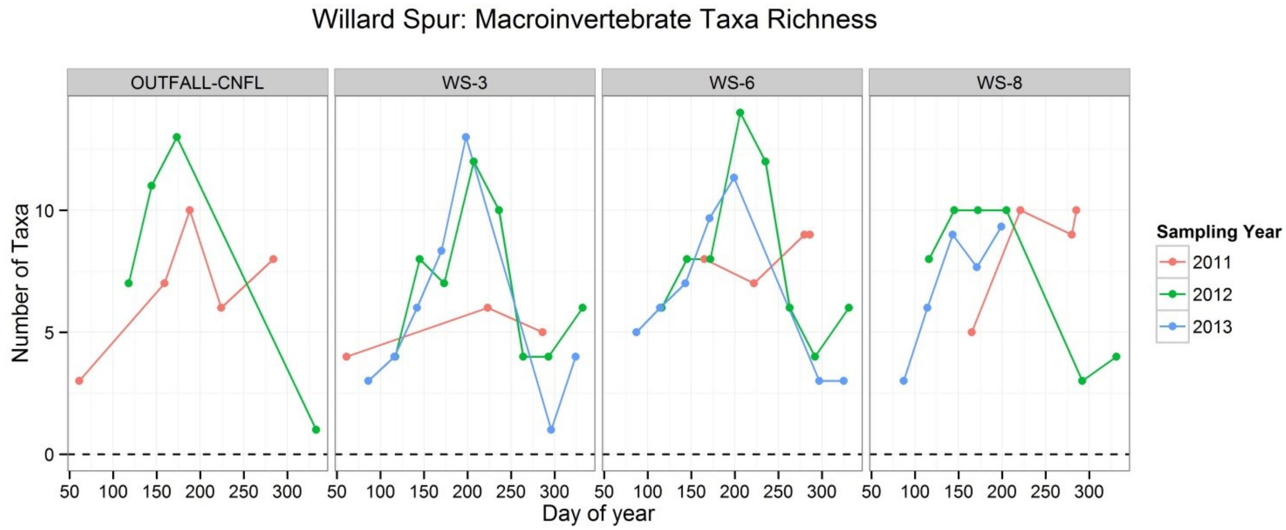


Figure 42. Macroinvertebrate Taxa Richness for Key Monitoring Sites by Sampling Year.

More integrated measures of macroinvertebrate community composition, illustrated below, display broadly similar patterns of peak diversity and stronger association with plant-based habitats during the summer growing season. For example, PMI values were typically low in spring and autumn, and higher in summer, consistent with the concept that PMI taxa are associated with healthy SAV (and similar) habitats (Figure 43).

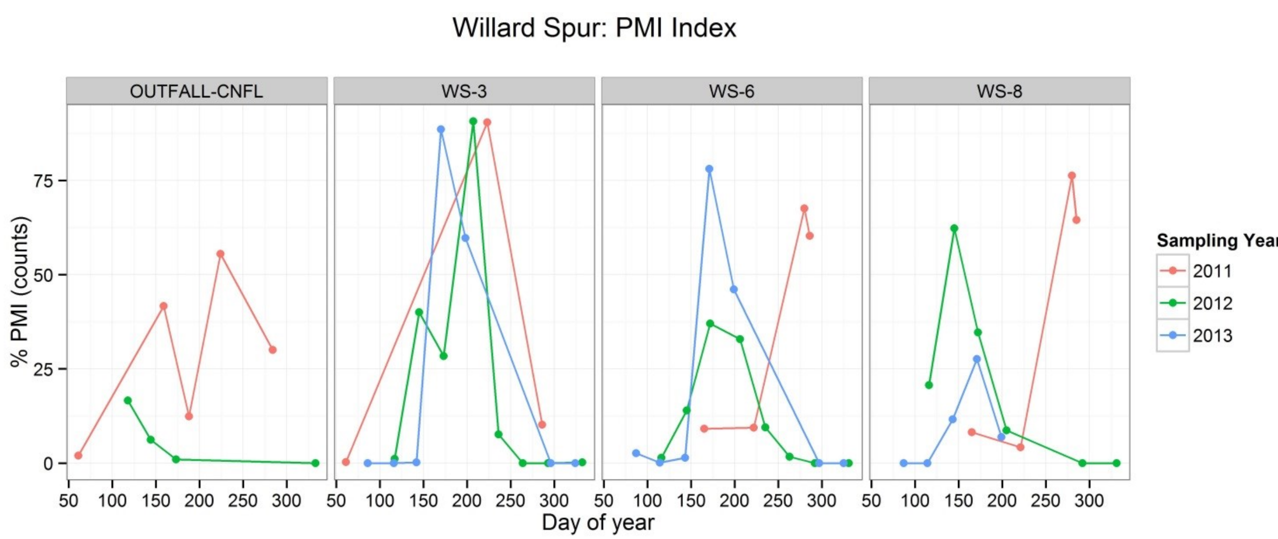


Figure 43. PMI Index values for Key Monitoring Sites by Sampling Year.

Simpson's index (SI) values were more variable over time among key monitoring sites (FIGURE) compared to PMI values (figure 44). This could be a result of the sensitivity of SI to low invertebrate abundance and low taxa richness in samples. However, peaks in macroinvertebrate abundance (Figure 41) are generally associated with low SI values usually due to the dominance of either larval chironomids or snails.

Additional figures illustrating spatial and temporal patterns of macroinvertebrate community are included in the Appendix (Figures 77 and 78).

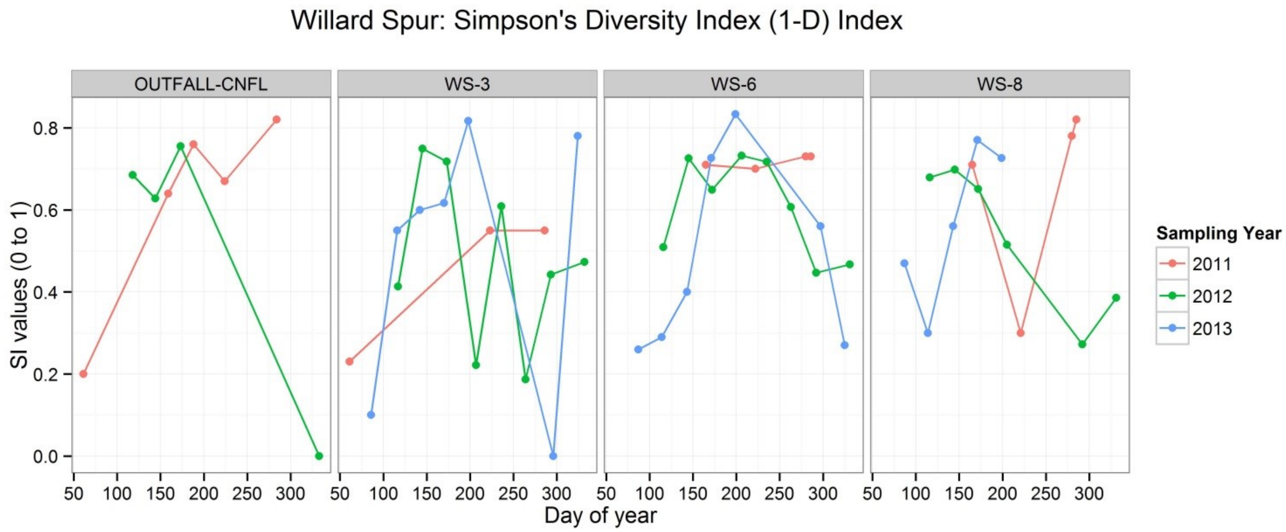


Figure 44. Simpson's Diversity Index (1-D) for Key Monitoring Sites by Sampling Year.

3.4 Effects of Hydrologic Isolation on Willard Spur

The magnitude and timing of surface water inflows and outflows are key hydrologic processes that exert strong controls over ecosystem function. Hydrologic conditions within the Spur were extremely dynamic during the 2011-2013 monitoring period, due to wide ranging surface water inflows from Bear River (through Bear River Migratory Bird Refuge), Weber River (through Willard Bay Reservoir and Harold Crane Waterfowl Management Area), and the local east side drainage basin (CH2Mhill, 2015). In 2011, the Spur was nearly entirely inundated by large inflow volumes and was hydrologically connected to Bear River Bay throughout the year. In contrast, the drier years of 2012 and 2013 had much smaller surface water inflow volumes and the outflows to Bear River Bay did not persist beyond spring runoff, such that the Spur was hydrologically isolated for much of the summer until inflows resumed in late-autumn (CH2Mhill, 2015). In this section, we examine the potential impact of hydrologic isolation on physical, chemical and biological water quality parameters.

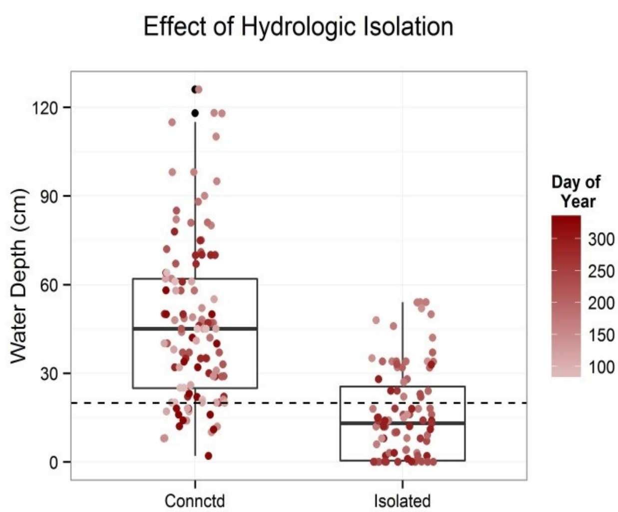
Key elements of environmental stress include shallow water depths, high temperature and salinity, extreme pH (< 6.5 and > 9.0), and low DO values. Differences between hydrologically 'Connected' versus 'Isolated' conditions were examined for indicators of environmental stress (listed above) as well as for other water chemistry, SAV health, and macroinvertebrate response variables.

The goal was to identify variables that had a strong response to hydrologic isolation. In 2011, the Spur was hydrologically connected the entire year. In 2012, the Spur was connected through mid-June (6/15/12), isolated through mid-autumn (11/6/2012), and reconnected thereafter. In 2013, the Spur was connected through late-spring (5/13/2013), isolated through mid-autumn (11/17/2013), and reconnected thereafter.

The following figures display boxplots of Willard Spur monitoring data for hydrologically connected versus isolated periods of time. The box portion of the plot represents the upper and lower quartiles (75th and 25th percentiles) of data, and the 'stem' shows 1.5 x the interquartile range. Data points are also shown on the figure to highlight the abundance of data along the tails of the distribution; these data points are shaded from gray to dark red (increasing with day of year), to illustrate any temporal progression in the data. Lastly, several plots have horizontal dashed lines that indicate important benchmarks for comparison (for example, 27 °C maximum temperature for warm water fishery aquatic wildlife use (3B), others are discussed in the text).

- Potential Drivers of Environmental Stress

Willard Spur became progressively hotter, drier and saltier after it became hydrologically isolated from Bear River Bay, and all surface water outflows ceased. Unsurprisingly, measured water depths were highly responsive to



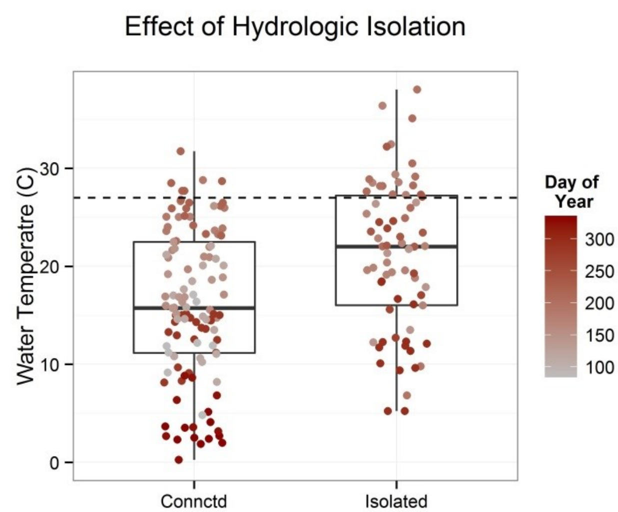


Figure 45. Distribution of Water Depth (left) and Temperature (right) during connected and isolated hydrologic conditions

hydrologic isolation (Figure 45, left); median water depths were approximately 45 cm for hydrologically connected versus 15 cm for isolated conditions, respectively. This latter depth was below a 20-cm benchmark noted by Gray (2015) as a critical depth affecting the diversity and composition of macroinvertebrate communities. In addition, water temperatures were higher under isolated vs. connected conditions (Figure 45, right); 25% of data for isolated conditions exceeded the 27 °C temperature standard for warm water fishery aquatic wildlife use (3B), suggesting additional environmental stress the Spur. We also observed a large increase in salinity (as TDS)

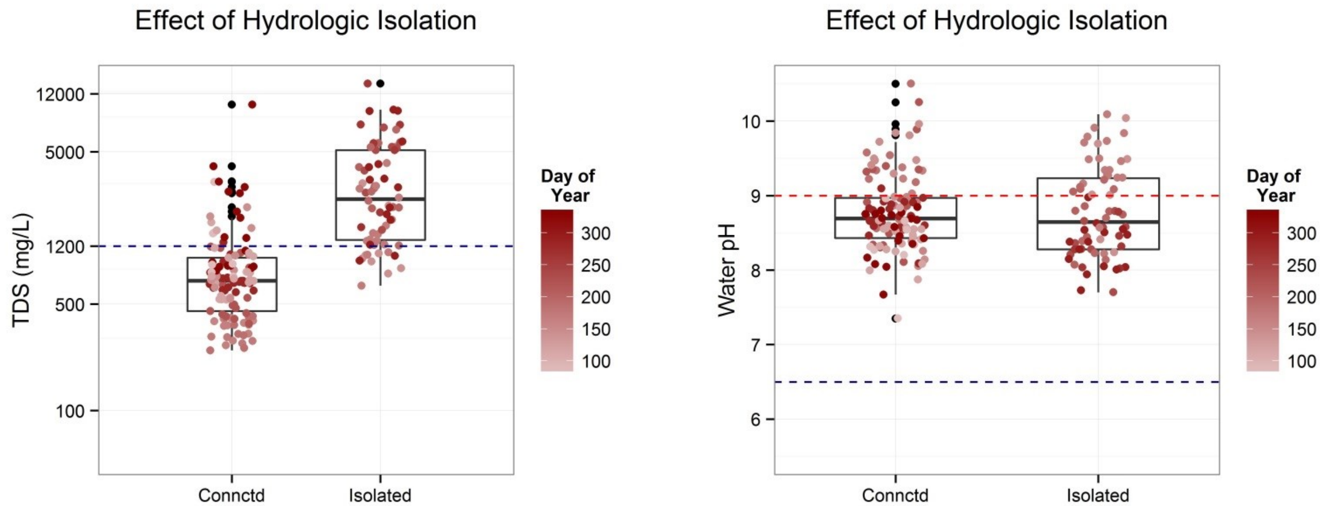


Figure 46. Distribution of TDS (left) and pH (right) during connected and isolated hydrologic conditions.

after hydrologic isolation (Figure 46, left), where >75% of data were greater than the 1200 mg/L standard for agricultural water (beneficial use class 4). While this standard is not specifically relevant to the surface waters of Willard Spur, it serves as a useful benchmark for evaluating the effects of hydrologic isolation. Interestingly, there was no apparent effect of hydrologic isolation on water pH (Figure 46, right) or on the number of samples exceeding the upper (9.0) pH standard. In addition, differences between connected and isolated hydrologic states were equivocal for both measures of DO (as concentration and as percent of saturation) (Figure 47).

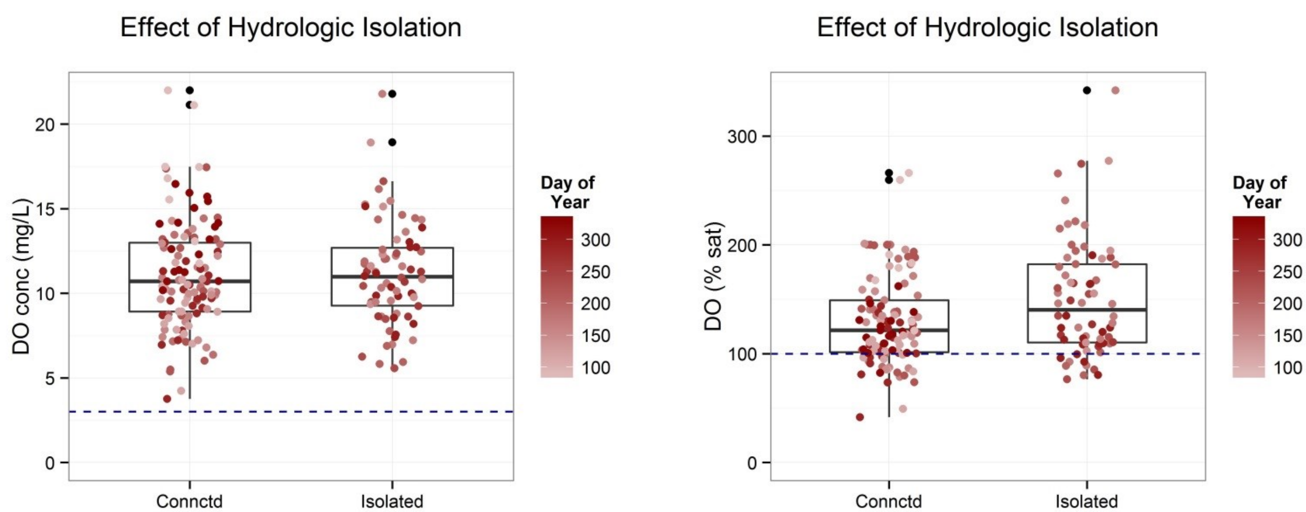


Figure 47. Distribution of DO concentration (left) and % saturation (right) during connected and isolated hydrologic conditions.

In summary, the key physical and chemical changes to water quality conditions after hydrologic isolation appear to be increasing stress from a decrease in water depth (less habitat and dilution volume), increase in temperature (faster rates of biological and chemical processes), and an increase in salinity (greater osmotic stress, altered chemical precipitation-dissolution equilibria).

- Response Variables to Hydrologic Isolation

The following figures illustrate the response of chemical and biological indicators to differences in hydrologic connectivity. We observed only a slight increase in TSS concentrations in isolated vs. connected hydrologic

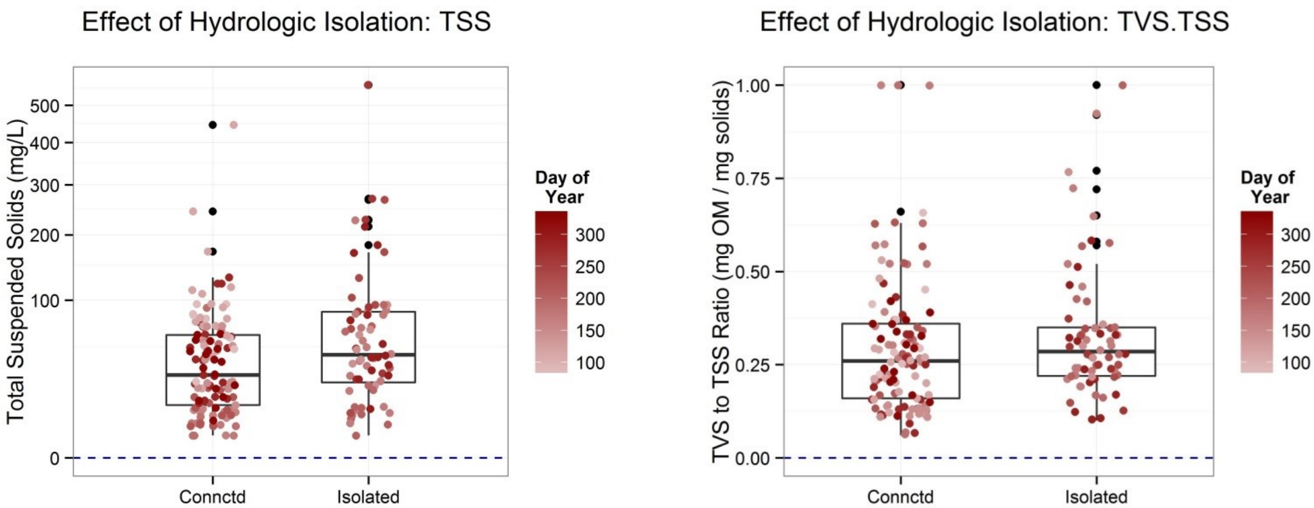


Figure 48. Distribution of TSS and TVS:TSS ratio during connected and isolated hydrologic conditions.

conditions (Figure 48). Higher TSS concentrations were most commonly from later in autumn (> day 250, mid-September) and could be related to a pulse of turbidity as water levels increased. The TVS:TSS ratio was not apparently affected by hydrologic isolation.

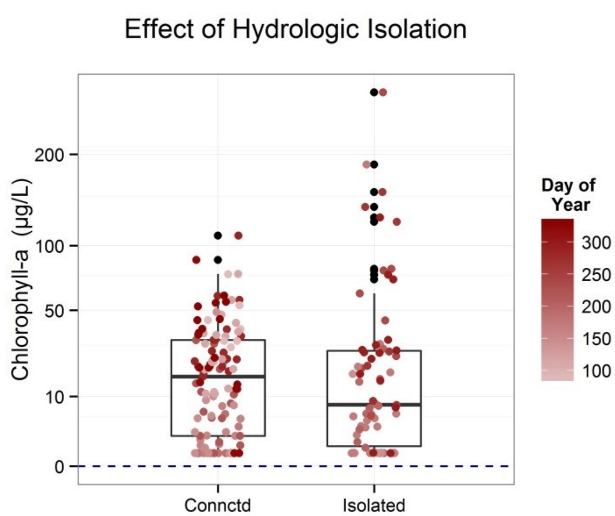


Figure 49. Distribution of Chl-a concentrations during connected and isolated hydrologic conditions.

Water column chlorophyll-a concentrations (Figure 49) were generally lower in isolated vs. connected conditions, except for a series of samples from hydrologically isolated waters that exceeded 70 μg/L in late-summer and early-autumn. This pattern is consistent with the temporal pattern of low chlorophyll-a concentrations in early summer and increasing values in late-summer and early-autumn (Figure 11). There may be a lag in response of the more integrative biological measures to hydrologic isolation, compared to the physical/chemical drivers of environmental stress (e.g water depth, temperature and TDS).

Both total phosphorus and total nitrogen were higher during isolated vs. connected hydrologic conditions (Figure 50). Given the paucity of dissolved nutrient data during the drier years it is not clear how much of the high TN and TP concentrations are due to suspended algal and detrital particles (as seston); however, higher total-nutrient

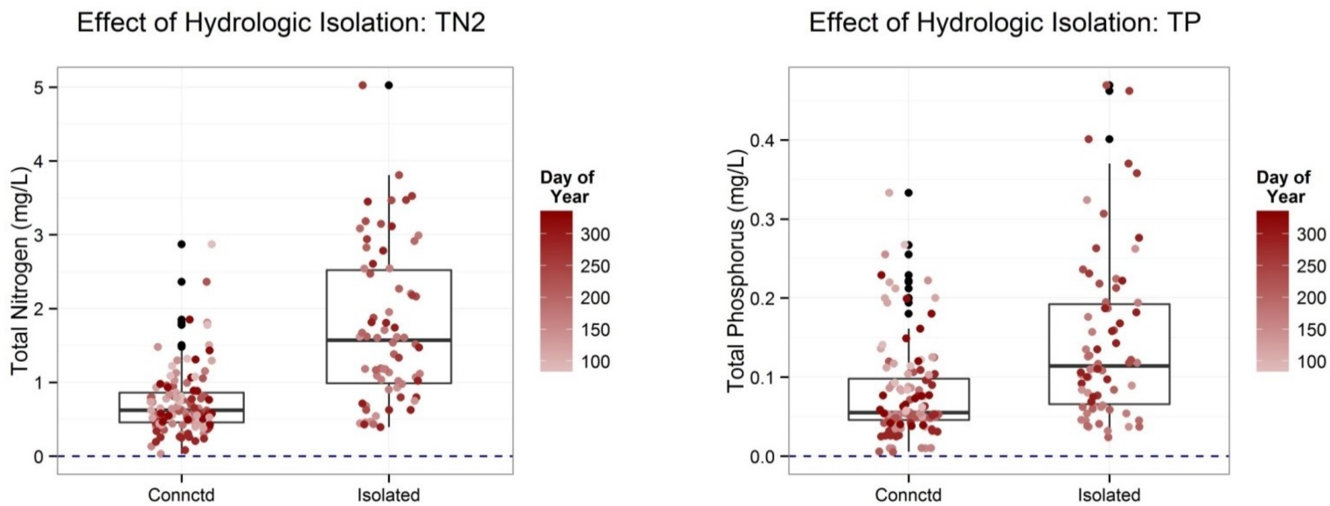


Figure 50. Distribution of TN and TP during connected and isolated hydrologic conditions.

concentrations may be more a consequence of detritus and/or dissolved organic constituents. This is supported by observations that higher concentrations of TON (Figure 51, left), but not TIN (Figure 51, right), after hydrologic solation, and that TN is dominated by DN (over 85%) (see Figures 21 and 22).

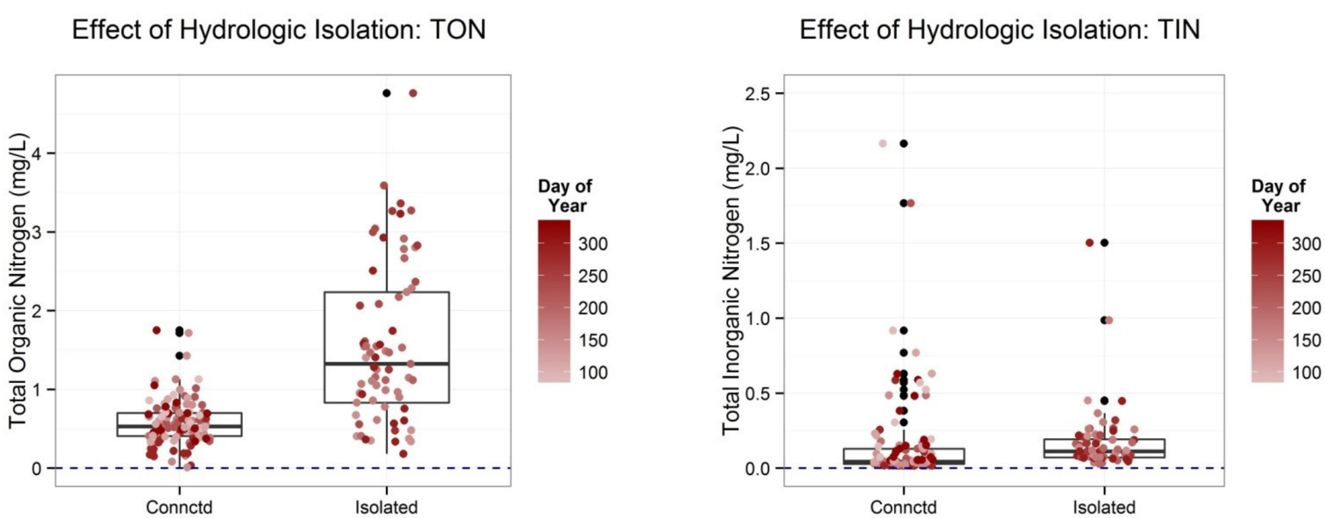


Figure 51. Distribution of TON and TIN during connected and isolated hydrologic conditions.

The net result of changes in total and dissolved N and P concentrations after hydrologic isolation was an increase in the TN:TP and DN:DP ratios (Figure 52). Since both TN and TP were greater in isolated vs. connected conditions, it follows that the relative increase in P was smaller than for N, suggesting relatively greater P limitation after hydrologic isolation. Isolated hydrologic conditions begins during the clear or blue phase of water clarity (Figure 1 (right)), when chlorophyll-a concentrations are low and SAV growth is likely to be high.

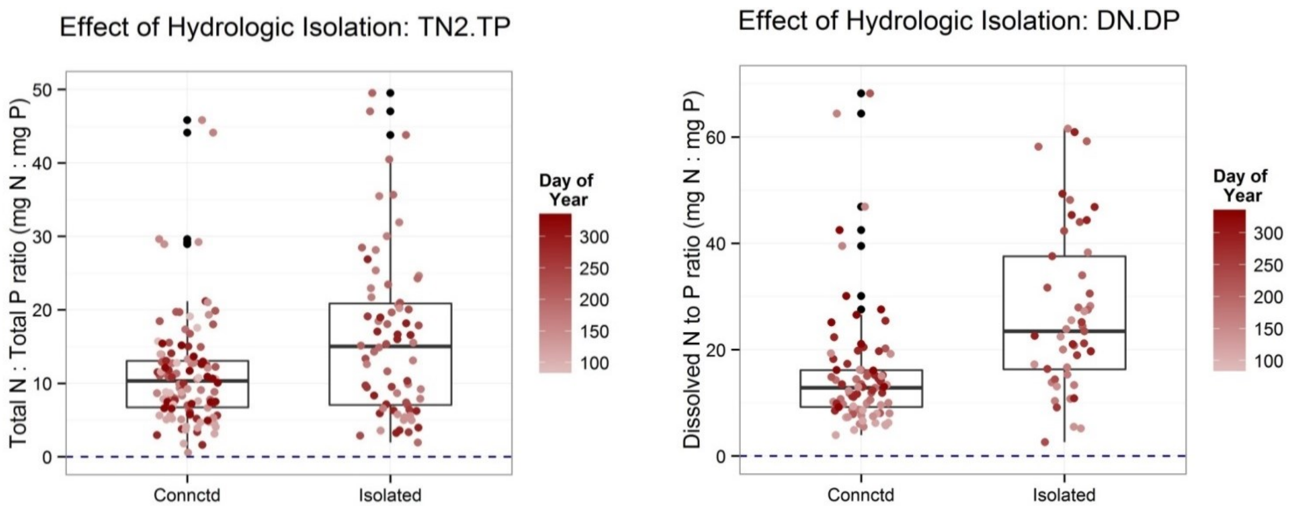


Figure 53. Distribution of TN:TP and DN:DP ratios during connected and isolated hydrologic conditions

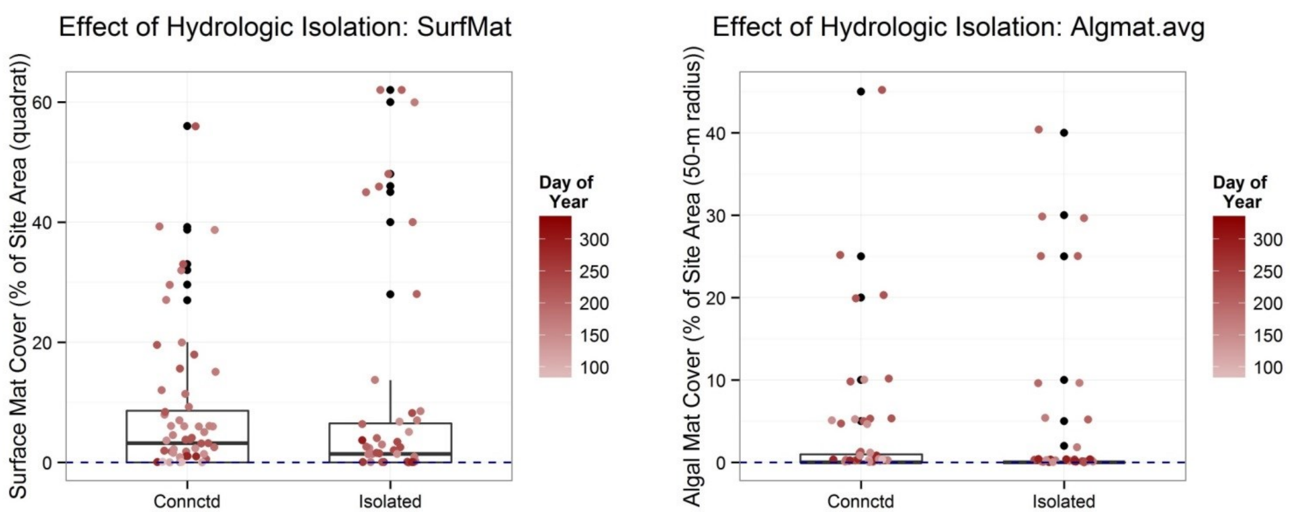


Figure 52. Distribution of Surface Mats and Algal Mats during connected and isolated hydrologic conditions.

Surface mats were calculated from field data as the sum of filamentous algae cover and floating aquatic vegetation cover (e.g. Lemna spp.) determined from quadrat sampling (see Willard Spur Sampling and Analysis Plans). 'Algal mats', on the other hand, were estimated for a 50-m radius area centered on each sampling location. We find little evidence of larger or more frequent surface or algal mats (Figure 53) after hydrologic isolation; however, development of these types of mats was uncommon in the Spur and difficult to track, particularly under conditions of rapidly receding surface waters.

The cover (Figure 54, left) and quality (as Condition Class; Figure 54, right) of SAV were slightly lower during isolated vs. connected hydrologic conditions. The same pattern was observed for SAV biovolume (Figure 55, left) and SAV vigor (Figure 55, right). Note that the effect of plant height on these metrics contributes to strong separation between hydrologic class, much greater than SAV cover or SAV condition class alone.

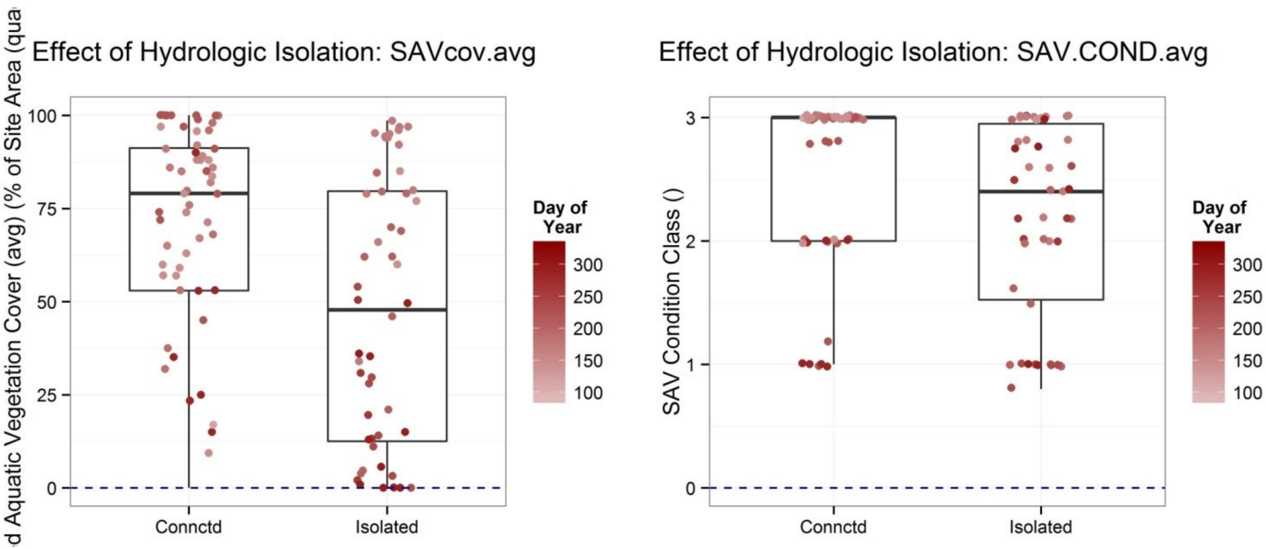


Figure 54. Distribution of SAV cover and SAV condition class during connected and isolated hydrologic conditions.

To summarize water chemistry and submerged vegetation indicators, hydrologic isolation appears to be associated with larger pools of TP and TN, particularly TON, with wider N:P ratios that suggest greater P limitations to algal growth. In addition, the cover and condition score (i.e. relative health) of SAV was lower after hydrologic isolation. Shallower water depths and shorter plant height contributed to severe reductions in SAV biovolume (an analog to biomass) and vigor under isolated conditions.

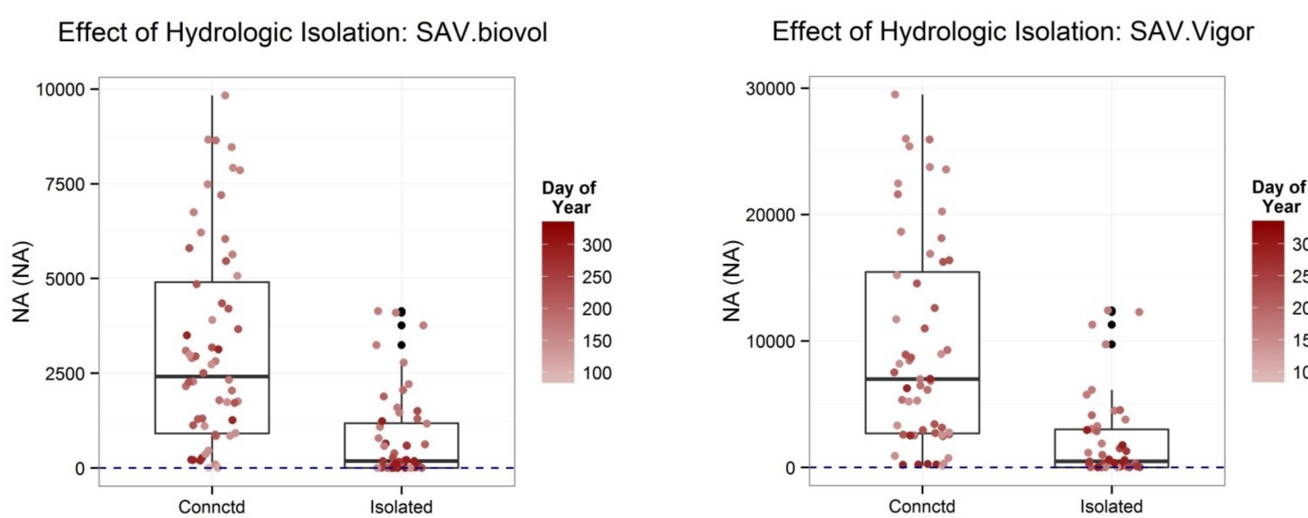


Figure 55. Distribution of SAV Biovolume and SAV Vigor during connected and isolated hydrologic conditions.

The abundance of macroinvertebrates was higher under hydrologically isolated versus connected conditions, median values of 1438 vs. 235, respectively. Much of this difference was due to the greater

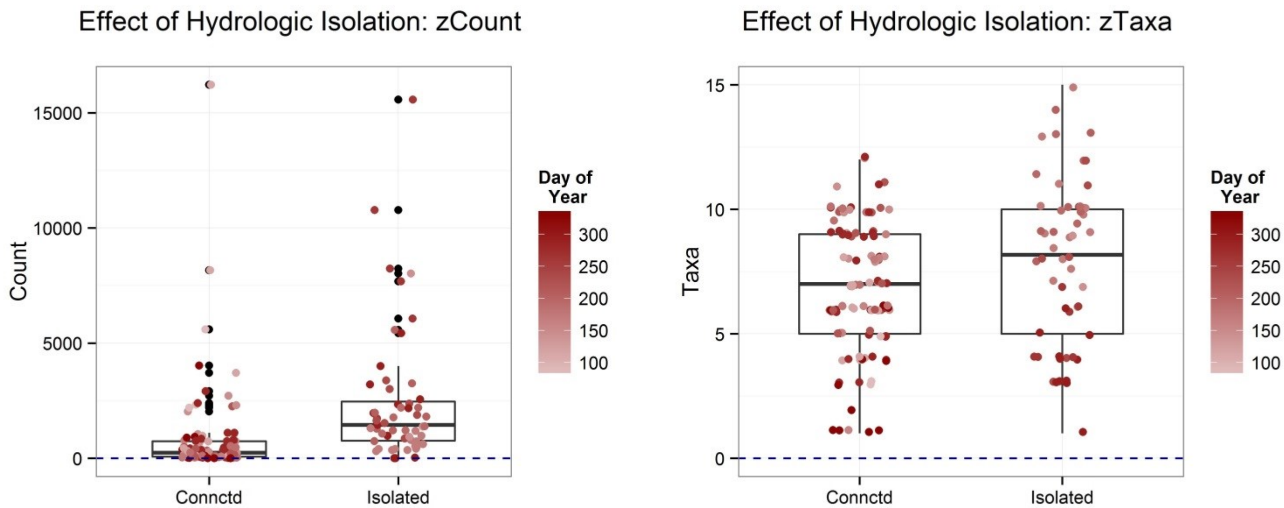


Figure 56. Distribution of Macroinvertebrate Abundance and Taxa Richness during connected and isolated hydrologic conditions.

abundance of chironomids (Chironominae and Tanypodinae) (Figure 58 [left]), snails (*Gyraulus* and *Physella*), Naididae worms, and a family of long-legged flies (Dolichopodidae). Taxa richness was not clearly affected by hydrologic condition, except that richness declined with time after isolation. Changes in the PMI metric after hydrologic isolation were consistent with greater abundance of chironomids and other non-PMI taxa, however

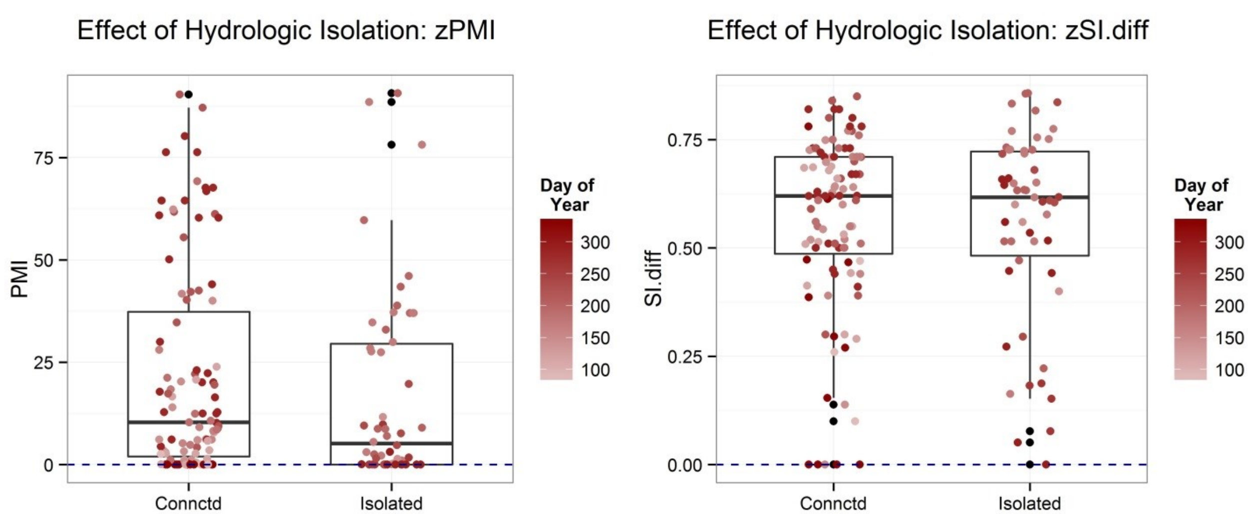


Figure 57. Distribution of PMI and SI values during connected and isolated hydrologic conditions.

the SI diversity metric show no clear change between connected and isolated conditions (Figure 57). Greater abundance of the low-DO tolerant and detritivorous Chironominae (subfamily) larvae are consistent with the decline in SAV cover and biovolume during periods of hydrologic isolation (Figure 55, left). However, we also observed greater abundance of the amphipod *Hyalella azteca* during isolated conditions (54 vs. 4 individuals / 1.5 m^2, respectively), which is distinct from Gray's (2015) reporting that *Hyalella* (and snails) was more abundant in

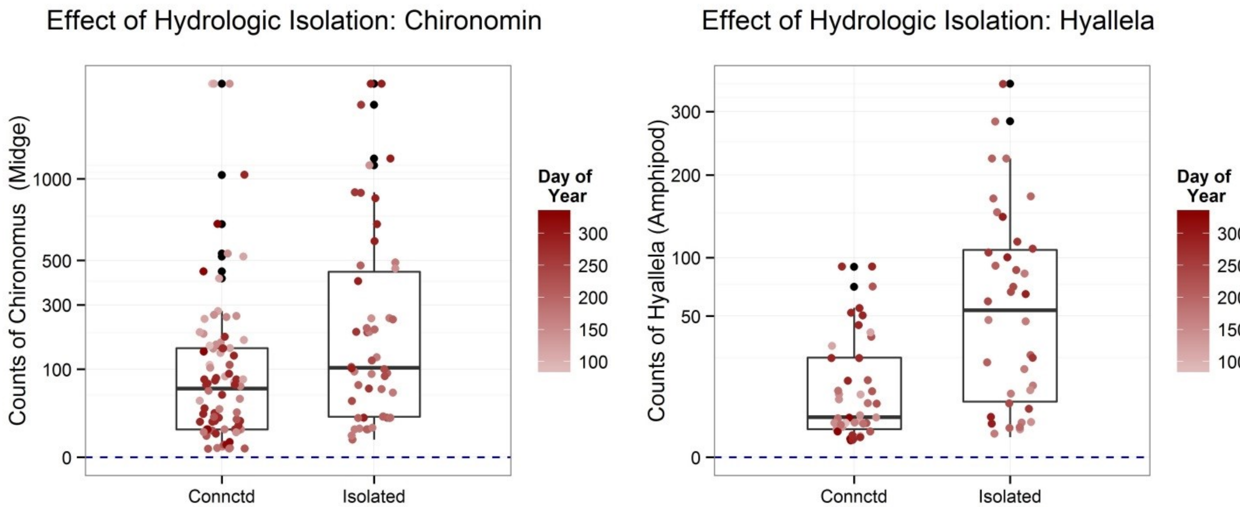


Figure 58. Distribution of Chironomid and Hyalella abundance during connected and isolated hydrologic conditions.

deeper vs. shallow waters. It may be that *Hyalella* were concentrated in deeper portions of rapidly declining waters after hydrologic isolation, but before several water depth-limitations began.

3.5 Potential Associations among Indicators

We used Pearson correlation to evaluate potential associations among physical, chemical, and biological variables for the Willard Spur monitoring dataset. These calculations quantify the degree of linear association between two variables. While the correlation coefficients are generally more straightforward to interpret than similar non-parametric coefficients (e.g. Spearman's rho, or Kendall's tau), Pearson correlations can be sensitive to outliers or data distributions to long tails. As such, we used an α (alpha) level of 0.01 as a conservative screen for potential associations among a wide variety of variables. The goal was to develop a broad view of potentially interesting correlative associations and/or screen for sets of multiple variables that appear to be multicollinear.

- Physical and Chemical Drivers versus Water Chemistry

The following correlation plot matrix summarizes results between the principal physical and chemical indicators of Willard Spur surface waters, including water depth and temperature, dissolved solids and particulate, and nutrients.

In the following four figures, each grid represents a pairwise correlation between variables that are labeled along the vertical and diagonal axes. Only grids with a correlation coefficient significant at the $p < 0.01$ level are included in the figures. Positive correlations are illustrated in blue, and negative correlations are illustrated in red. Both the brightness of the color (see color scale at bottom of each figure) and the eccentricity of the correlation ellipse signify the degree of correlation (or association); brighter colors and narrow shapes correspond to higher degrees of association.

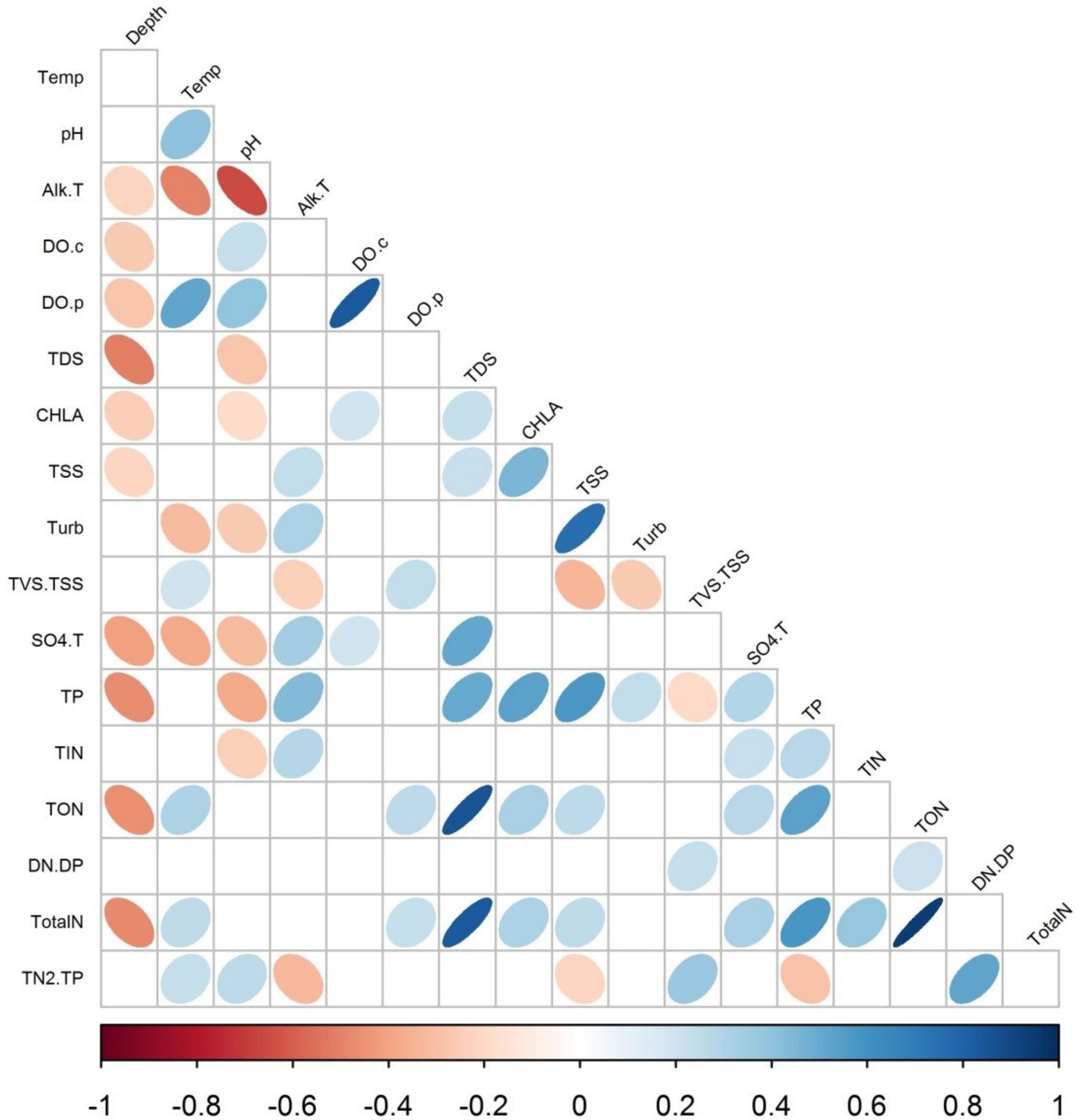


Figure 59. Correlation matrix for Water Chemistry variables.

Correlations among water chemistry variables were consider strong enough ($p < 0.01$) for closer examination in 75 of 136 possible comparisons (Figure 59). Water depth was negatively correlated (red colored ellipses) with a wide range of chemical variables, with the strongest associations with TDS, TP, TN, and TON. Interestingly, the correlation between TDS and TP was weaker than between TDS and TN or TON.

Both water temperature and pH were negatively correlated with total alkalinity (an estimate of HCO_3^- ion concentrations), likely reflecting both the lower solubility of gases (i.e. CO_2) and the higher rates of photosynthetic activity at warmer temperatures.

Chlorophyll-a was positively correlated with TSS, TP, TON and TN, with the strongest correlation with TP; chlorophyll-a vs. N:P ratios were not significant at $P < 0.01$.

- Physical and Chemical Drivers versus SAV Metrics

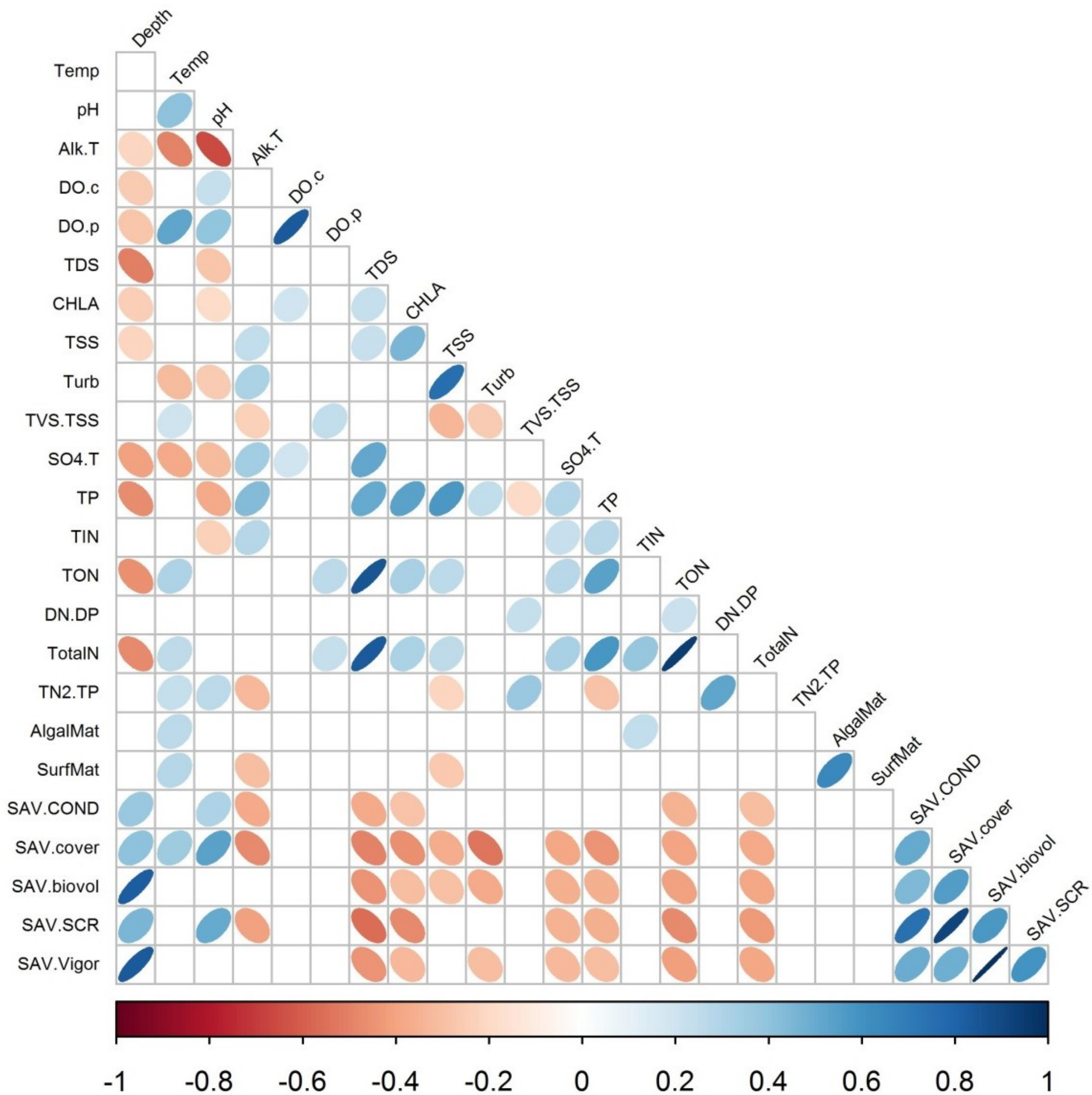


Figure 60. Correlation matrix for Water Chemistry and SAV health variables.

There were 61 new associations (at $p < 0.01$; out of 300 possible) when SAV variables were included with water chemistry (Figure 60). As described previously, both SAV biovolume and SAV vigor metrics increased strongly with water depth and were nearly identical metrics. Interestingly, SAV cover – but not SAV biovolume – was positively correlated with water pH while chlorophyll-a and pH were only slightly, but negatively correlated; this suggests that the seasonal pattern in pH described above(Figure 12) may be more strongly related to SAV (and associated epiphyte) photosynthesis than free-floating algae in the water column (as chlorophyll-a measurements). Lastly, many SAV-related metrics were negatively associated with dissolved and suspended solids concentrations; this could be a consequence of the positive association between SAV growth and water depth and increasing detritus within the water column after SAV begins to senesce.

- Physical and Chemical Drivers versus Macroinvertebrate Metrics

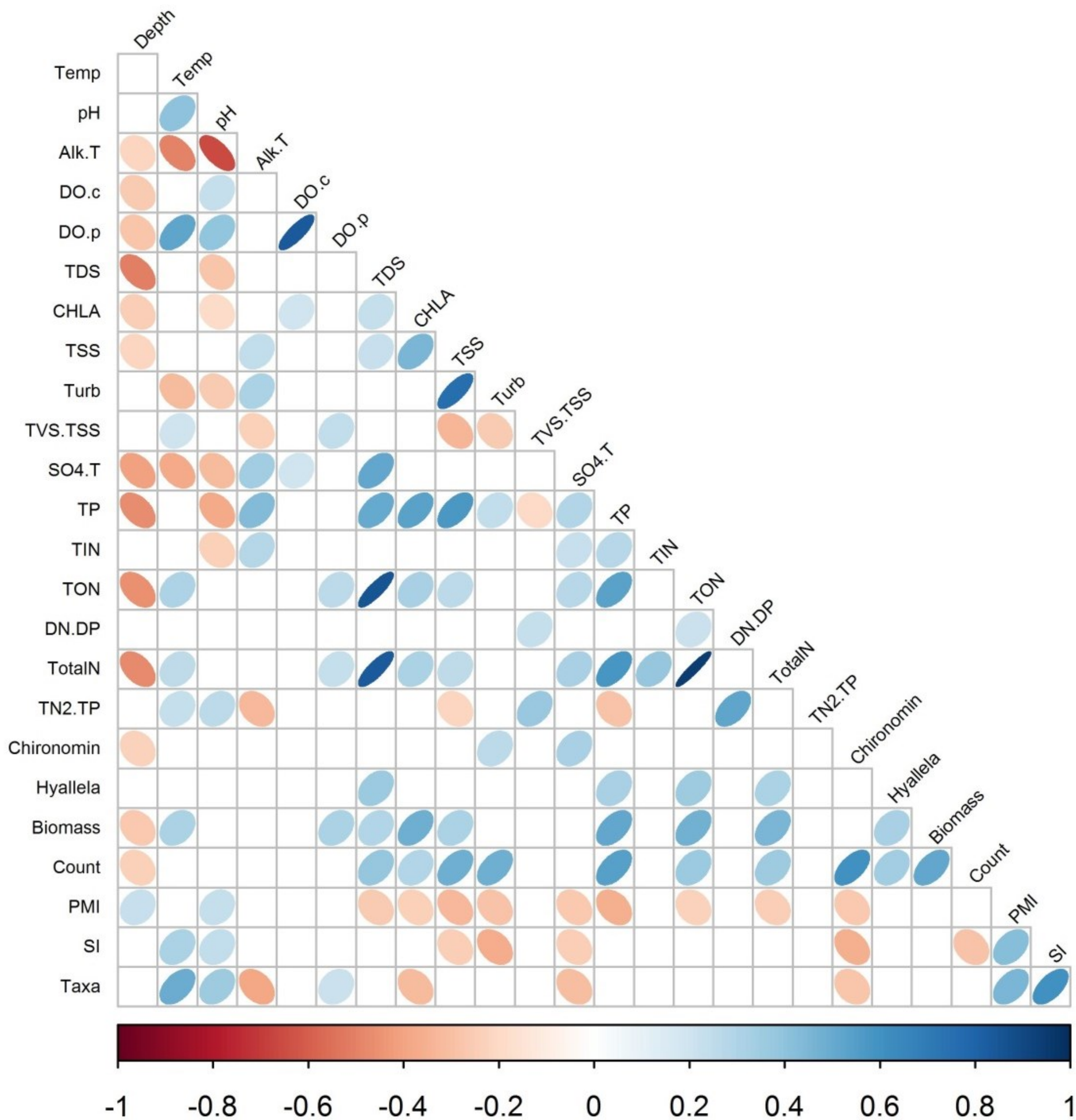


Figure 61. Correlation matrix of Water Chemistry and Invertebrate variables.

There were 56 new associations (at $P < 0.01$; out of 300 possible) when macroinvertebrate variables were included with water chemistry (Figure 61). Chironomids were strongly and positively associated with total invertebrate abundance and negatively associated with measures of community diversity (PMI, SI and taxa richness). Invertebrate abundance was positively associated with TDS, TSS, and total nutrients (TP, TON and TN), while PMI index was negatively associated with these same variables.

- SAV versus Macroinvertebrate Metrics

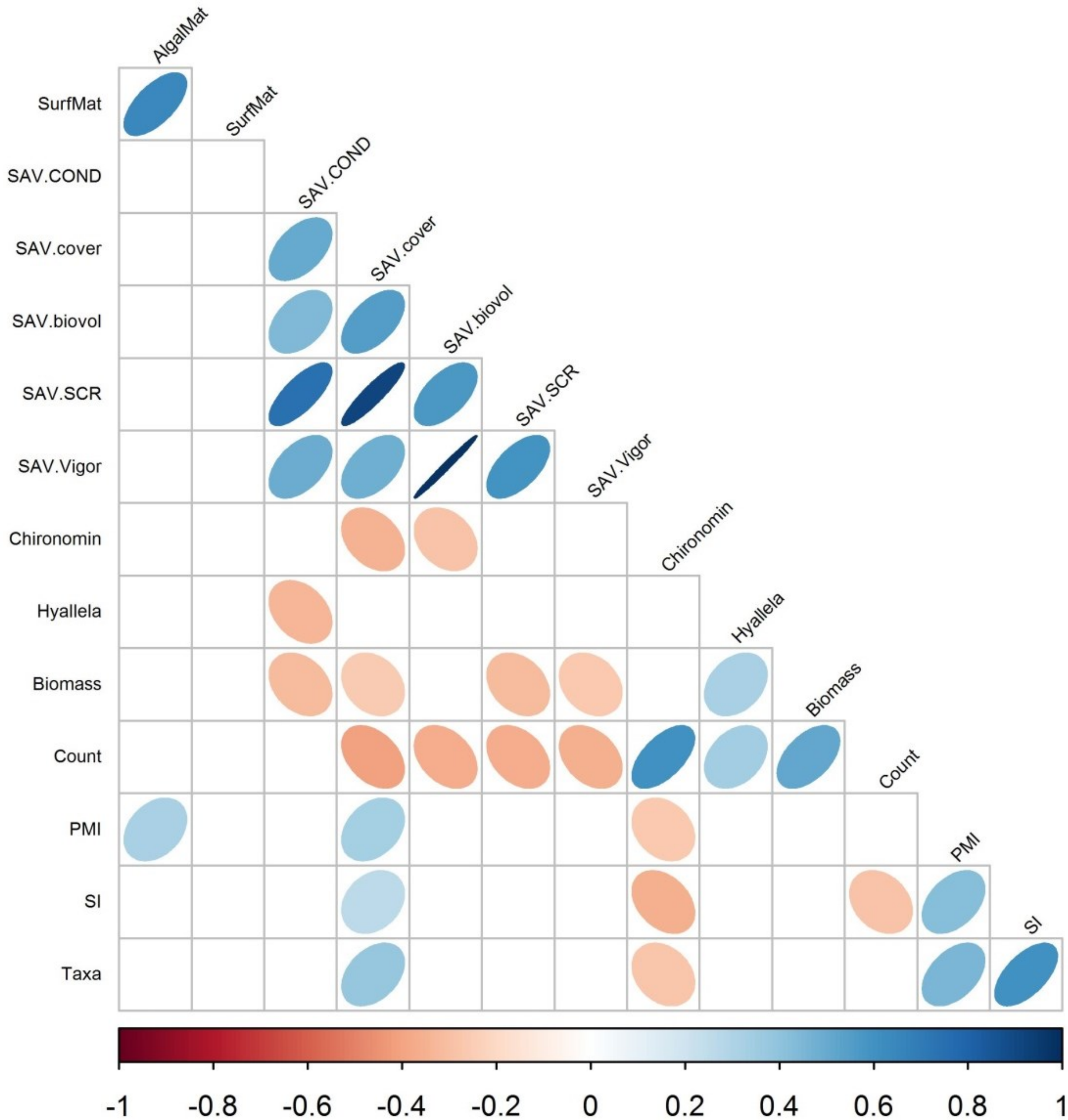


Figure 62. Correlation matrix of SAV and Invertebrate variables.

There were 37 associations (at $p < 0.01$; out of 91 possible) among SAV and macroinvertebrate variables (Figure 62). There was a great deal of correlation among SAV variables, but SAV was neither negatively nor positively associated with algal mats or surface mats. Interestingly, cover of algal mats was positively correlated with PMI. Hyalella was negatively correlated with SAV condition classes and positively correlated with total invertebrate abundance.

4. Late-season Impoundment: the Critical Condition

Previous sections of this report described the ambient physical, chemical, and biological conditions of open water portions of Willard Spur during the 2011 to 2013 monitoring period. We also examined whether and how hydrologic isolation affected key variables, and explored potential associations among water chemistry, SAV health and macroinvertebrate variables. An accompanying hydrologic assessment of Willard Spur (CH2MHill, 2015) suggested that the time periods when Willard Spur is hydrologically isolated from Bear River Bay, or impounded, could be a critical condition to the Willard Spur ecosystem, presumably due to limited dilution volume and increasing environmental stresses to aquatic organisms. In addition, a focused evaluation of macroinvertebrates and zooplankton estimated that key changes to macroinvertebrate community composition occurred for water depths below 20 cm.

This section of the report further illustrates potential patterns between chemical and biological characteristics of Willard Spur versus water depth, under both connected and isolated hydrologic conditions. The goal was to examine how multi-variable relationships are affected by hydrologic isolation.

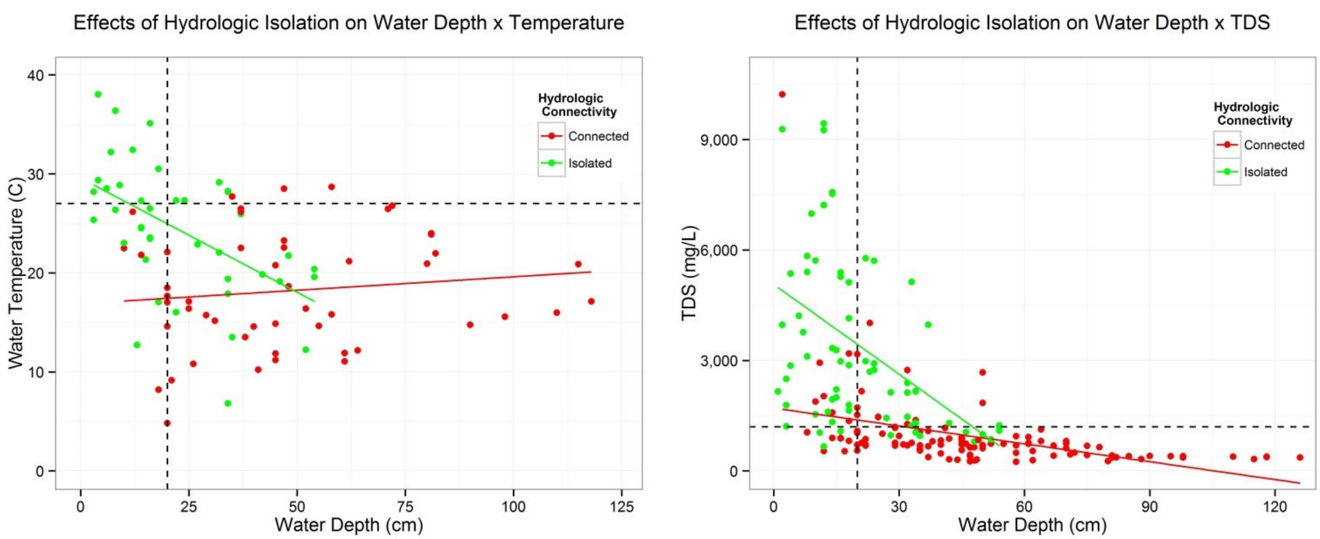


Figure 63. Water Temperature and TDS vs. Water Depth under hydrologically isolated and connected conditions.

As shown previously, water temperatures and salinities were higher under isolated vs. connected hydrologic conditions (Figure 63). The above figure also illustrates that water temperature increases in shallower depths when the Spur is isolated, but not when it is hydrologically connected. Moreover, TDS increases as water depth declines; but the slope of this relationship is distinct, and much greater after hydrologic isolation.

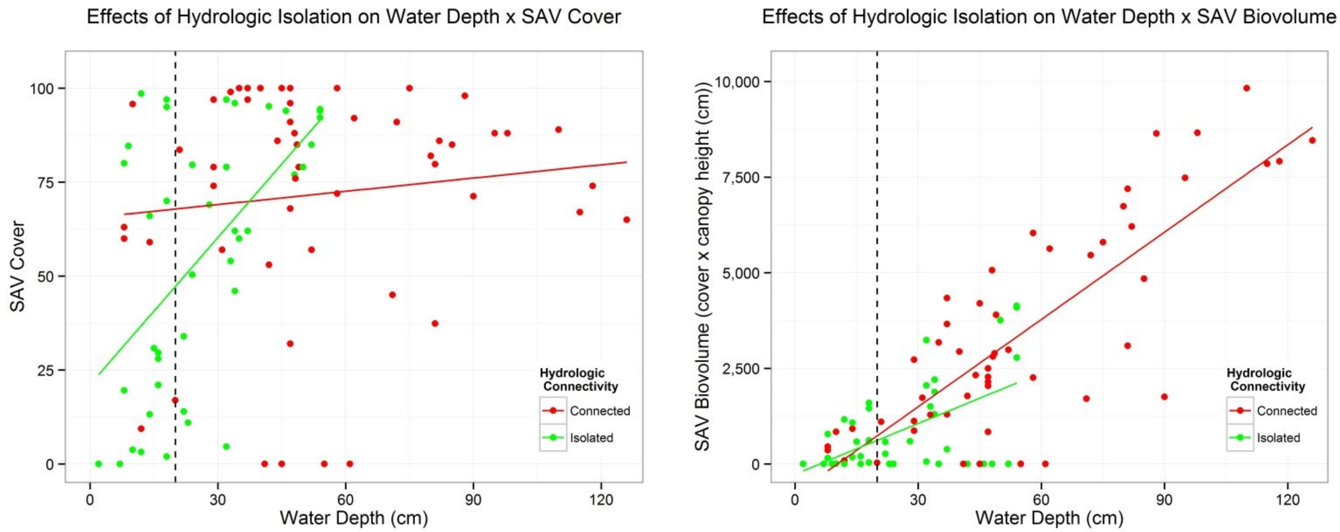


Figure 64. SAV cover and Biovolume vs. Water Depth under hydrologically isolated and connected conditions

SAV cover during the monitoring period was not clearly related to water depth when the Spur was connected, however, SAV cover when the Spur was isolated appeared to decrease as water levels fell below approximately 40 cm (Figure 64). For many sites, SAV cover was less than 50% when depths were shallower than 20 cm, consistent with Gray's (2015) estimate of 20 cm depth as an important transition for macroinvertebrate communities. The increase in SAV biovolume with water depth was similar for the connected and isolated

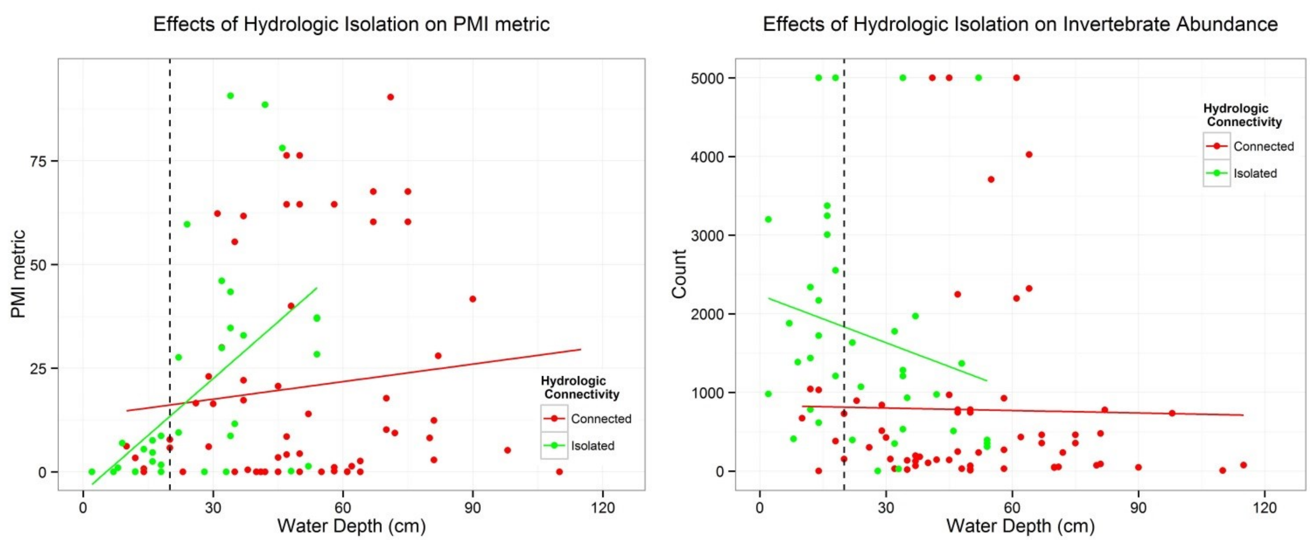


Figure 65. PMI and Invertebrate abundance vs. Water Depth under hydrologically isolated and connected conditions

hydrologic conditions. Under connected hydrologic conditions, the relative abundance of plant-associated macroinvertebrates (PMI index) does not appear to be related to water depth, however, PMI values decline abruptly for water depths below 20 to 30 cm (Figure 65). By contrast, water depth did not appear to affect the SI metric (not shown). Invertebrate abundance appeared to be greater under isolated than connected conditions for waters between 5 to 40 cm.

While total N and P concentrations were observed to be positively correlated and greater under isolated vs. hydrologically connected conditions, Figure 66 illustrates a distint pattern of depth-dependece of TN vs. TP after isolated hydrologic conditions set in; i.e. TN increases to a greater degree than TP, consistent with the higher TN:TP ratio under isolated conditions.

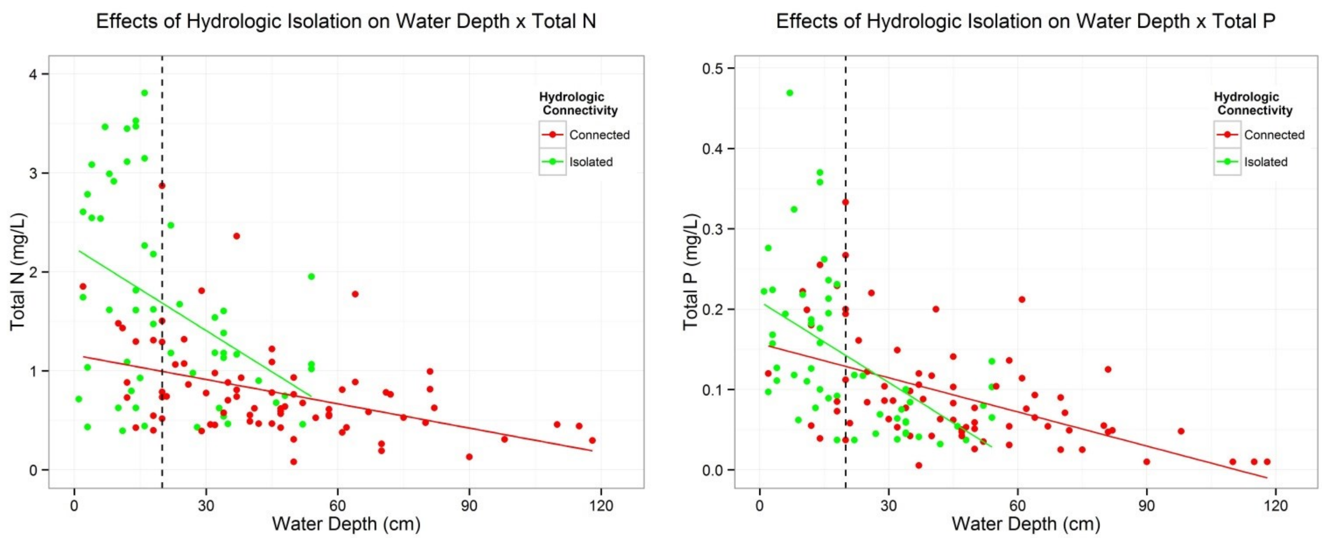


Figure 66. TN and TP vs. Water Depth under hydrologically isolated and connected conditions

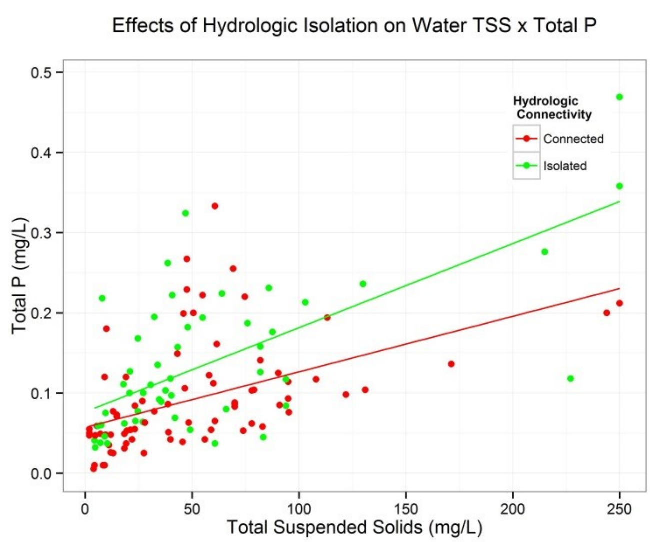


Figure 67. TP vs. TSS under hydrologically isolated and connected conditions

In addition, while Total Suspended Solids was only slighty elevated under isolated vs. connected conditions, there appears to be greater P associated with TSS after the Spur becomes isolated (Figure 67). It may be that available P becomes increasingly sorbed to mineral solids (Fe- and Al-oxyhydroxides and/or precipitating calcite ($CaCO_3$)) that are suspended in the water column in mid-summer, particularly during hydrologically isolated periods.

We found that SAV cover (and SAV condition score (cover x condition class), *not shown*) decreased with increasing TN and TP during isolated, but not connected, hydrologic conditions (Figure 68). While a range of SAV cover was observed at low TN and TP concentrations, SAV cover were rarely above 50% cover when TN and TP concentrations were greater than approximately 2.5 mg N/L and 0.25 mg P/L, respectively.

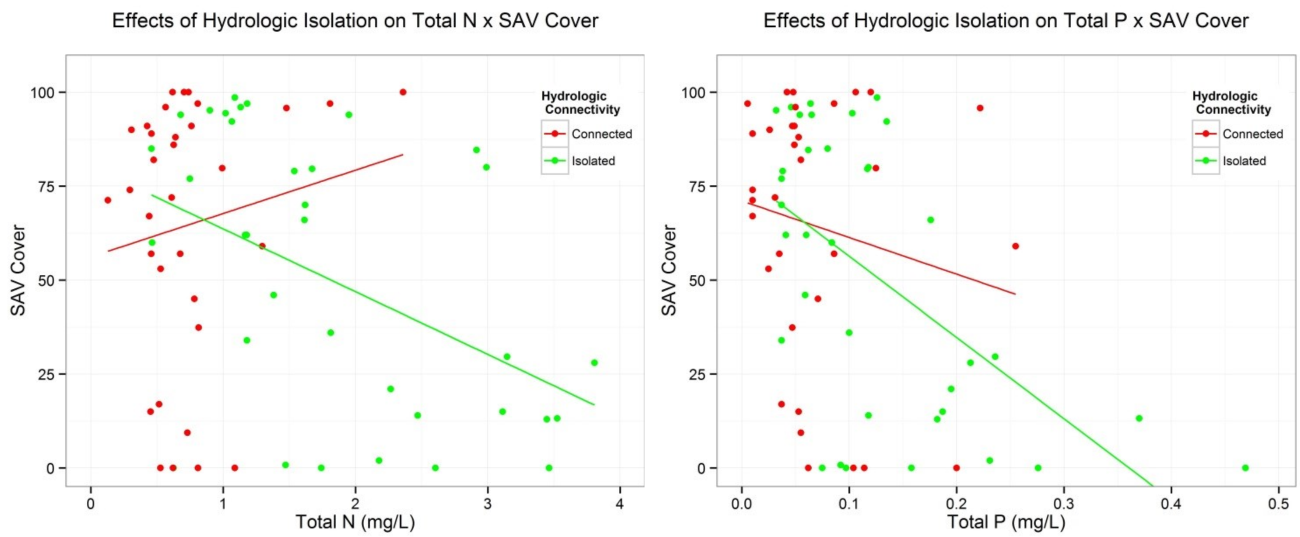


Figure 68. SAV Cover vs. TN and TP under hydrologically isolated and connected conditions

A similar pattern emerged for SAV biovolume, where values >2,500 (e.g. 75% cover and 33 cm tall) were rare for TN and TP concentrations greater than 2.0 mg N/L or 0.2 mg P/L (Figure 68).

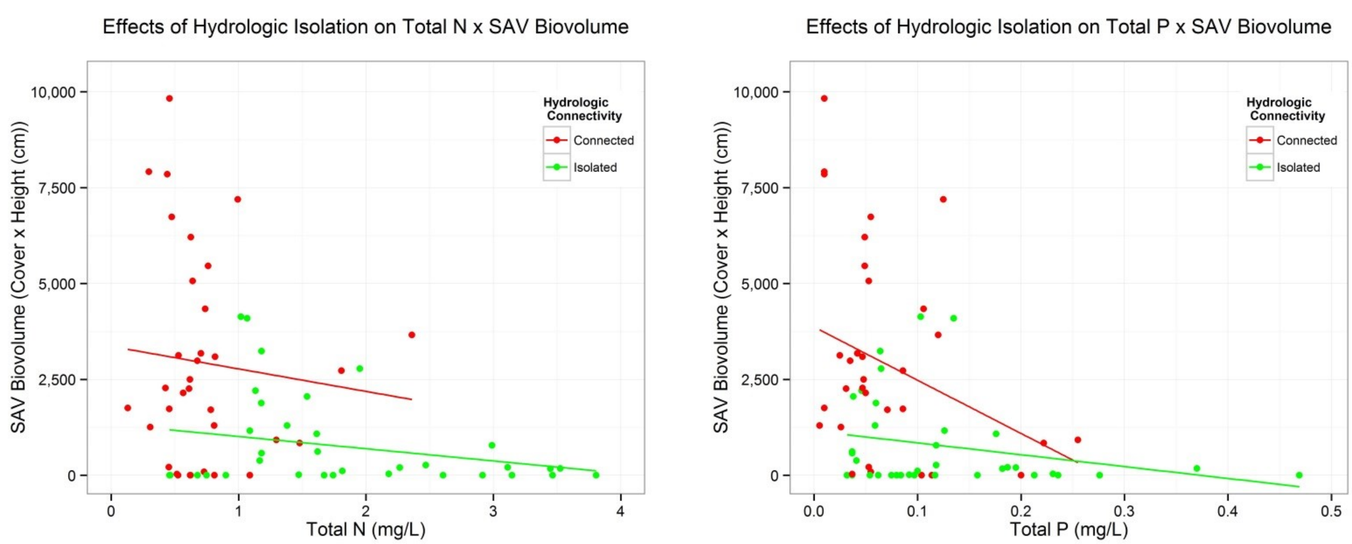


Figure 69. SAV Biovolume vs. TN and TP under hydrologically isolated and connected conditions

5. Appendix – Additional Figures

Water Depth

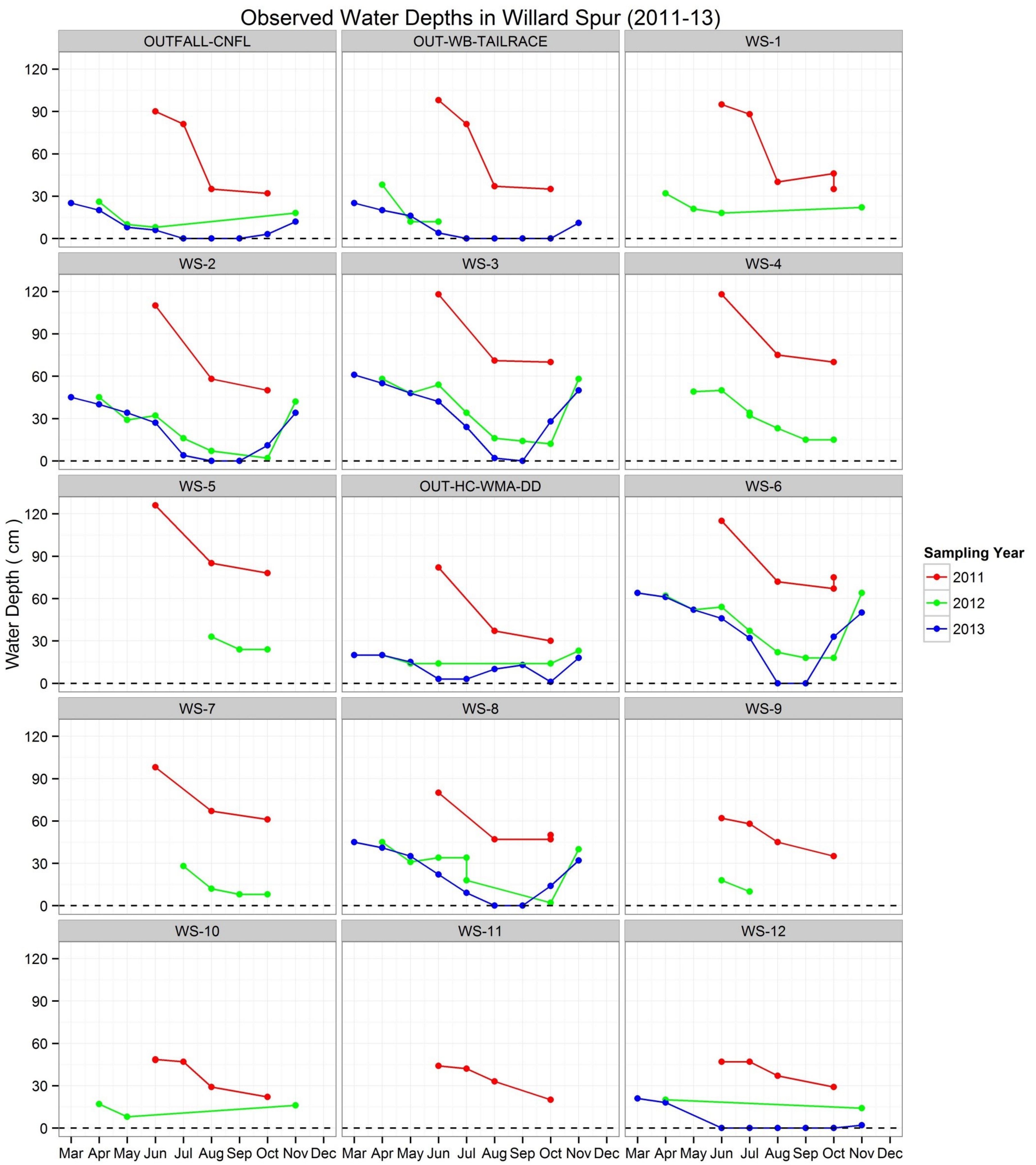


Figure 70. Water Depths for all Willard Spur open water monitoring sites

Inorganic N pulses

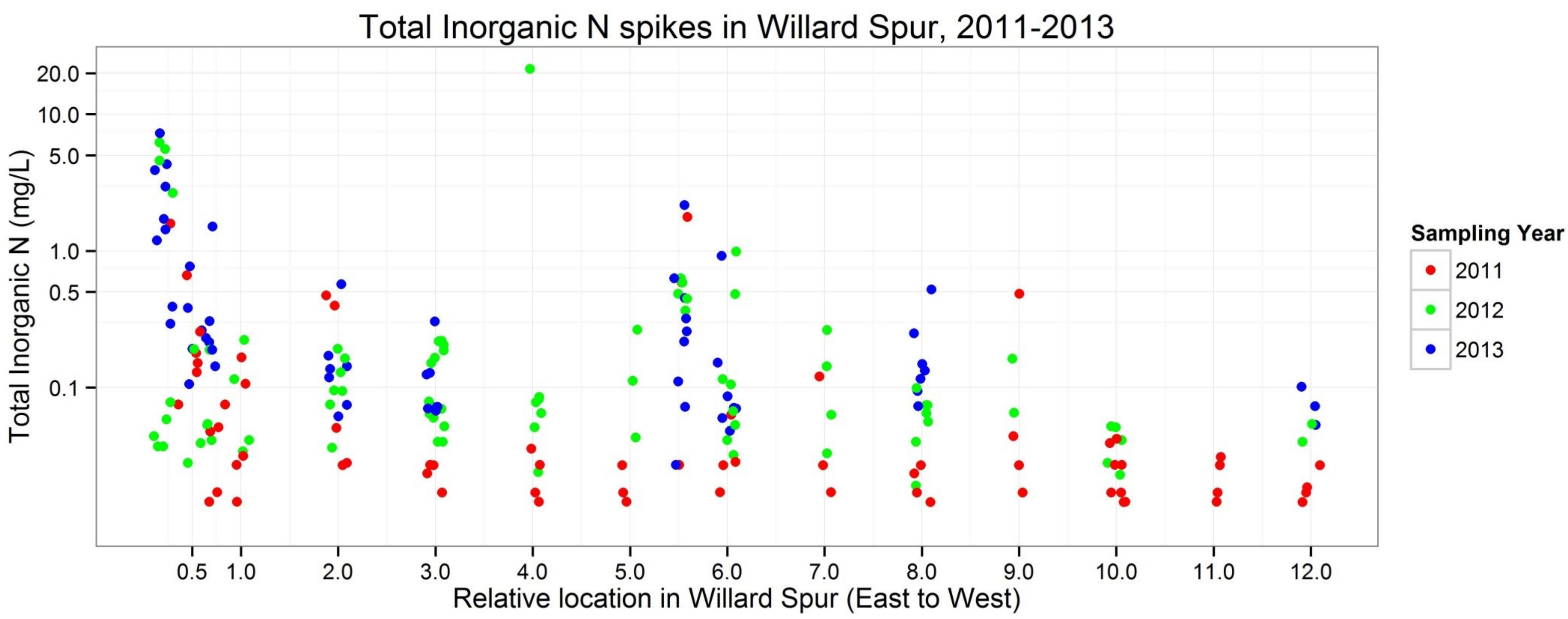


Figure 71. Total Inorganic N concentrations by sampling year.

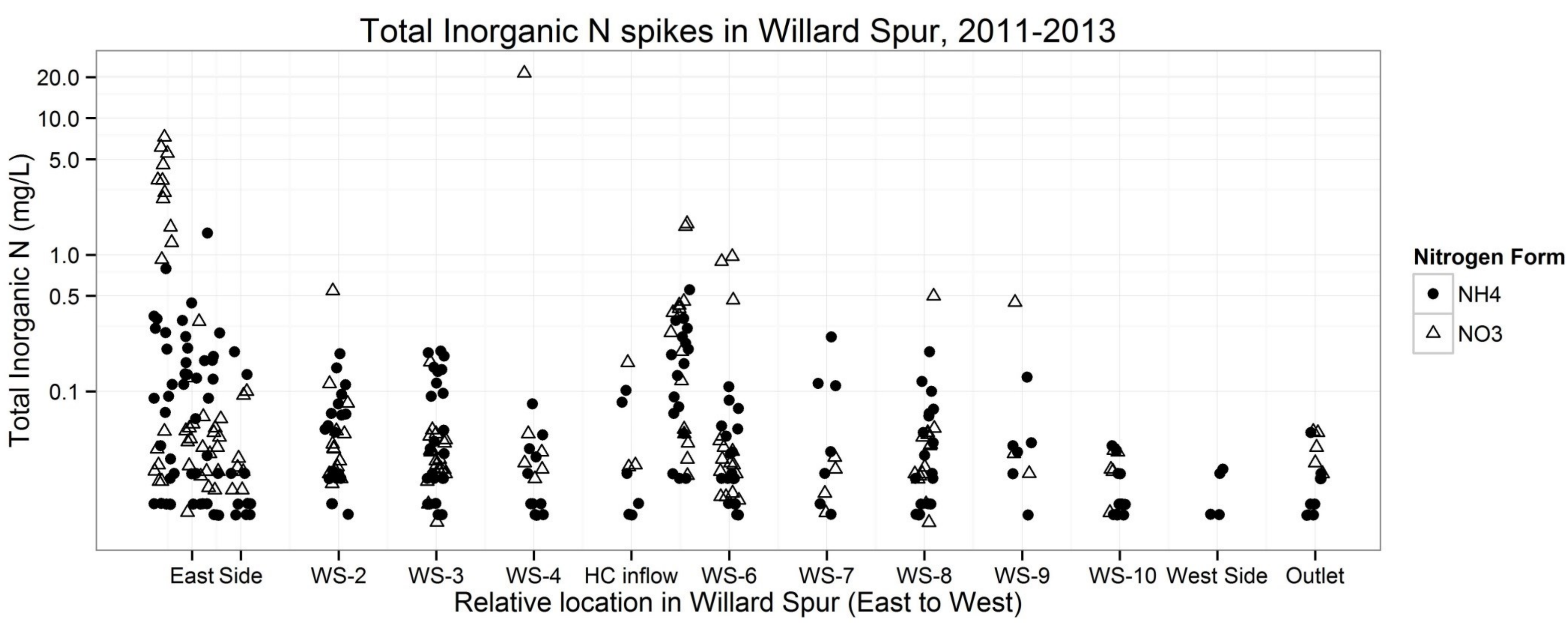


Figure 72. Total Ammonium and Nitrate concentrations by sampling year.

SAV Cover

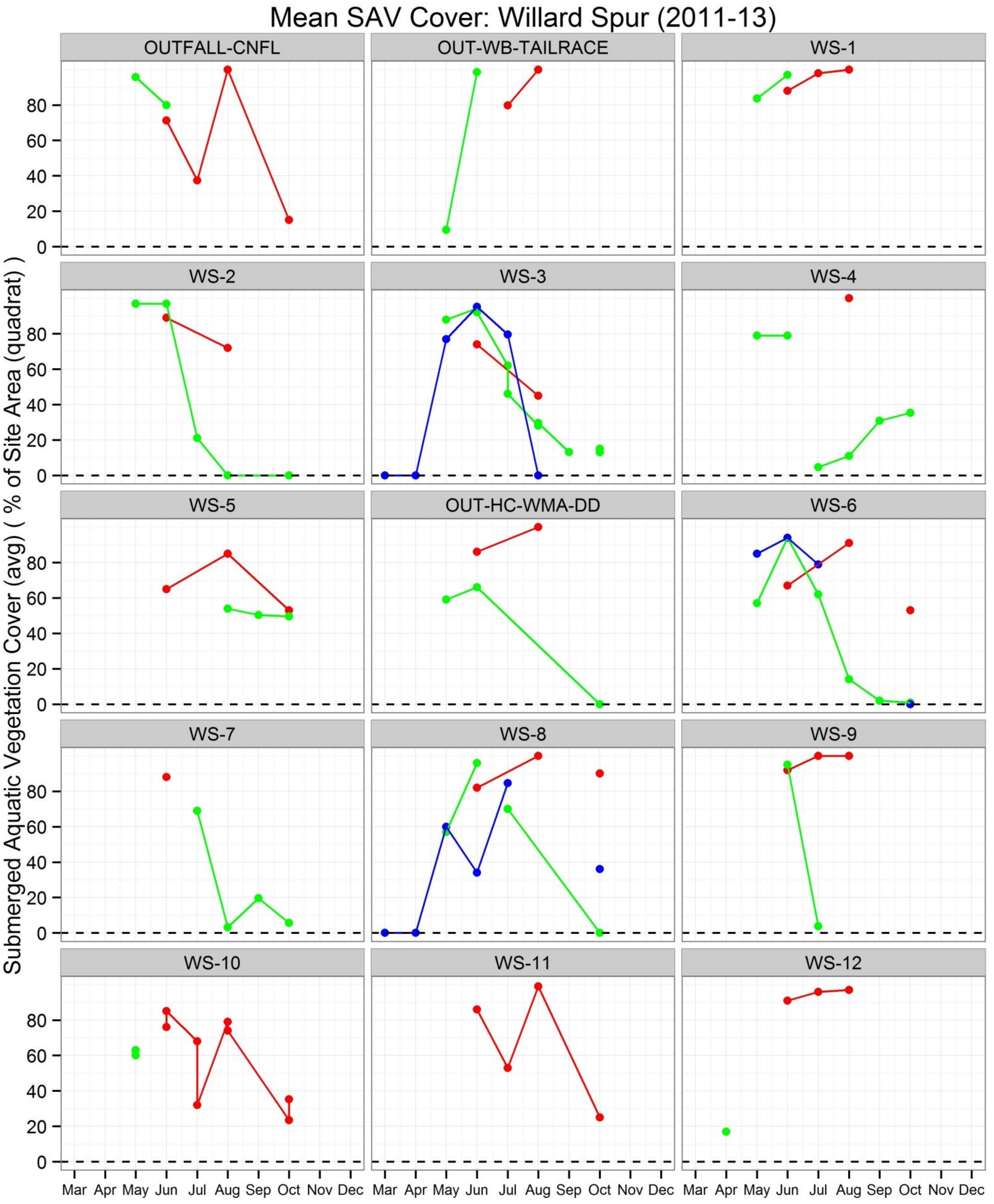


Figure 73. Mean SAV cover for all open water monitoring locations

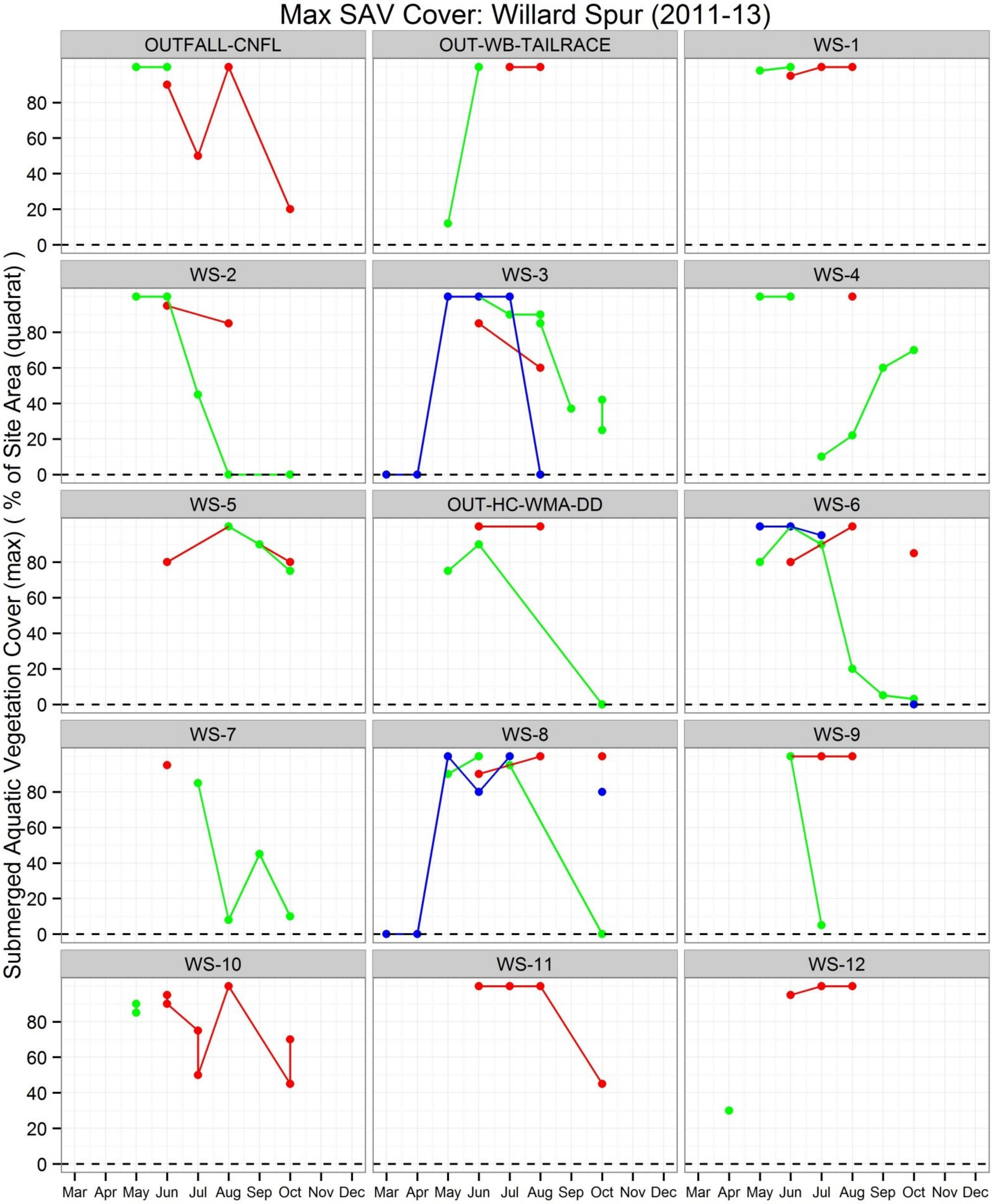


Figure 74. Maximum SAV cover for all open water monitoring locations

SAV Condition Class

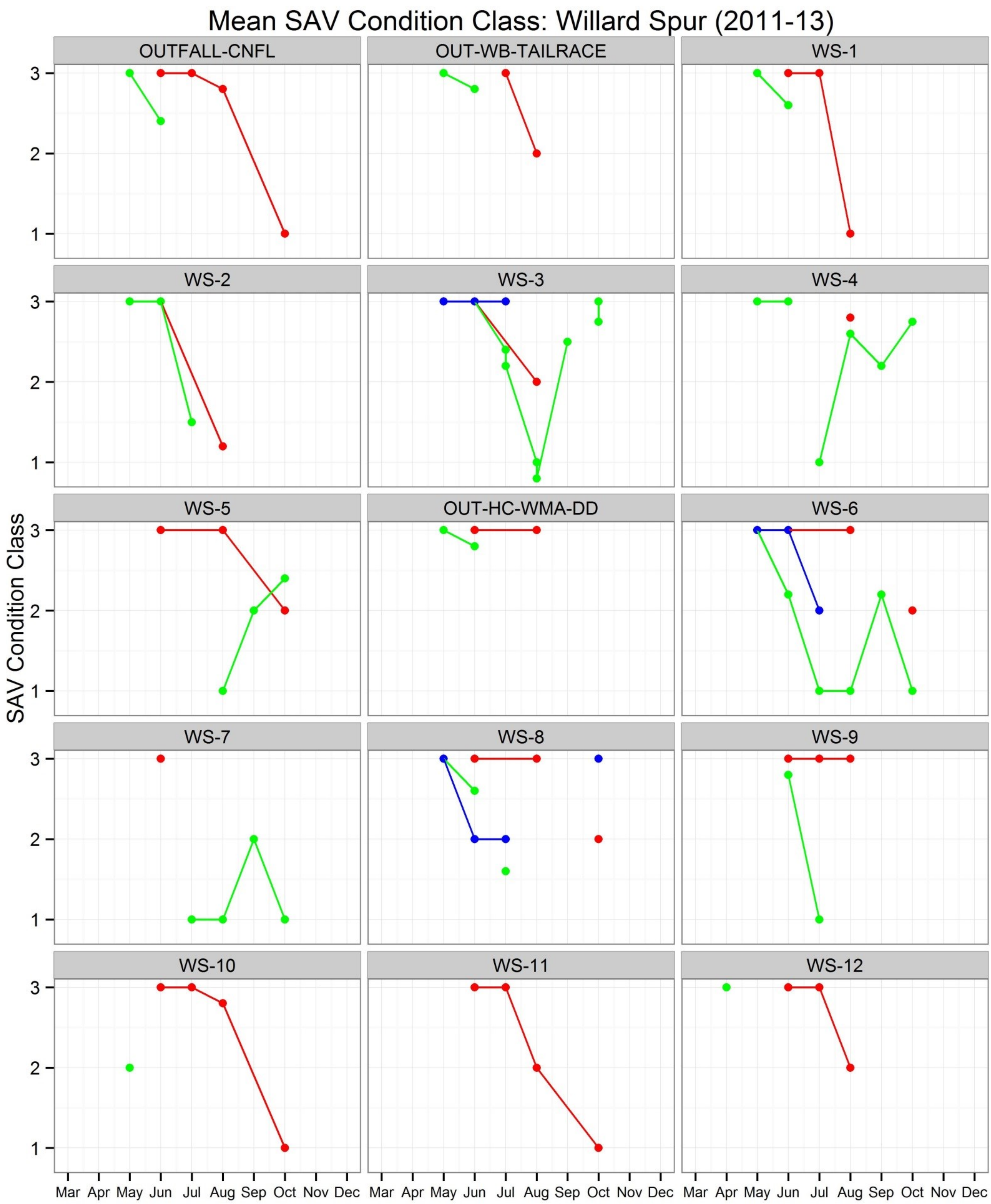


Figure 75. Mean SAV Condition Class scores for all open water monitoring locations

Surface Mat cover

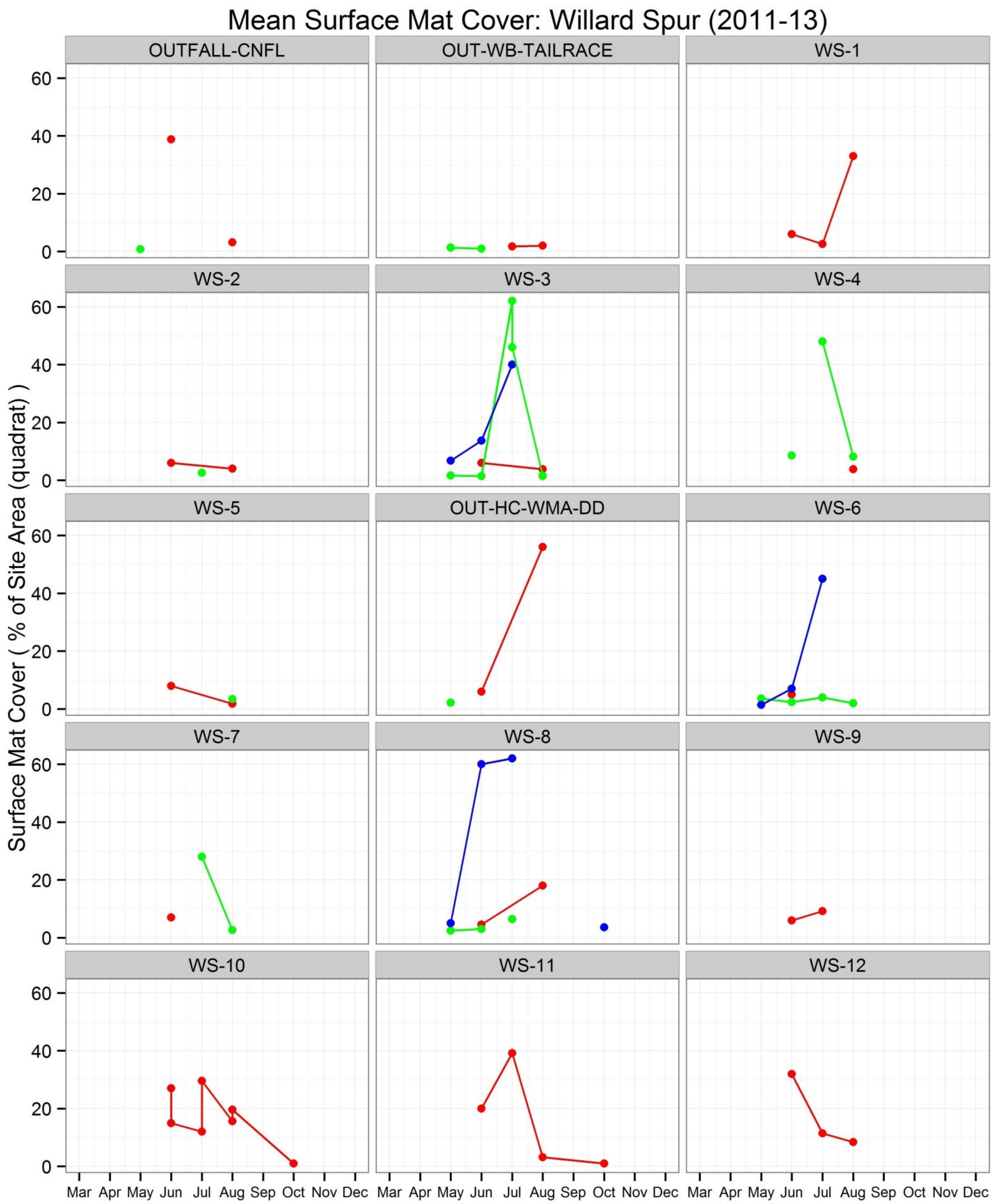


Figure 76. Mean cover of Surface mats (filamentous algae and floating aquatic vegetation) for all open water monitoring locations

Algal Mat cover

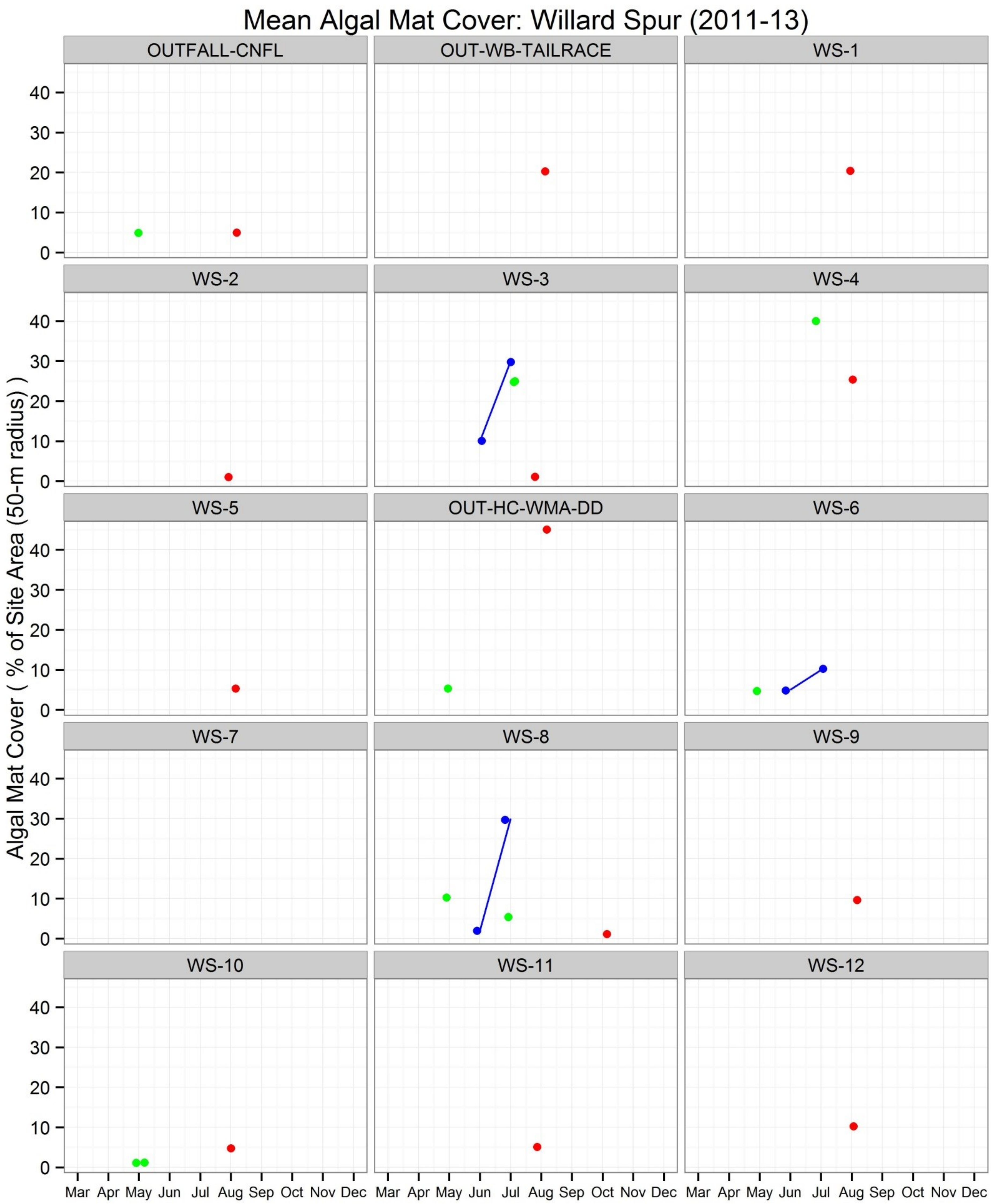


Figure 77 Mean algal mat cover for all open water monitoring locations

Macroinvertebrates

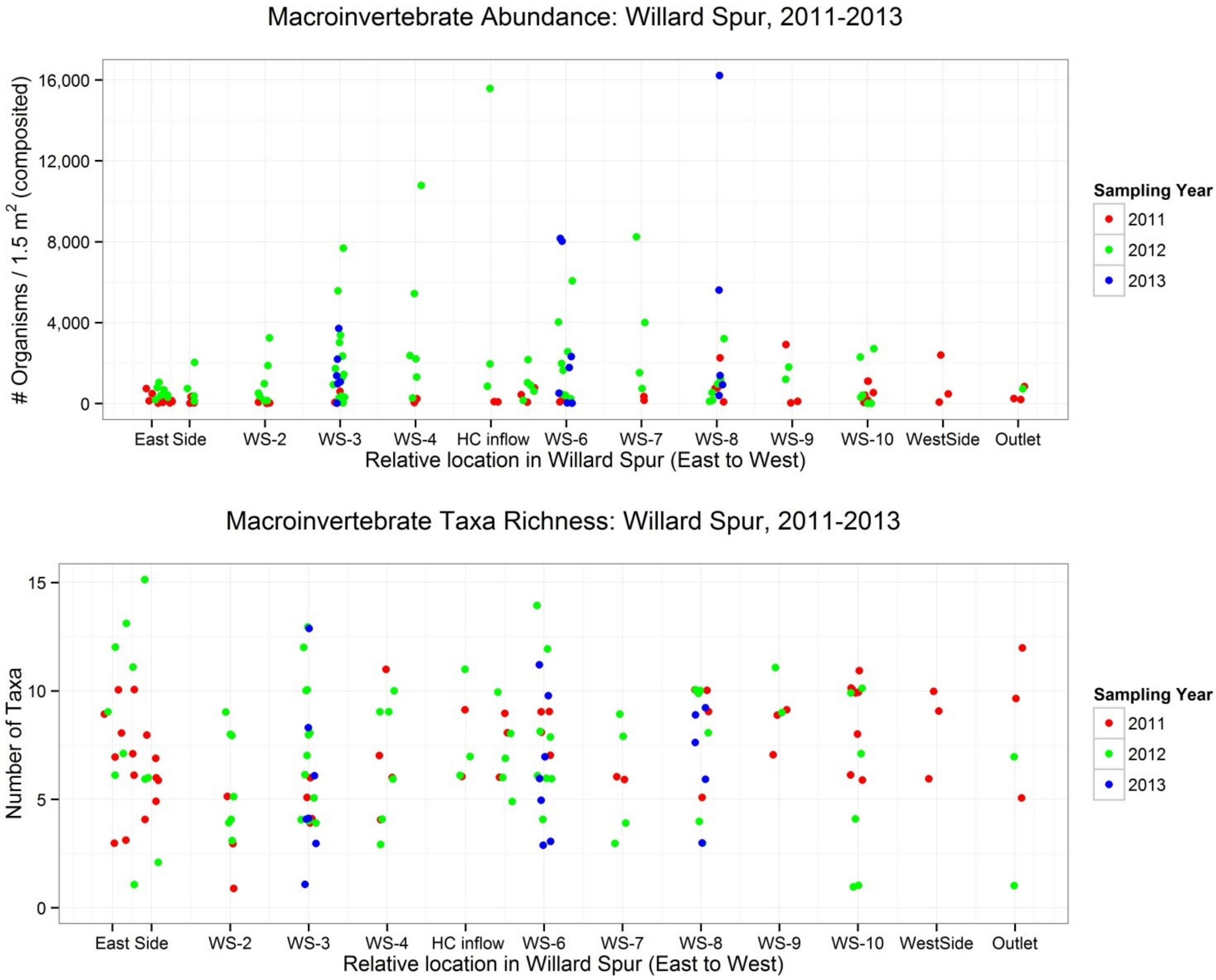


Figure 78. Distribution of Macroinvertebrate abundance and taxa richness across the Willard Spur Project Area.

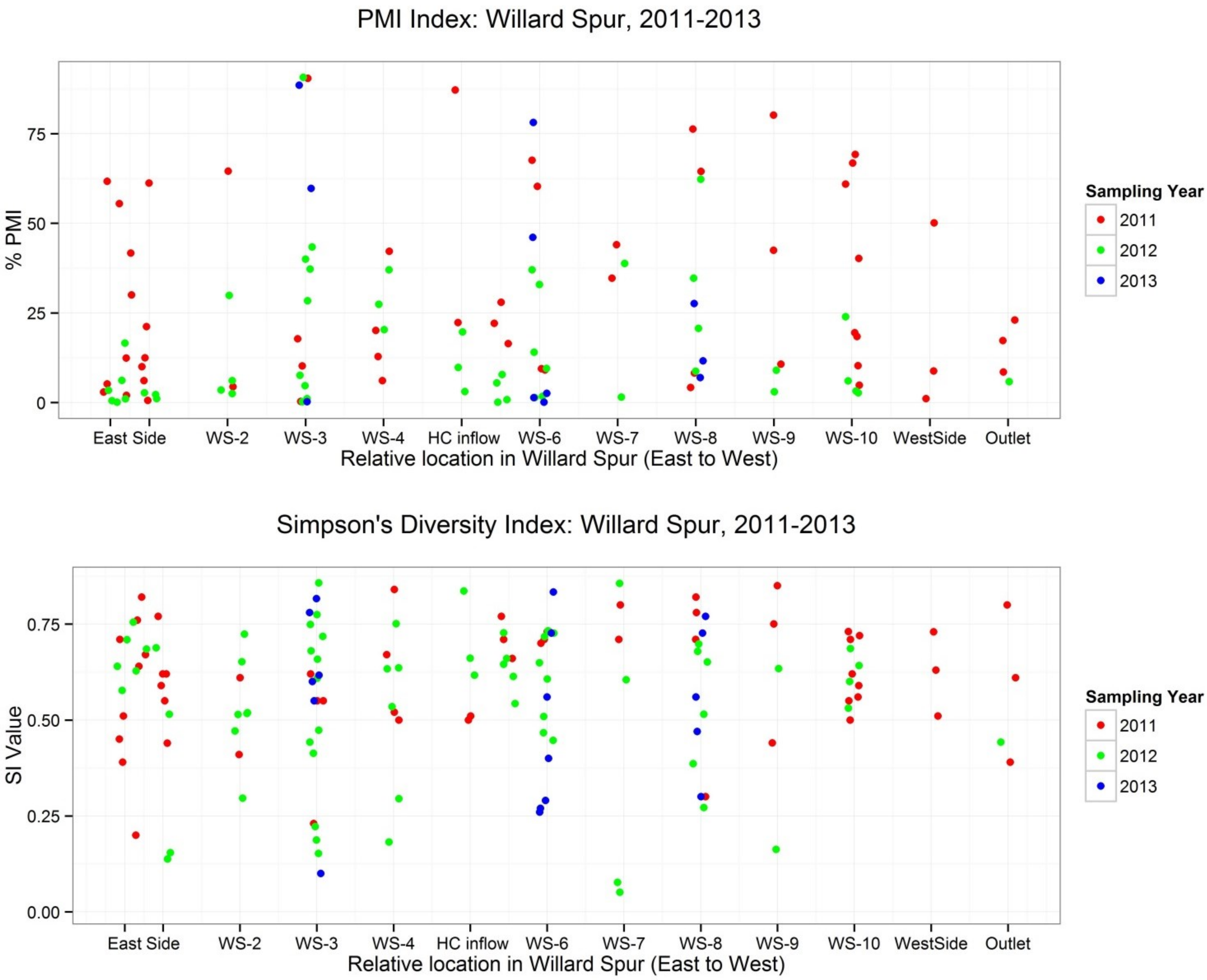


Figure 79. Distribution of PMI and SI indices across the Willard Spur Project Area.

Table 3. Pearson correlation coefficients for a subset of Physical and Chemical Water Chemistry Parameters, SAV metrics, and Macroinvertebrate metrics.

Depth	Temp	pH	Alk.T	DO.c	DO.p	TDS	CHLA	TSS	Turb	TVS.TSS	SO4.T	TP	TIN	TON	DN.DP	TotalN	TN2.TP	AlgalMat	SurfMat	SAV.COND	SAV.cover	SAV.biovol	SAV.SCR	SAV.Vigor	Chironomin	Hyallela	Biomass	Count	PMI	SI	Taxa
	-0.06	0.13	-0.21	-0.26	-0.27	-0.50	-0.24	-0.21	-0.08	0.03	-0.41	-0.47	-0.16	-0.46	-0.07	-0.48	0.04	-0.06	0.02	0.38	0.41	0.83	0.45	0.83	-0.22	-0.26	-0.27	-0.24	0.22	0.13	-0.05
-0.06		0.40	-0.49	0.01	0.53	0.02	-0.11	-0.01	-0.31	0.21	-0.38	0.09	-0.09	0.30	0.15	0.25	0.23	0.27	0.29	-0.04	0.36	0.10	0.18	0.02	-0.18	0.13	0.32	-0.01	0.16	0.31	0.50
0.13	0.40		-0.66	0.24	0.39	-0.28	-0.19	-0.16	-0.26	0.15	-0.31	-0.37	-0.24	-0.11	0.19	-0.18	0.26	-0.03	0.01	0.31	0.54	0.16	0.50	0.11	-0.15	-0.25	-0.07	-0.18	0.23	0.25	0.35
-0.21	-0.49	-0.66		0.00	-0.20	0.19	0.21	0.25	0.31	-0.23	0.34	0.43	0.28	-0.06	-0.23	0.06	-0.32	-0.07	-0.30	-0.37	-0.48	-0.25	-0.41	-0.20	0.17	-0.18	-0.05	0.16	-0.18	-0.24	-0.39
-0.26	0.01	0.24	0.00		0.84	0.04	0.20	-0.05	-0.05	0.17	0.19	0.02	0.01	0.08	0.11	0.07	0.07	0.06	0.07	0.13	0.05	-0.14	0.14	-0.12	0.08	-0.09	0.10	-0.01	-0.13	-0.20	-0.12
-0.27	0.53	0.39	-0.20	0.84		0.09	0.15	-0.03	-0.17	0.24	0.00	0.10	-0.03	0.26	0.18	0.23	0.18	0.17	0.21	0.08	0.16	-0.10	0.16	-0.11	-0.04	0.02	0.32	0.01	-0.03	0.03	0.21
-0.50	0.02	-0.28	0.19	0.04	0.09		0.23	0.23	0.02	-0.04	0.52	0.51	0.11	0.86	0.21	0.83	0.04	-0.02	-0.06	-0.37	-0.49	-0.45	-0.55	-0.44	0.21	0.36	0.29	0.39	-0.26	-0.17	-0.07
-0.24	-0.11	-0.19	0.21	0.20	0.15	0.23		0.46	0.17	-0.10	0.13	0.53	0.05	0.32	-0.07	0.31	-0.17	-0.10	-0.20	-0.29	-0.46	-0.30	-0.48	-0.32	0.12	0.23	0.48	0.30	-0.24	-0.14	-0.32
-0.21	-0.01	-0.16	0.25	-0.05	-0.03	0.23	0.46		0.76	-0.33	0.07	0.58	0.02	0.26	-0.10	0.25	-0.21	-0.15	-0.26	-0.10	-0.36	-0.29	-0.24	-0.24	0.22	-0.05	0.31	0.49	-0.32	-0.25	-0.17
-0.08	-0.31	-0.26	0.31	-0.05	-0.17	0.02	0.17	0.76		-0.25	0.00	0.24	0.08	-0.05	-0.18	-0.01	-0.19	-0.17	-0.27	-0.21	-0.53	-0.37	-0.28	-0.30	0.26	-0.08	0.12	0.49	-0.28	-0.37	-0.22
0.03	0.21	0.15	-0.23	0.17	0.24	-0.04	-0.10	-0.33	-0.25		-0.08	-0.19	-0.03	0.05	0.24	0.04	0.38	-0.01	0.16	0.09	0.15	0.02	0.12	0.02	-0.08	0.02	0.03	-0.08	0.12	0.09	0.11
-0.41	-0.38	-0.31	0.34	0.19	0.00	0.52	0.13	0.07	0.00	-0.08		0.29	0.22	0.28	0.09	0.33	-0.07	-0.01	-0.04	-0.14	-0.38	-0.35	-0.35	-0.33	0.33	0.24	0.00	0.15	-0.27	-0.24	-0.30
-0.47	0.09	-0.37	0.43	0.02	0.10	0.51	0.53	0.58	0.24	-0.19	0.29		0.27	0.54	-0.12	0.59	-0.29	-0.09	-0.22	-0.12	-0.45	-0.35	-0.35	-0.31	0.19	0.32	0.51	0.54	-0.35	-0.18	-0.16
-0.16	-0.09	-0.24	0.28	0.01	-0.03	0.11	0.05	0.02	0.08	-0.03	0.22	0.27		0.06	-0.06	0.38	-0.01	0.25	0.12	0.09	0.02	0.00	0.11	0.04	0.06	-0.08	0.01	0.04	-0.14	0.01	-0.05
-0.46	0.30	-0.11	-0.06	0.08	0.26	0.86	0.32	0.26	-0.05	0.05	0.28	0.54	0.06		0.21	0.94	0.15	0.00	-0.05	-0.35	-0.40	-0.40	-0.48	-0.42	0.08	0.35	0.47	0.37	-0.22	-0.09	0.07
-0.07	0.15	0.19	-0.23	0.11	0.18	0.21	-0.07	-0.10	-0.18	0.24	0.09	-0.12	-0.06	0.21		0.18	0.53	0.18	0.02	-0.16	0.06	-0.06	-0.03	-0.08	0.02	-0.03	0.05	0.01	0.03	0.07	0.09
-0.48	0.25	-0.18	0.06	0.07	0.23	0.83	0.31	0.25	-0.01	0.04	0.33	0.59	0.38	0.94	0.18		0.14	0.07	-0.02	-0.30	-0.37	-0.38	-0.42	-0.38	0.10	0.31	0.45	0.36	-0.25	-0.08	0.06
0.04	0.23	0.26	-0.32	0.07	0.18	0.04	-0.17	-0.21	-0.19	0.38	-0.07	-0.29	-0.01	0.15	0.53	0.14		0.14	0.13	-0.02	0.22	0.08	0.12	0.05	-0.07	0.04	0.01	-0.09	0.11	0.09	0.13
-0.06	0.27	-0.03	-0.07	0.06	0.17	-0.02	-0.10	-0.15	-0.17	-0.01	-0.01	-0.09	0.25	0.00	0.18	0.07	0.14		0.65	-0.06	0.19	-0.01	0.08	-0.07	-0.17	0.19	0.05	-0.09	0.33	0.19	0.24
0.02	0.29	0.01	-0.30	0.07	0.21	-0.06	-0.20	-0.26	-0.27	0.16	-0.04	-0.22	0.12	-0.05	0.02	-0.02	0.13	0.65		0.02	0.17	-0.02	0.05	-0.08	-0.20	0.25	0.08	-0.11	0.24	0.18	0.23
0.38	-0.04	0.31	-0.37	0.13	0.08	-0.37	-0.29	-0.10	-0.21	0.09	-0.14	-0.12	0.09	-0.35	-0.16	-0.30	-0.02	-0.06	0.02		0.50	0.44	0.75	0.50	-0.10	-0.34	-0.31	-0.20	-0.12	-0.07	-0.08
0.41	0.36	0.54	-0.48	0.05	0.16	-0.49	-0.46	-0.36	-0.53	0.15	-0.38	-0.45	0.02	-0.40	0.06	-0.37	0.22	0.19	0.17	0.50		0.56	0.92	0.49	-0.35	-0.17	-0.26	-0.40	0.33	0.26	0.39
0.83	0.10	0.16	-0.25	-0.14	-0.10	-0.45	-0.30	-0.29	-0.37	0.02	-0.35	-0.35	0.00	-0.40	-0.06	-0.38	0.08	-0.01	-0.02	0.44	0.56		0.58	0.99	-0.29	-0.27	-0.25	-0.37	0.13	0.11	0.00
0.45	0.18	0.50	-0.41	0.14	0.16	-0.55	-0.48	-0.24	-0.28	0.12	-0.35	-0.35	0.11	-0.48	-0.03	-0.42	0.12	0.08	0.05	0.75	0.92	0.58		0.60	-0.23	-0.31	-0.31	-0.36	0.11	0.09	0.11
0.83	0.02	0.11	-0.20	-0.12	-0.11	-0.44	-0.32	-0.24	-0.30	0.02	-0.33	-0.31	0.04	-0.42	-0.08	-0.38	0.05	-0.07	-0.08	0.50	0.49	0.99	0.60		-0.25	-0.30	-0.26	-0.35	0.00	0.03	-0.15
-0.22	-0.18	-0.15	0.17	0.08	-0.04	0.21	0.12	0.22	0.26	-0.08	0.33	0.19	0.06	0.08	0.02	0.10	-0.07	-0.17	-0.20	-0.10	-0.35	-0.29	-0.23	-0.25		0.18	0.14	0.60	-0.27	-0.35	-0.27
-0.26	0.13	-0.25	-0.18	-0.09	0.02	0.36	0.23	-0.05	-0.08	0.02	0.24	0.32	-0.08	0.35	-0.03	0.31	0.04	0.19	0.25	-0.34	-0.17	-0.27	-0.31	-0.30	0.18		0.32	0.34	0.04	0.18	0.08
-0.27	0.32	-0.07	-0.05	0.10	0.32	0.29	0.48	0.31	0.12	0.03	0.00	0.51	0.01	0.47	0.05	0.45	0.01	0.05	0.08	-0.31	-0.26	-0.25	-0.31	-0.26	0.14	0.32		0.52	-0.03	-0.02	0.19
-0.24	-0.01	-0.18	0.16	-0.01	0.01	0.39	0.30	0.49	0.49	-0.08	0.15	0.54	0.04	0.37	0.01	0.36	-0.09	-0.09	-0.11	-0.20	-0.40	-0.37	-0.36	-0.35	0.60	0.34	0.52		-0.18	-0.28	-0.05
0.22	0.16	0.23	-0.18	-0.13	-0.03	-0.26	-0.24	-0.32	-0.28	0.12	-0.27	-0.35	-0.14	-0.22	0.03	-0.25	0.11	0.33	0.24	-0.12	0.33	0.13	0.11	0.00	-0.27	0.04	-0.03	-0.18		0.42	0.46
0.13	0.31	0.25	-0.24	-0.20	0.03	-0.17	-0.14	-0.25	-0.37	0.09	-0.24	-0.18	0.01	-0.09	0.07	-0.08	0.09	0.19	0.18	-0.07	0.26	0.11	0.09	0.03	-0.35	0.18	-0.02	-0.28	0.42		0.61
-0.05	0.50	0.35	-0.39	-0.12	0.21	-0.07	-0.32	-0.17	-0.22	0.11	-0.30	-0.16	-0.05	0.07	0.09	0.06	0.13	0.24	0.23	-0.08	0.39	0.00	0.11	-0.15	-0.27	0.08	0.19	-0.05	0.46	0.61	

Table 4. P-values for Pearson correlation coefficients (see previous table) for selected variables.

Depth	Temp	pH	Alk.T	DO.c	DO.p	TDS	CHLA	TSS	Turb	TVS.TSS	SO4.T	TP	TIN	TON	DN.DP	TotalN	TN2.TP	AlgalMat	SurfMat	SAV.COND	SAV.cover	SAV.biovol	SAV.SCR	SAV.Vigor	Chironomin	Hyallela	Biomass	Count	PMI	SI	Taxa
	0.423	0.067	0.009	0.000	0.000	0.000	0.001	0.003	0.326	0.633	0.000	0.000	0.023	0.000	0.382	0.000	0.537	0.496	0.862	0.000	0.000	0.000	0.000	0.000	0.009	0.020	0.001	0.003	0.005	0.104	0.564
0.423		0.000	0.000	0.874	0.000	0.780	0.136	0.841	0.000	0.004	0.000	0.234	0.237	0.000	0.068	0.000	0.001	0.004	0.002	0.661	0.000	0.285	0.073	0.840	0.034	0.255	0.000	0.912	0.046	0.000	0.000
0.067	0.000		0.000	0.001	0.000	0.000	0.009	0.023	0.002	0.033	0.000	0.000	0.001	0.139	0.022	0.014	0.000	0.789	0.884	0.001	0.000	0.096	0.000	0.262	0.073	0.021	0.406	0.020	0.004	0.002	0.000
0.009	0.000	0.000		0.993	0.013	0.022	0.012	0.002	0.000	0.005	0.000	0.000	0.000	0.480	0.017	0.458	0.000	0.512	0.006	0.001	0.000	0.027	0.000	0.086	0.103	0.184	0.583	0.097	0.063	0.011	0.000
0.000	0.874	0.001	0.993		0.000	0.577	0.006	0.481	0.520	0.021	0.007	0.792	0.937	0.296	0.185	0.321	0.311	0.535	0.437	0.179	0.605	0.135	0.153	0.233	0.385	0.446	0.219	0.883	0.109	0.011	0.151
0.000	0.000	0.000	0.013	0.000		0.222	0.041	0.670	0.041	0.001	0.971	0.171	0.660	0.000	0.029	0.001	0.011	0.071	0.022	0.397	0.092	0.312	0.098	0.274	0.672	0.843	0.000	0.880	0.711	0.693	0.007
0.000	0.780	0.000	0.022	0.577	0.222		0.001	0.001	0.851	0.562	0.000	0.000	0.132	0.000	0.011	0.000	0.553	0.843	0.512	0.000	0.000	0.000	0.000	0.000	0.013	0.001	0.000	0.000	0.001	0.039	0.398
0.001	0.136	0.009	0.012	0.006	0.041	0.001		0.000	0.033	0.173	0.067	0.000	0.479	0.000	0.414	0.000	0.018	0.312	0.037	0.003	0.000	0.001	0.000	0.001	0.171	0.042	0.000	0.000	0.003	0.075	0.000
0.003	0.841	0.023	0.002	0.481	0.670	0.001	0.000		0.000	0.000	0.325	0.000	0.737	0.000	0.203	0.000	0.003	0.112	0.005	0.296	0.000	0.002	0.014	0.014	0.012	0.661	0.000	0.000	0.000	0.002	0.032
0.326	0.000	0.002	0.000	0.520	0.041	0.851	0.033	0.000		0.002	0.999	0.003	0.310	0.558	0.065	0.910	0.018	0.122	0.014	0.067	0.000	0.001	0.015	0.009	0.008	0.545	0.227	0.000	0.003	0.000	0.020
0.633	0.004	0.033	0.005	0.021	0.001	0.562	0.173	0.000	0.002		0.283	0.007	0.646	0.474	0.003	0.610	0.000	0.956	0.085	0.340	0.117	0.803	0.215	0.838	0.347	0.834	0.738	0.319	0.140	0.262	0.178
0.000	0.000	0.000	0.000	0.007	0.971	0.000	0.067	0.325	0.999	0.283		0.000	0.002	0.000	0.290	0.000	0.337	0.909	0.686	0.144	0.000	0.000	0.000	0.001	0.000	0.029	0.953	0.065	0.001	0.002	0.000
0.000	0.234	0.000	0.000	0.792	0.171	0.000	0.000	0.000	0.003	0.007	0.000		0.000	0.000	0.143	0.000	0.000	0.356	0.017	0.218	0.000	0.000	0.000	0.001	0.025	0.003	0.000	0.000	0.000	0.028	0.042
0.023	0.237	0.001	0.000	0.937	0.660	0.132	0.479	0.737	0.310	0.646	0.002	0.000		0.434	0.482	0.000	0.847	0.009	0.225	0.389	0.845	0.993	0.256	0.724	0.498	0.469	0.890	0.595	0.077	0.886	0.518
0.000	0.000	0.139	0.480	0.296	0.000	0.000	0.000	0.000	0.558	0.474	0.000	0.000	0.434		0.010	0.000	0.031	0.972	0.575	0.000	0.000	0.000	0.000	0.000	0.330	0.001	0.000	0.000	0.005	0.254	0.356
0.382	0.068	0.022	0.017	0.185	0.029	0.011	0.414	0.203	0.065	0.003	0.290	0.143	0.482	0.010		0.024	0.000	0.078	0.852	0.108	0.561	0.552	0.791	0.447	0.836	0.824	0.556	0.898	0.747	0.408	0.275
0.000	0.000	0.014	0.458	0.321	0.001	0.000	0.000	0.000	0.910	0.610	0.000	0.000	0.000	0.000	0.024		0.053	0.480	0.829	0.002	0.000	0.000	0.000	0.000	0.265	0.004	0.000	0.000	0.002	0.298	0.482
0.537	0.001	0.000	0.000	0.311	0.011	0.553	0.018	0.003	0.018	0.000	0.337	0.000	0.847	0.031	0.000	0.053		0.150	0.180	0.805	0.019	0.397	0.244	0.630	0.429	0.694	0.880	0.272	0.176	0.241	0.093
0.496	0.004	0.789	0.512	0.535	0.071	0.843	0.312	0.112	0.122	0.956	0.909	0.356	0.009	0.972	0.078	0.480	0.150		0.000	0.557	0.048	0.938	0.428	0.510	0.102	0.122	0.594	0.379	0.001	0.053	0.014
0.862	0.002	0.884	0.006	0.437	0.022	0.512	0.037	0.005	0.014	0.085	0.686	0.017	0.225	0.575	0.852	0.829	0.180	0.000		0.865	0.070	0.804	0.592	0.427	0.053	0.043	0.404	0.250	0.014	0.071	0.018
0.000	0.661	0.001	0.001	0.179	0.397	0.000	0.003	0.296	0.067	0.340	0.144	0.218	0.389	0.000	0.108	0.002	0.805	0.557	0.865		0.000	0.000	0.000	0.000	0.377	0.006	0.002	0.050	0.261	0.488	0.430
0.000	0.000	0.000	0.000	0.605	0.092	0.000	0.000	0.000	0.000	0.117	0.000	0.000	0.845	0.000	0.561	0.000	0.019	0.048	0.070	0.000		0.000	0.000	0.000	0.001	0.180	0.007	0.000	0.001	0.006	0.000
0.000	0.285	0.096	0.027	0.135	0.312	0.000	0.001	0.002	0.001	0.803	0.000	0.000	0.993	0.000	0.552	0.000	0.397	0.938	0.804	0.000	0.000		0.000	0.000	0.006	0.026	0.011	0.000	0.187	0.245	0.999
0.000	0.073	0.000	0.000	0.153	0.098	0.000	0.000	0.014	0.015	0.215	0.000	0.000	0.256	0.000	0.791	0.000	0.244	0.428	0.592	0.000	0.000	0.000		0.000	0.032	0.014	0.002	0.000	0.301	0.376	0.262
0.000	0.840	0.262	0.086	0.233	0.274	0.000	0.001	0.014	0.009	0.838	0.001	0.001	0.724	0.000	0.447	0.000	0.630	0.510	0.427	0.000	0.000	0.000	0.000		0.020	0.015	0.009	0.000	0.989	0.747	0.151
0.009	0.034	0.073	0.103	0.385	0.672	0.013	0.171	0.012	0.008	0.347	0.000	0.025	0.498	0.330	0.836	0.265	0.429	0.102	0.053	0.377	0.001	0.006	0.032	0.020		0.135	0.102	0.000	0.002	0.000	0.001
0.020	0.255	0.021	0.184	0.446	0.843	0.001	0.042	0.661	0.545	0.834	0.029	0.003	0.469	0.001	0.824	0.004	0.694	0.122	0.043	0.006	0.180	0.026	0.014	0.015	0.135		0.003	0.002	0.692	0.106	0.459
0.001	0.000	0.406	0.583	0.219	0.000	0.000	0.000	0.000	0.227	0.738	0.953	0.000	0.890	0.000	0.556	0.000	0.880	0.594	0.404	0.002	0.007	0.011	0.002	0.009	0.102	0.003		0.000	0.731	0.784	0.019
0.003	0.912	0.020	0.097	0.883	0.880	0.000	0.000	0.000	0.000	0.319	0.065	0.000	0.595	0.000	0.898	0.000	0.272	0.379	0.250	0.050	0.000	0.000	0.000	0.000	0.000	0.002	0.000		0.027	0.000	0.500
0.005	0.046	0.004	0.063	0.109	0.711	0.001	0.003	0.000	0.003	0.140	0.001	0.000	0.077	0.005	0.747	0.002	0.176	0.001	0.014	0.261	0.001	0.187	0.301	0.989	0.002	0.692	0.731	0.027		0.000	0.000
0.104	0.000	0.002	0.011	0.011	0.693	0.039	0.075	0.002	0.000	0.262	0.002	0.028	0.886	0.254	0.408	0.298	0.241	0.053	0.071	0.488	0.006	0.245	0.376	0.747	0.000	0.106	0.784	0.000	0.000		0.000
0.564	0.000	0.000	0.000	0.151	0.007	0.398	0.000	0.032	0.020	0.178	0.000	0.042	0.518	0.356	0.275	0.482	0.093	0.014	0.018	0.430	0.000	0.999	0.262	0.151	0.001	0.459	0.019	0.500	0.000	0.000	