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Chemistry of Surface Water, Pore Water, and Sediment in seven impounded wetlands bordering Great Salt Lake

Prepared for:

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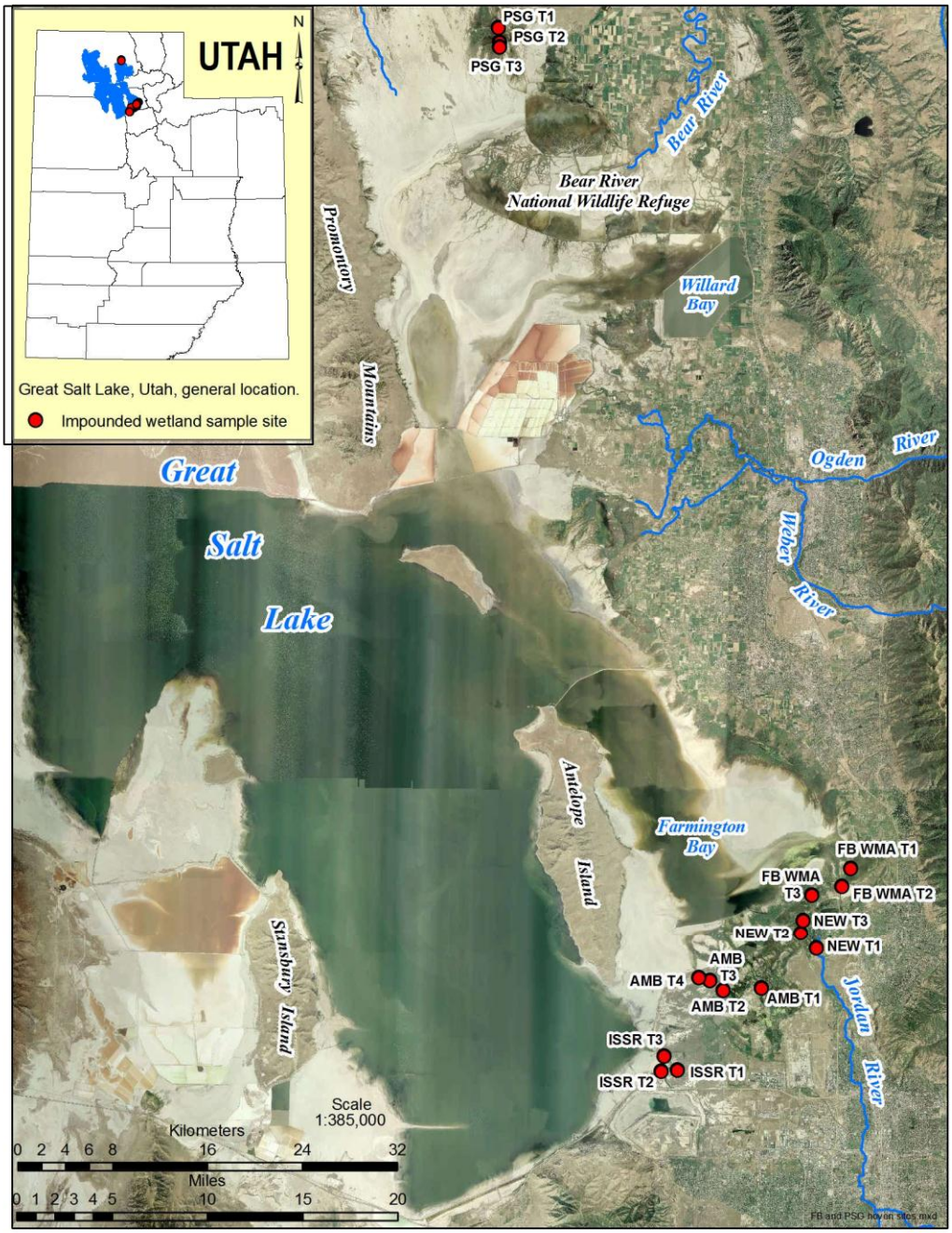
Overview

Surface water, pore water, and sediment chemistry was examined at wetlands adjacent to Great Salt Lake during summer 2010 (map below). Surface water samples were collected at Ambassador W-1 (AM), Newstate 47 (N47), Farmington Bay Unit 1 & Unit 2 (FB1 & FB2), Bear River Unit 4C (BR), and Public Shooting Grounds Pintail & Widgeon (PN & WD). Pore water samples were collected at all sites except WD, and sediment samples were collected at all sites except WD and BR. This report provides a summary of the surface water, pore water, and sediment chemistry (i.e. trace and major elements, nutrients, redox conditions) at each of these ponds.

The following questions are addressed in this report:

- How does multivariate chemistry compare across the different wetland sites for surface water? Pore water? Sediment?
- How do single element concentrations compare between surface water and pore water at all wetlands sites? Between surface water and sediment? Between pore water and sediment?
- Which elements co-vary in surface water across all sites? Pore water? Sediment?
- Which chemical parameters show changes in concentration with time in surface water? Pore water?



Eastern shore of Great Salt Lake, U.S.A. showing original impounded wetland sites of the study on beneficial use assessment of Farmington Bay wetlands. Reference sites are located at the PSG (Public Shooting Grounds) and nutrient-enriched sites are located at FB WMA (Farmington Bay Wildlife Management Area), NEW (New State Duck Club), AMB (Ambassador Duck Club), and ISSR (Inland Sea Shorebird Reserve, discontinued as a target site). Two additional sites along the D-line dyke of Bear River Migratory Bird Refuge (shown as Bear River National Wildlife Refuge, B) were added in 2008 to represent moderate water quality conditions. T with numerals or numerals alone indicate the transect numbers at each location (from H. Hoven report for plant metrics aspects of the project).

1. How does multivariate chemistry compare across the different wetland sites for surface water? Pore water? Sediment?

Multiple variables were measured in the surface water, pore water, and sediment at each pond; therefore ordination was used to explore multivariate relationships within each of these compartments. Ordination is a statistical technique used to arrange data on derived axes so that similar objects are near each other and dissimilar objects are far from each other in terms of these axes. Discerning these relationships may require multiple axes. Several types of ordination exist; non-metric multidimensional scaling (NMDS) was used for this data.

The major finding from the ordinations is that the impounded wetlands are distinct from one another in surface water, pore water, and sediment chemistry. In separate ordinations for surface water, pore water, and sediment, the ends of the spectrum among the population of ponds were always occupied by ponds N47 and PN; whereas, the other ponds always plotted somewhere in between. N47 is characterized by elevated anthropogenic-associated trace elements, whereas PN is characterized by elevated major elements. The fact that the ordination yields similar arrangements for surface water, pore water, and sediment shows that these compartments are generally related. The relationship of individual elements across these compartments is described in Section 2 of this report. The results of surface water, pore water, and sediment ordinations are summarized below.

1.1 Surface water chemistry across sites

Figure 1 shows ordination results for surface water chemistry including all samples collected and all elements analyzed with concentrations twice greater than detection limit. Axes 1 & 2 explain 87.2% of variability in the data; plots involving Axis 3 are shown in Appendix 1. Three chemically distinct groups were delineated on the basis of Axes 1 & 2: 1) BR, PN, and WD; 2) FB1 and FB2; and 3) N47 and AM. BR, PN, and WD surface water is distinguished by relatively high concentrations of major elements Na, Cl, K and dissolved organic carbon (DOC), as well as THg, and corresponding low concentrations of the nutrients NO_3, HPO_4, nitrite and ammonia, and the anthropogenic trace elements Pb, Se, Sb, and U. The opposite is true for AM and N47, which contain relatively low concentrations of major elements and high concentrations of nutrients and anthropogenic trace elements. FB1 and FB2 have an intermediate chemical signature. Differences in MeHg, THg, Pb, and $PO4^{2-}$ are primarily explained by Axis 2: sites with elevated surface water MeHg (FB1 & FB2 and BR during July) occur at the positive extreme of Axis 2.

1.2 Pore water chemistry across sites

Figure 2 shows ordination results for pore water chemistry including all samples collected and all elements analyzed with concentrations twice greater than detection limit. Pore water samples collected from two depths (0-7 cm and 7-13 cm below sediment-water interface) were averaged for the ordination since top and bottom samples had similar chemistry at all sites.

Axes 1 & 2 explain 84.7% of variability in the data; plots including Axis 3 are shown in Appendix 2. Three chemically distinct groups were delineated on the basis of Axes 1 & 2: 1) PN; 2) AM, FB1, FB2, and BR; and 3) N47. PN pore water is distinguished by elevated sulfide, THg, Cu, and major elements Na, K, Mg, Ba, Li, and Sr, and low concentrations of Fe and anthropogenic trace elements Se, As, Cr, Mn, Ni, Ti, and Pb. The opposite is true for pore water at N47, which contains relatively low concentrations of sulfide, major elements, THg, and Cu, and high concentrations of Fe and anthropogenic trace elements. AM, FB1, FB2, and BR contain intermediate concentrations of these elements, except that they contain elevated sulfide and low Fe. A major distinction between pore water chemistry is that Fe:sulfide ratios show that N47 pore water is dominated by Fe-reduction, whereas pore water at all other sites is dominated by SO_4-reduction. Axis 2 further delineates the sites on the basis of elevated THg and MeHg pore water concentrations, as was the case for surface water.

1.3 Sediment chemistry across sites

Figure 3 shows ordination results for sediment chemistry including all samples collected and all elements analyzed with concentrations twice greater than detection limit. Axes 1 and 2 explain 98.4% of variability in the data, with Axis 1 explaining 92.8%. Four chemically distinct groups were delineated on the basis of Axes 1 & 2: 1) PN; 2) FB1 and FB2; 3) AM; and 4) N47. PN sediment contains elevated concentrations of major elements Na, Mg, Ca, Li, Mn, Sr, and (curiously) Mo, and low concentrations of (primarily) anthropogenic elements Fe, Sb, Ag, THg, MeHg, Cd, Tl, Cu, Zn, and Pb. The opposite is true for sediment at N47, and to a lesser extent at AM, which contain elevated concentrations of anthropogenic trace elements and low concentrations of major elements. FB1 and FB2 have an intermediate chemical signature. Axis 2 explains a small amount of variability (5.7%) on the basis of MeHg concentrations: for example, N47 contains elevated MeHg compared to AM.

The similarity of ordination results from the three compartments (surface water, pore water, and sediment) demonstrates that the impounded wetlands are characterized by a chemical spectrum bounded by N47 on one side, and PN on the other. The chemical characteristic of N47 is anthropogenic-associated elements such as Fe, Sb, Ag, THg, MeHg, Cd, Tl, Cu, Zn, and Pb, whereas the chemical characteristic of PN is major elements such as Na, Mg, Ca, Li, Mn, and Sr. Notably, MeHg is associated with PN and intermediate sites in surface water, but with N47 and intermediate sites in pore water and sediment. MeHg is associated with the intermediate sites in all compartments, and in fact it is in the intermediate sites (FB) that the highest MeHg concentrations were observed.

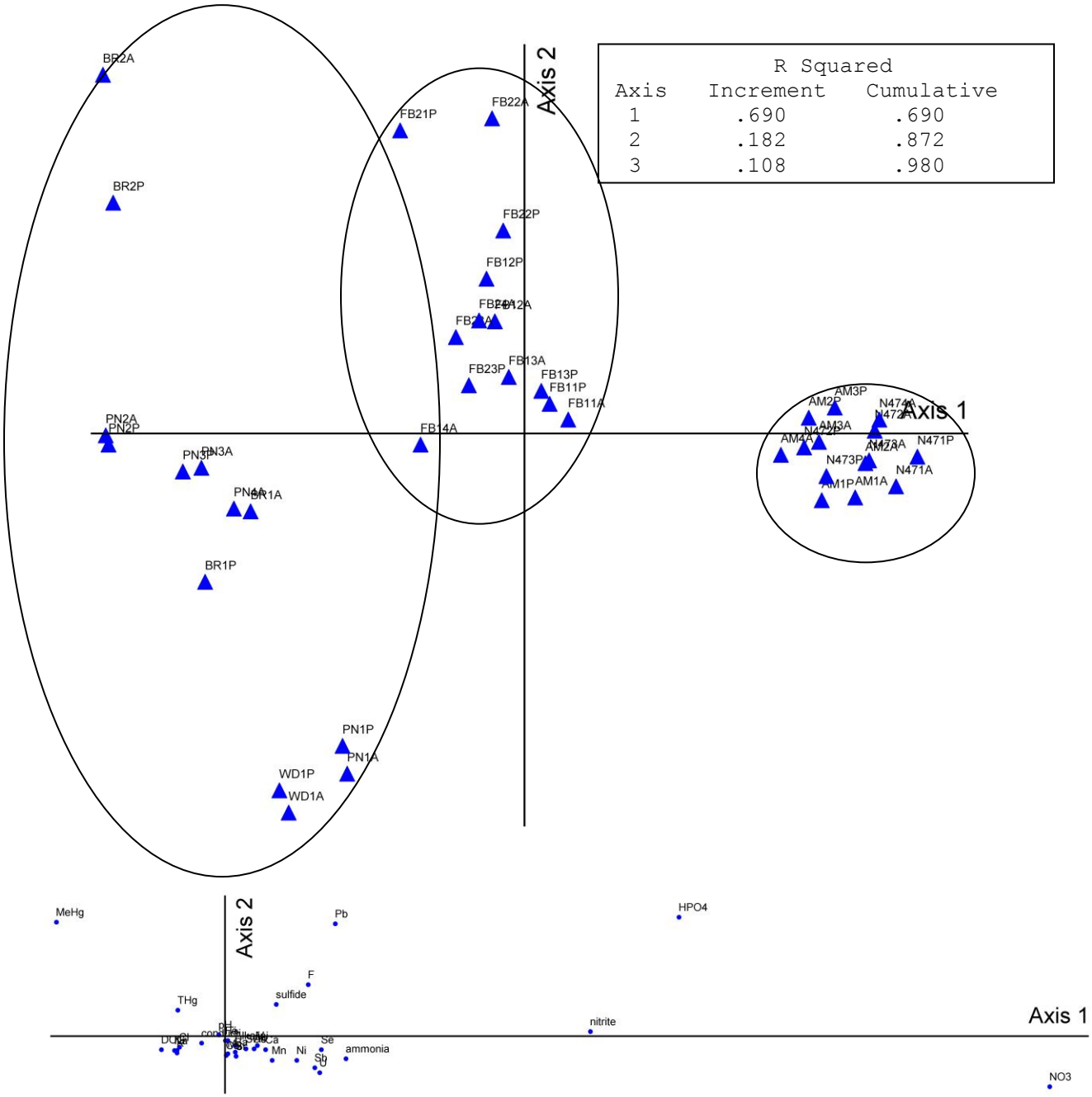


Figure 1. Ordination results for surface water chemistry. Axis 1 explained 69% of variance and Axis 2 explained 18.2%. Axis 3 is shown in Appendix 1. Explanation of sample IDs: AM=Ambassador W1, N47=Newstate 47, FB1 & FB2=Farmington Bay Unit 1 & 2, BR=Bear River Unit 4C, WD=Widgeon, PN=Pintail. 1=June, 2=July, 3=August, 4=September. A=AM (morning) sample, P=PM (afternoon) sample.

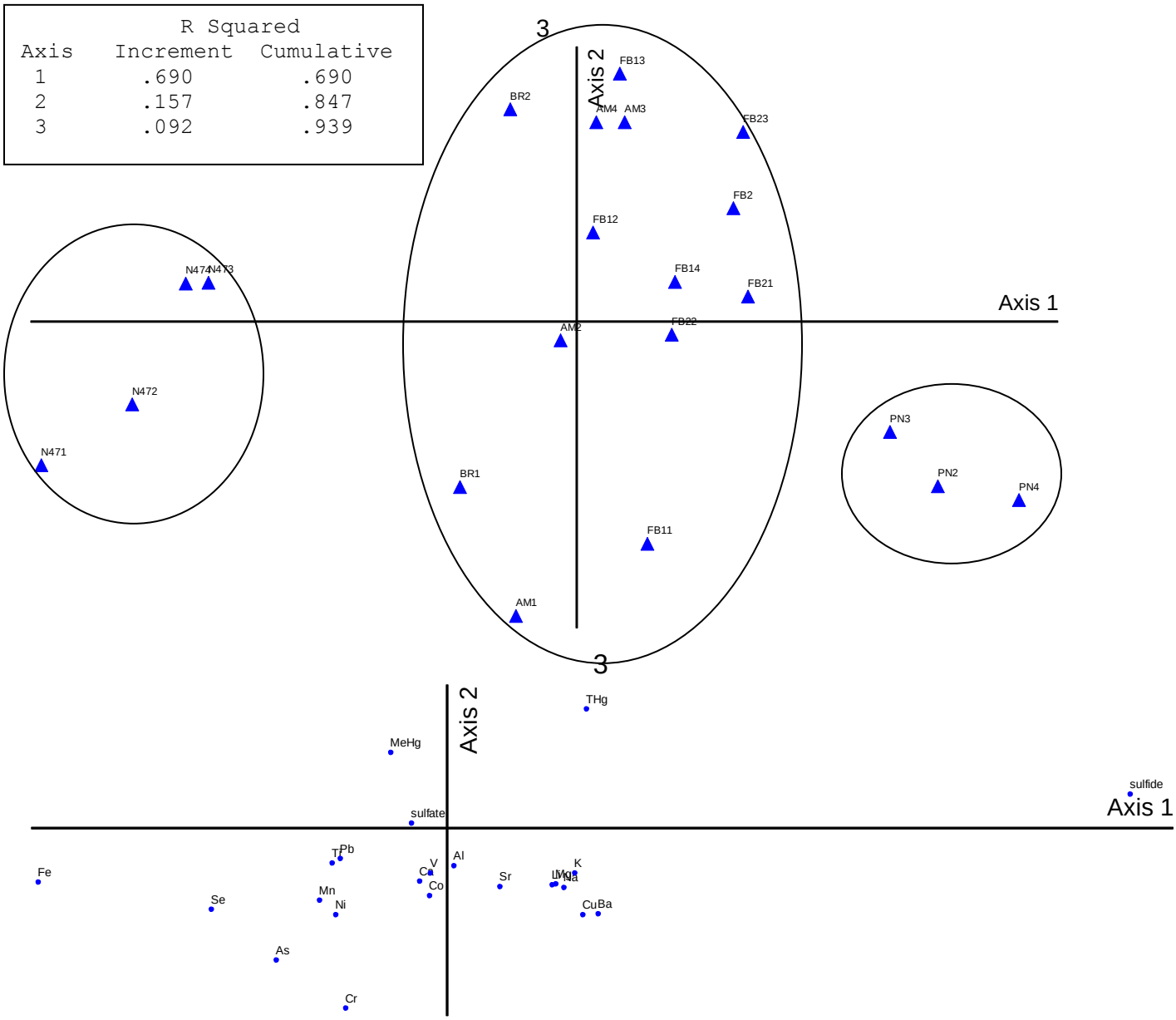


Figure 2. Ordination results for pore water chemistry. Axis 1 explained 69% of variance and Axis 2 explained 15.7%. Axis 3 is shown in Appendix 1. Explanation of sample IDs: AM=Ambassador W1, N47=Newstate 47, FB1 & FB2=Farmington Bay Unit 1 & 2, BR=Bear River Unit 4C, PN=Pintail. 1=June, 2=July, 3=August, 4=September. Top and bottom pore water samples were averaged for the ordination.

Axis	R Squared Increment	Cumulative
1	.928	.928
2	.057	.984

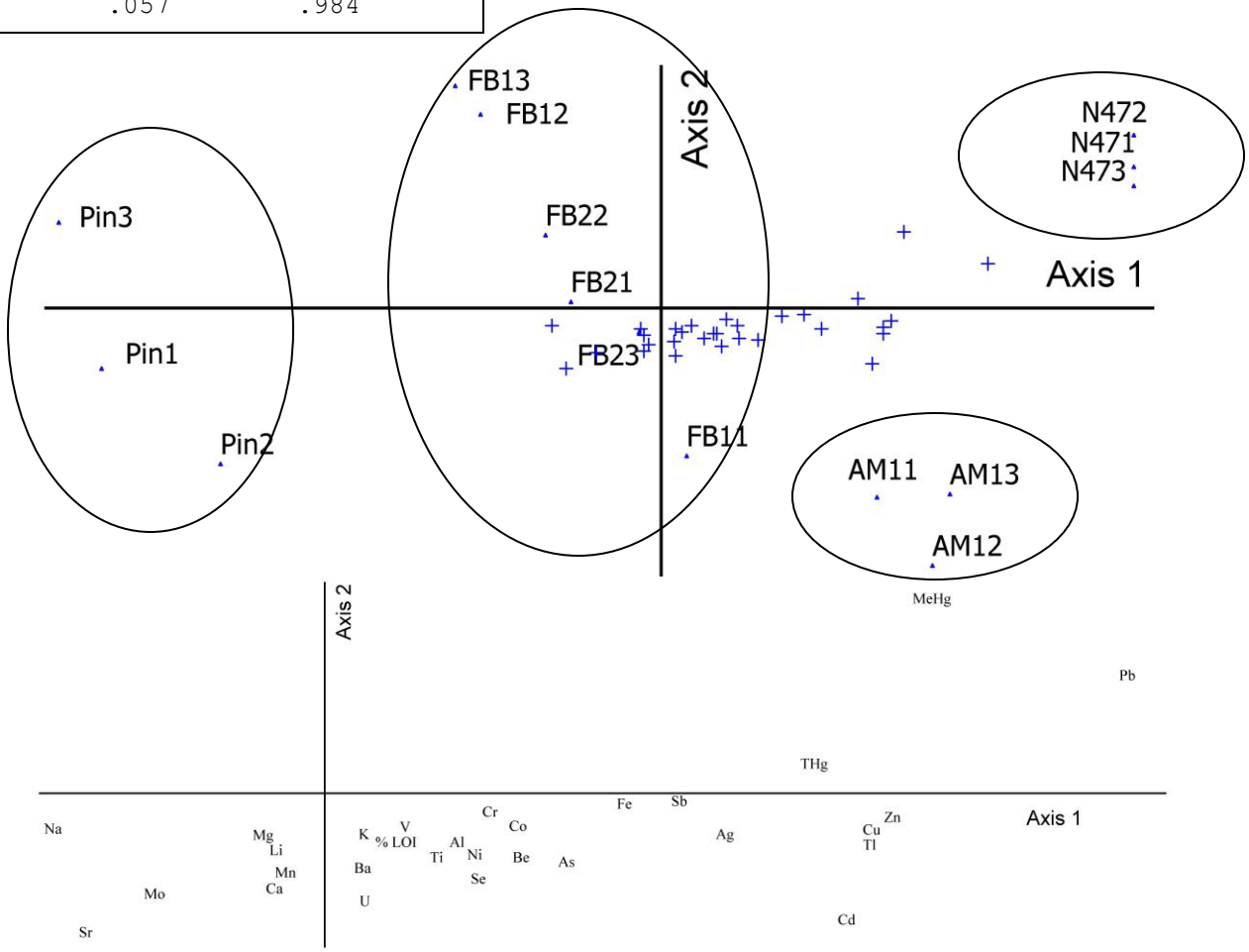


Figure 3. Ordination results for pore sediment chemistry. Axis 1 explained 92.8% of variance and Axis 2 explained 5.7%. Explanation of sample IDs: AM=Ambassador W1, N47=Newstate 47, FB1 & FB2=Farmington Bay Unit 1 & 2, Pin=Pintail. 1=August sample #1, 2=August sample #2, 3=September.

2. How do single element concentrations compare between surface water and pore water across all wetland sites? Between surface water and sediment? Between pore water and sediment?

The multivariate approach described in Section 1 (above) shows that the wetland ponds delineate in a similar manner for surface water, pore water, and sediment chemistry: PN is defined by elevated major elements, N47 is defined by elevated anthropogenic trace elements, and the other ponds fall somewhere in between (but are defined by elevated MeHg). However, in order to determine direct relationships between surface water, pore water, and sediment chemistries, the correlation of individual elements across these compartments must be examined.

To simplify element comparisons across compartments, chemical parameters were averaged within each compartment at each site. Sediment was collected at 5 sites; therefore, only those sites (AM, N47, FB1, FB2, and PN) were used for comparisons. Pearson correlations (R) and p-values were determined for element relationships across compartments. In order to make strict comparisons of data, only relationships with $R>0.7$ (or $R^2>0.49$) and $p<0.1$ were considered significant.

Element correlations show that surface water and pore water are most closely related, having the greatest number of elements (9) with significant relationships. The relationship between surface water and sediment is not as strong, nor is the relationship between pore water and sediment, since only 3 and 4 elements, respectively, show significant relationships. Thus the aqueous phases (surface water and pore water) seem to comprise one closely related system; whereas, the sediment appears to comprise a somewhat separate, but still related, system.

It is not surprising that the two aqueous compartments (pore water and surface water) are more closely aligned with each other than they are aligned with sediment. Aqueous compounds are considerably more mobile and able to diffuse and advect between pore water and surface water compartments. In addition to mobility differences, geochemical differences define aqueous relative to sediment compartments. Pore water is geochemically related to sediment via sediment:pore water interfacial contact. Surface reactions include surface complexation and other forms of sorption/desorption to/from sediment, as well as dissolution and precipitation to/from sediment. Elements in sediment and aqueous phases exist on opposite sides of these geochemical equilibria. As a result of both mobility and geochemical differences it is not surprising that the statistical relationship between sediment and pore water or surface water is weaker than that between pore water and surface water. The relationship between these compartments is described in further detail below.

2.1 Element comparisons between surface water and pore water

Figure 4 shows those elements/compounds with significant correlations between surface water and pore water. Of the nine elements with significant relationships, six are conservative major elements: Li, Na, Mg, K, Sr, Ba. The relationships for the major elements are strongly controlled

by elevated concentrations at PN (the outlier in the top six plots in Figure 4). However, even without PN data the relationships between major elements in surface water are fairly robust for all elements besides Ba. The remaining three elements/ions are non-conservative elements which are strongly affected by redox conditions: Se, Mn, and SO_4. The Se correlation is strongly influenced by the high concentrations at N47 (the outlier in the Se plot in Figure 4); without N47 data the Se relationship would likely not be significant. The relationship between Se and Mn in surface water and pore water is surprising given that they should be out-of-phase in diel cycles characterized by pH-driven sorption-desorption. However, their correspondence likely indicates that other geochemical equilibria dominate this relationship. All sites (except N47) contain a high concentration of sulfide in pore water; therefore the correspondence of SO_4 concentrations between oxidizing surface water and reducing pore water is unexpected. It is likely that this correspondence reflects a preponderance of SO_4 in surface water that is retained even in pore water where the SO_4 is transformed to sulfide.

A secondary method for relating surface water and pore water (besides element correlations) is to compare absolute element concentrations. This is useful because concentration gradients determine potential direction of element transport via diffusion. At all wetland sites, Mn and Ti concentrations are much greater in pore water than surface water. The reducing conditions found in pore water most likely inhibit sorption of the cations Mn and Ti to sediment (due to reductive dissolution of metal oxyhydroxide coatings) and result in elevated aqueous concentrations. The opposite is true for oxidizing surface water conditions.

Concentrations of the major elements Na, Ca, Mg, K, Li, Sr, and Ba, as well as Cu, are similar in surface water and pore water at all wetland sites except PN, where the elements are more concentrated in pore water, indicating that pore water (groundwater) feeds the surface water system at PN, although this is likely also true at the other sites. Concentrations of Cr, Pb, Ni, and V are similar in surface water and pore water at all wetland sites. Fe concentrations are similar in surface water and pore water at all sites besides N47, where Fe-reducing conditions have resulted in substantially elevated pore water Fe concentrations. At all wetland sites, concentrations of MeHg and the oxyanions Se, Sb, U, and As are lower in pore water than surface water (except for As at N47, where concentrations are similar in the two compartments).

Low concentrations of MeHg in pore water relative to surface water are surprising, since MeHg is produced in SO_4- and Fe-reducing conditions, which were observed in pore water. One possibility is that MeHg is forming insoluble complexes with sulfide or other elements and being removed from pore water. However, more work is needed to understand the complex relationships of MeHg with Fe and sulfides and other elements in pore water and surface water. The oxyanion concentrations are possibly lower in pore water relative to surface water because reducing pore water conditions (that are expected to be accompanied by reduced pH) promote anion sorption to sediment. Thus sorption/desorption may explain both elevated concentrations of cations Mn and Ti and low concentrations of anions Se, Sb, U, and As in reducing pore water relative to oxidizing surface water.

2.2 Element comparisons between surface water and sediment

Figure 5 shows that only three elements (Na, Pb, and Sb) were significantly correlated between surface water and sediment among the sites. This finding illustrates that surface water chemistry is more closely related to pore water chemistry than sediment chemistry (as described above).

2.3 Element comparisons between pore water and sediment

Figure 6 shows that only four elements (Na, Sr, V, and Pb) were significantly correlated between sediment and pore water among the sites. This may be surprising given that these two compartments are in direct contact with each other (and are expected to be in equilibrium). However, geochemical equilibrium does not necessarily mean that the two phases demonstrate corresponding chemical characteristics (as described above).

The correspondence of Na and Sr between the two compartments is driven by elevated concentrations at PN (outliers in top two plots in Figure 6), whereas the correspondence of Pb is driven by elevated concentrations at N47 (outlier in Pb plot in Figure 6). Excluding the outliers, only V is significantly correlated between pore water and sediment. This further illustrates the observation that pore water chemical characteristics are more closely related to surface water chemical characteristics than sediment chemical characteristics (as described above) despite the intimate geochemical linkage between pore water and sediment.

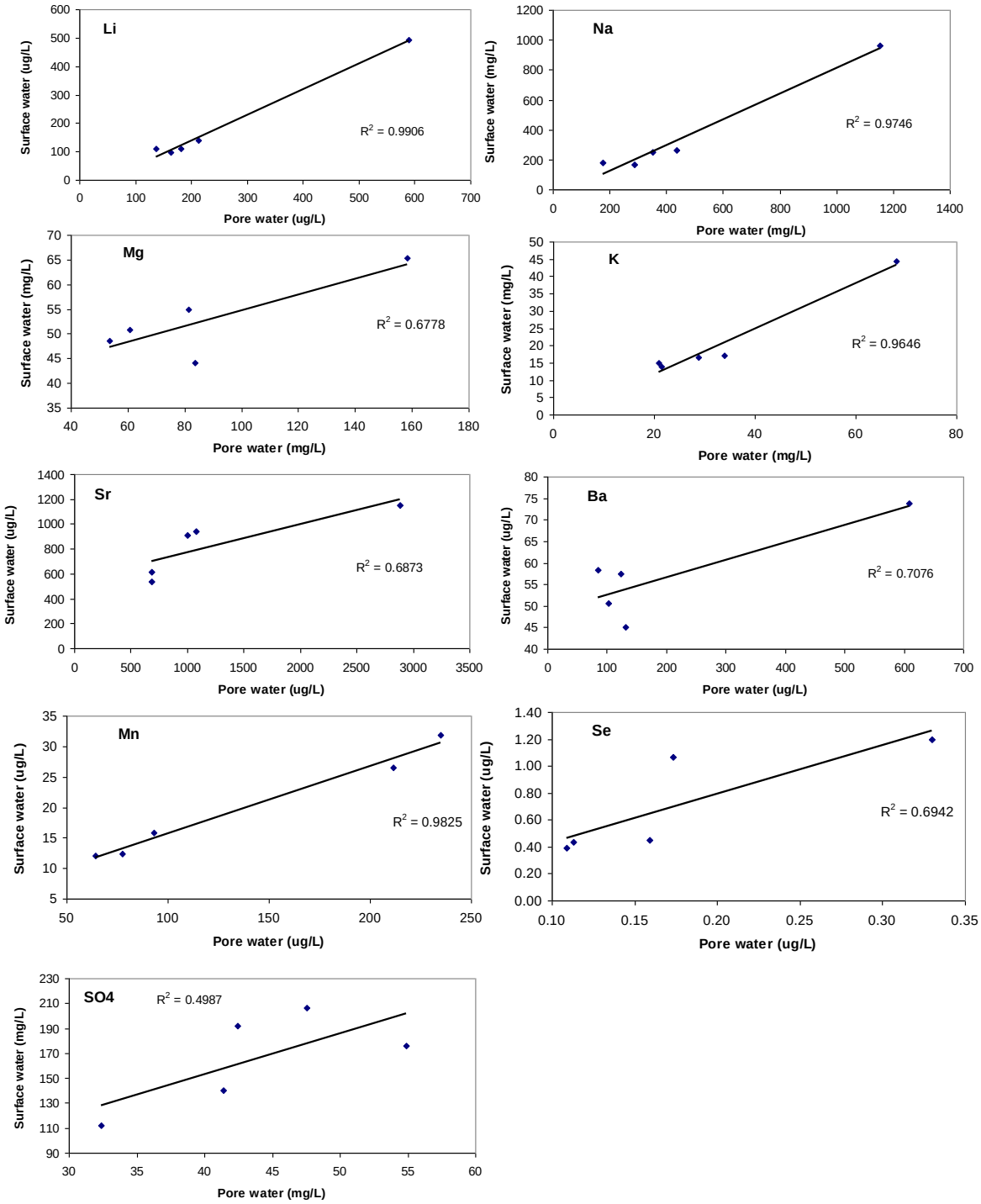


Figure 4. Elements with significant ($p<0.10$) relationships between concentrations in surface water and pore water. Each point represents the average surface water and pore water concentration from a single pond (AM, N47, FB1, FB2, and PN). Outliers in Li, Na, Mg, K, Sr, and Ba plots are data from PN, whereas outlier in Se plot are data from N47.

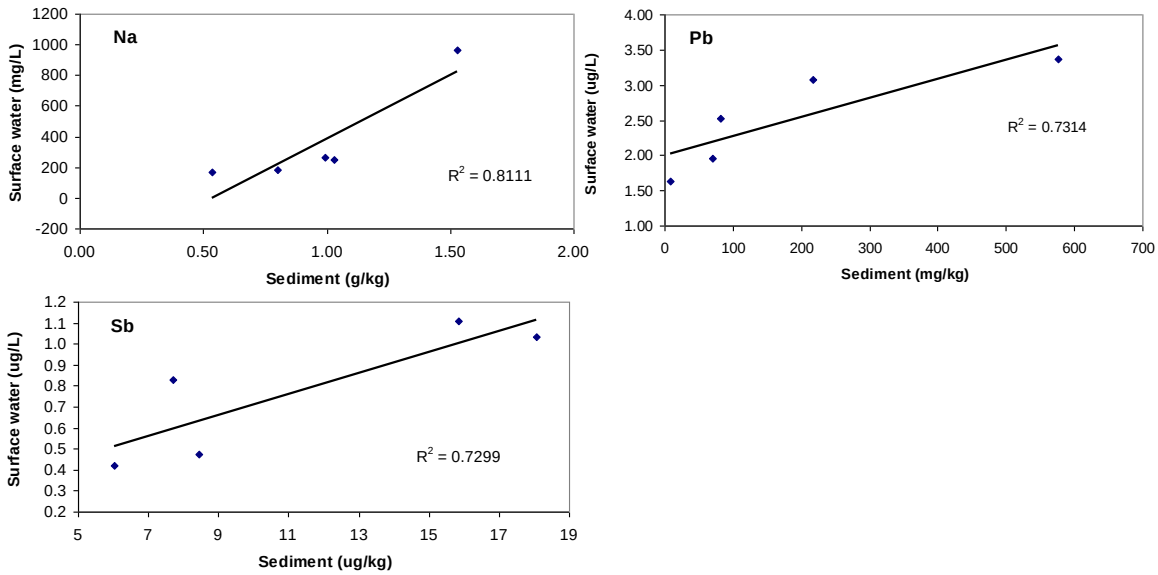


Figure 5. Elements with significant (p<0.10) relationships between concentrations in surface water and sediment. Each point represents the average surface water and sediment concentration from a single pond (AM, N47, FB1, FB2, and PN). Outliers in Na plots are data from PN, whereas outlier in Pb plot are data from N47.

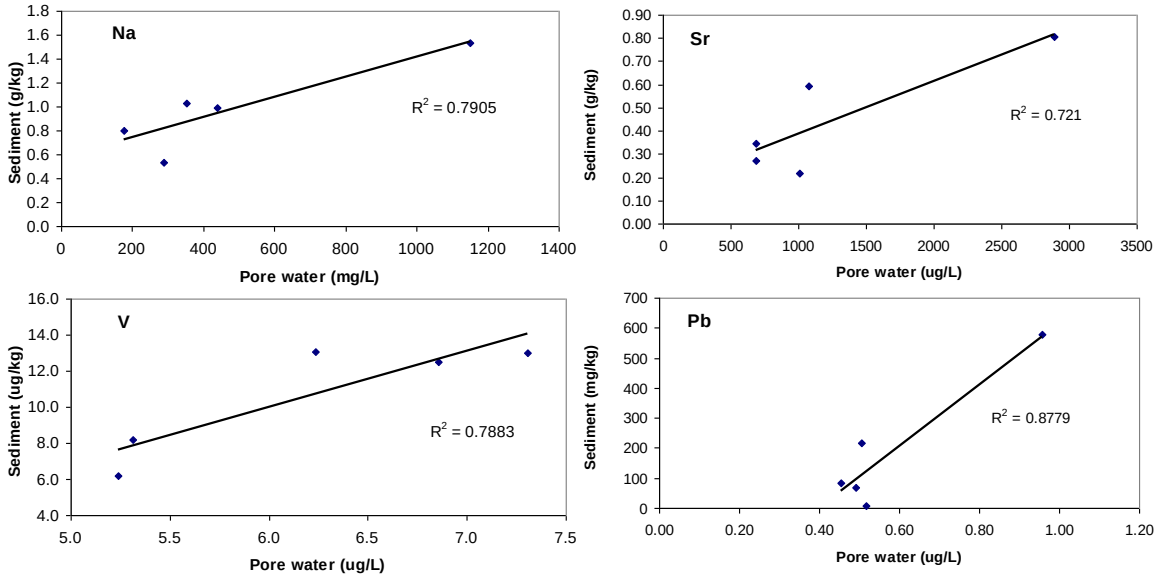


Figure 6. Elements with significant (p<0.10) relationships between concentrations in pore water and sediment. Each point represents the average pore water and sediment concentration from a single pond (AM, N47, FB1, FB2, and PN). Outliers in Na and Sr plots are data from PN, whereas outlier in Pb plot are data from N47.

3. Which elements co-vary in surface water across all sites? Pore water? Sediment?

Understanding which elements are positively or negatively correlated in surface water, pore water, or sediment is important for determining how different chemical parameters may affect one another. For example, a positive or negative relationship between sulfide, Cl, pH, Se, etc. and MeHg concentrations in sediment would help delineate potential factors responsible for mercury methylation. Pearson correlations (R) and p-values were determined for each element with all other elements within each compartment. All data from all sampling dates and locations were used in the correlations; thus large sample sizes for surface water (n=40), pore water (n=66), and sediment (n=15) help make the bivariate comparisons more robust. In order to make substantive comparisons, only relationships with $R>0.7$ (or $R^2>0.49$) and $p<0.01$ were considered significant.

3.1 Co-varying elements in surface water from all samples across all sites

Numerous elements co-vary in surface water. The positive correlations can be grouped as follows:

1) Those involving nutrients (Figure 7; NO_3, nitrite, HPO_4)
2) Those involving major elements (Figure 8; Na, Cl, K, Li, Sr, alkalinity)
3) Those involving oxyanions (Figure 9; U, Sb, As).

Significant ($p<0.01$) negative correlations exist, but none with $R>0.7$. Of the significant negative correlations, the most prominent trends are:

4) Between the major elements (particularly Na and Cl) and the oxyanions (V, As, Sb, and U). The negative correlation between these groups likely reflects the elevated concentrations of major elements (and relatively low concentrations of oxyanions) at PN, with the opposite being true at AM and N47 (as already demonstrated via ordination).
5) Between pH and a number of elements including nitrite, NO_3, HPO_4, Ca, Ni, Mn, Se, Sb, and U.

3.2 Co-varying elements in pore water from all samples across all sites

Similar to surface water, numerous elements co-vary in pore water. As observed in surface water, the major elements Na, Mg, K, Li, Sr, and Ba are all strongly positively correlated with one another (data not shown, but are similar to major elements in surface water shown in Figure 8). Furthermore, Cu is positively correlated to the major elements. Bivariate positive correlations including other trace elements are shown in Figure 10. As observed in surface water, pore water concentrations of Ti, Ni, and Se are all positively correlated. Furthermore, Ni is positively correlated with Mn and Ca, and Se is positively correlated with Fe and Pb. Al and V also show a strong positive correlation.

As was observed for surface water, significant ($p<0.01$) negative correlations exist but none with $R>0.7$. However, bivariate plots show that negative correlations are actually stronger than

indicated by Pearson correlations because the relationships are better described hyperbolic rather than linear functions (Figure 11). The hyperbolic relationship is likely rooted in geochemical equilibria, for example, that between Fe^{2+} and S^{2-} which are prevalent under reducing conditions characteristic of pore water, and which together form insoluble mackinawite (FeS). Precipitation of mackinawite removes both elements from solution, such that the occurrence of elevated levels of either Fe^{2+} or S^{2-} requires that either production of Fe^{2+} (iron reducing conditions) or S^{2-} (sulfate reducing conditions) predominate. This is why the ratio of Fe^{2+} to S^{2-} is used to identify iron-reducing versus sulfate reducing conditions.

Thus the elevated metal and metalloid concentrations that correspond to low sulfide concentrations in Figure 11 are likely driven by such equilibria with sulfides (e.g. precipitation of sulfide minerals such as MnS, PbS, As_2S_3, and SeS_2), although arsenide and selenide minerals also form under reducing conditions and may influence the observed relationships. In particular it is the pore water at site N47 that contains the low concentrations of sulfide and elevated concentrations of dissolved Fe, Mn, Pb, As, and Se that correspond to iron-reducing conditions.

3.3 Co-varying elements in sediment from all samples across all sites

A large number of elements co-vary in the sediment. Overall, more elements co-vary in sediment than in surface water or pore water. The major elements Ca, Sr, Ba show significant ($p<0.01$) positive correlations, Mg and Li co-vary, as do K and Ba, and Na and Sr. Of the trace elements, a closely associated group of co-varying elements includes THg, MeHg, Al, Be, Cr, Fe, Co, Cu, Zn, As, Ag, Cd, Sb, Tl, Pb, Ti, and V. Some of these relationships are shown in Figure 12. Notably, sediment Na and Sr correlate negatively with THg, MeHg, Cr, Fe, Co, Cu, Zn, As, Ag, Sb, Tl, Pb, Be. This negative correlation is due to high concentrations of Na and low concentrations of anthropogenic trace elements at PN, and vice versa at N47.

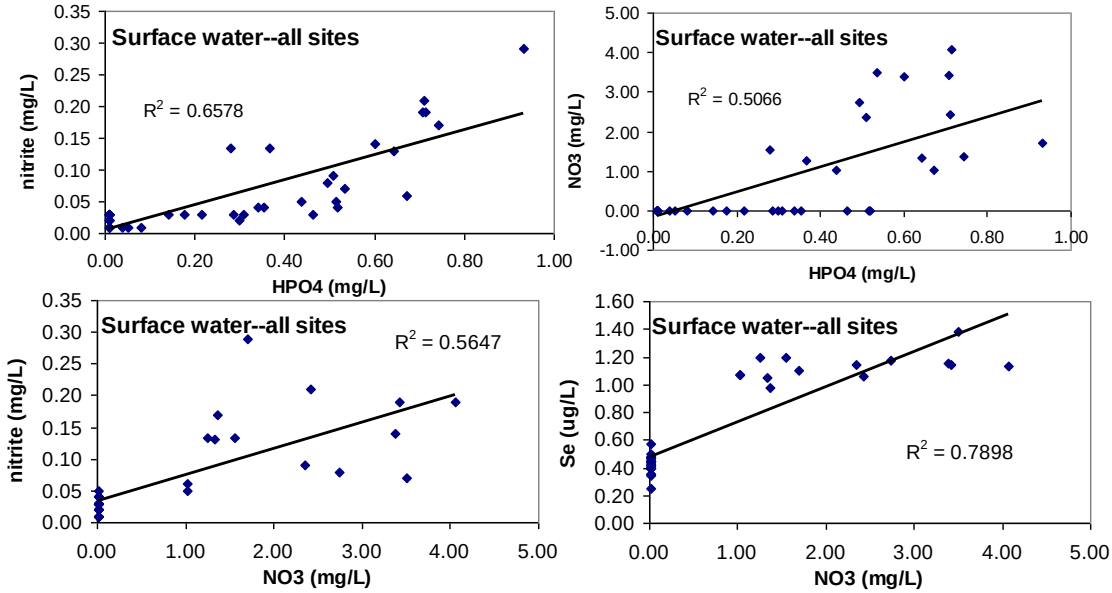


Figure 7. Significant ($p<0.01$) bivariate correlations involving nutrients (NO_3, HPO_4, and/or nitrite) and/or Se in surface water.

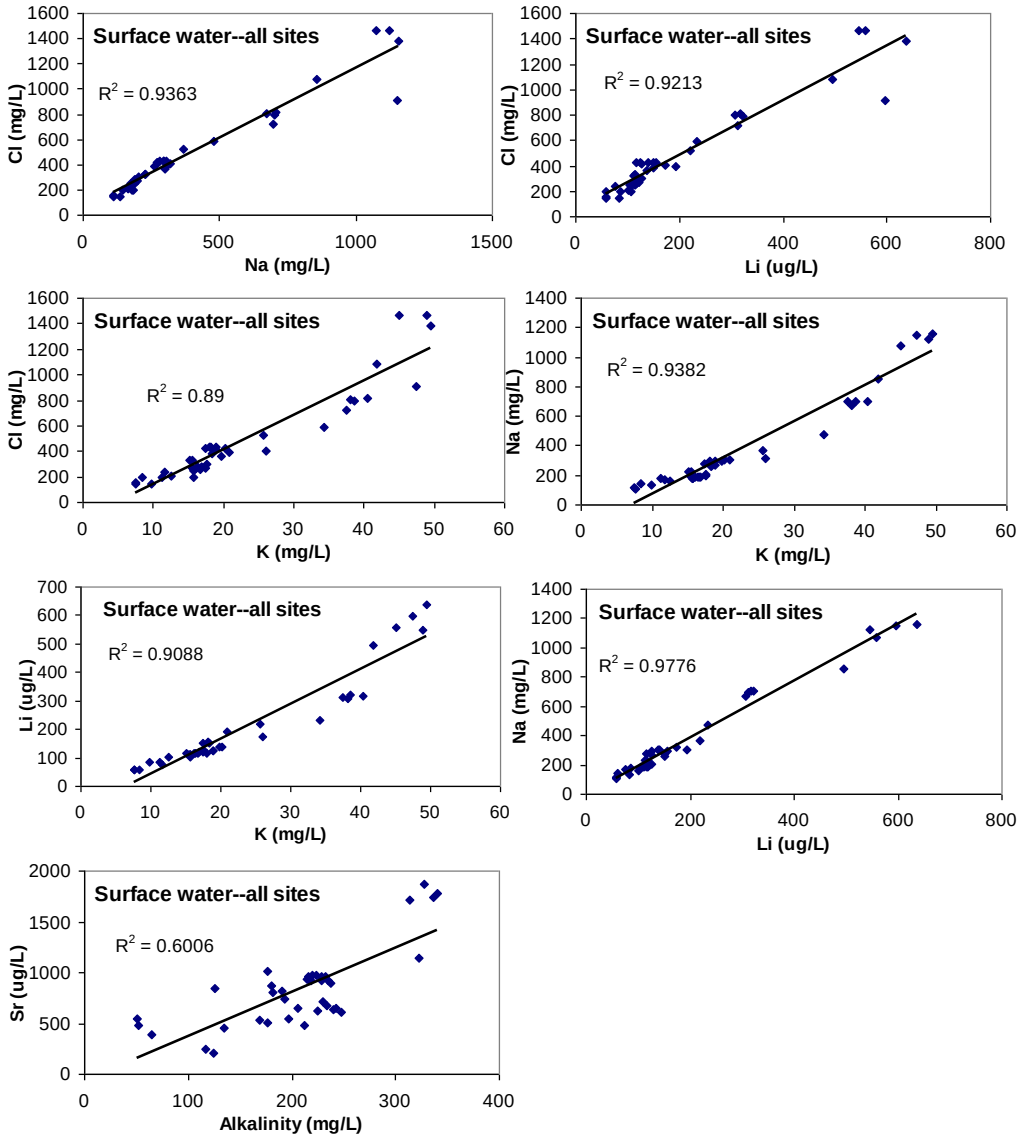


Figure 8. Significant ($p<0.01$) bivariate correlations involving major elements (Na, Cl, K, Li, Sr, and/or alkalinity) in surface water.

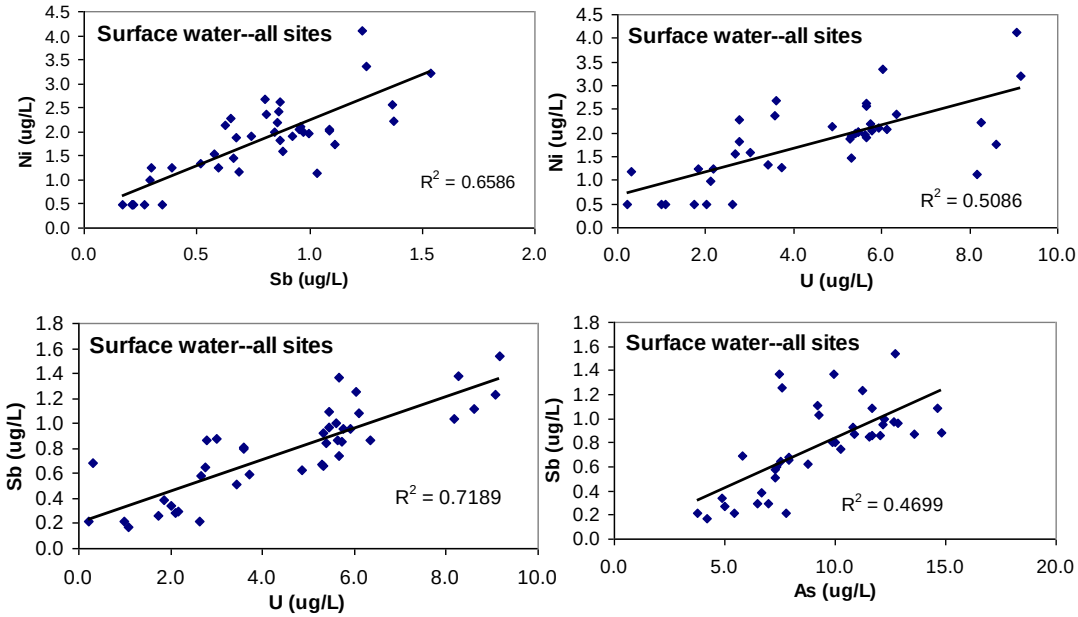


Figure 9. Significant ($p<0.01$) bivariate correlations involving oxyanions (Sb, U, and/or As) and/or Ni in surface water. Note correlation of Se (another oxyanion) and NO_3 shown in Figure 7.

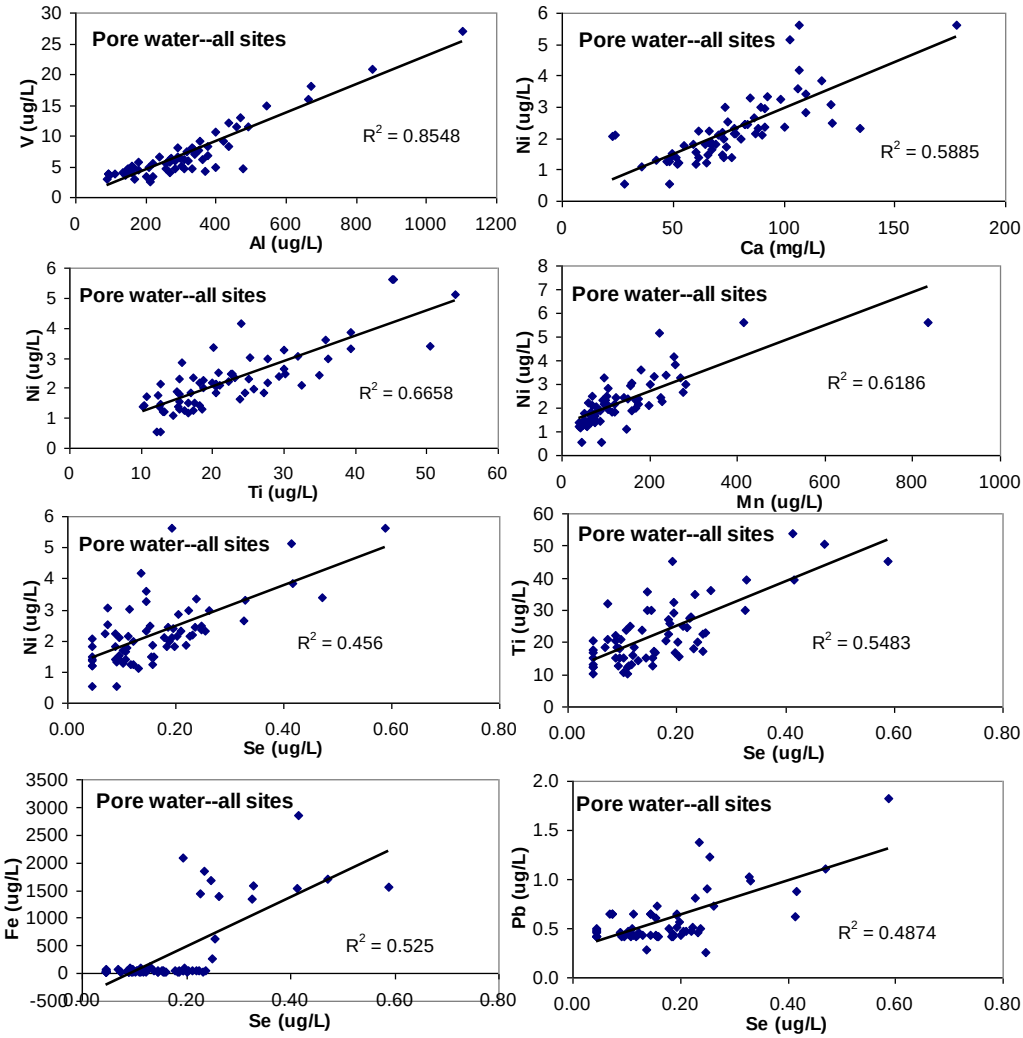


Figure 10. Significant ($p<0.01$) bivariate correlations involving trace elements (V, Al, Ni, Ti, Mn, Se, Fe, and/or Pb) in pore water.

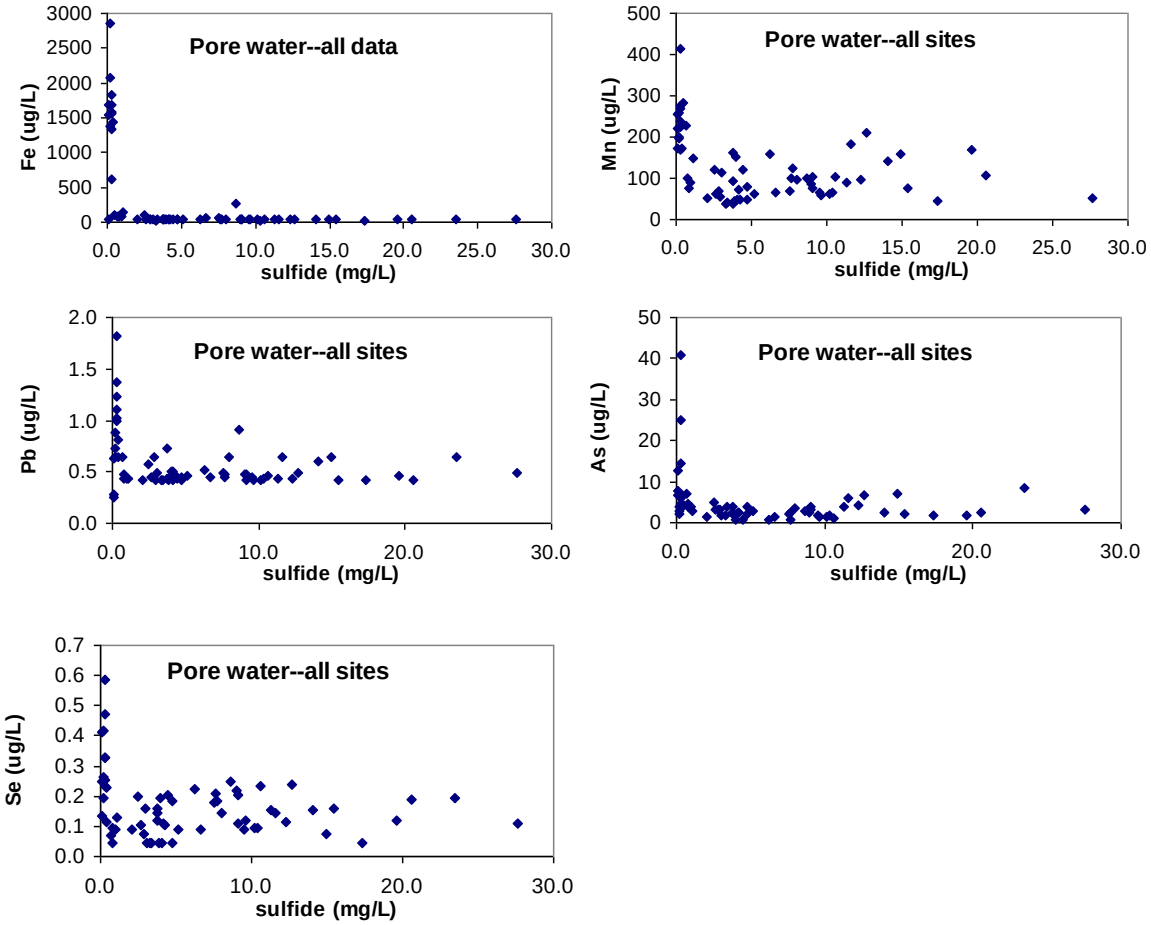


Figure 11. Elements with negative hyperbolic relationship relative to sulfide concentration in pore water. Pore water at N47 contains low concentrations of sulfide and elevated concentrations of Fe, Mn, Pb, As, and Se (as shown by the data plotted vertically near the y-axis of these plots).

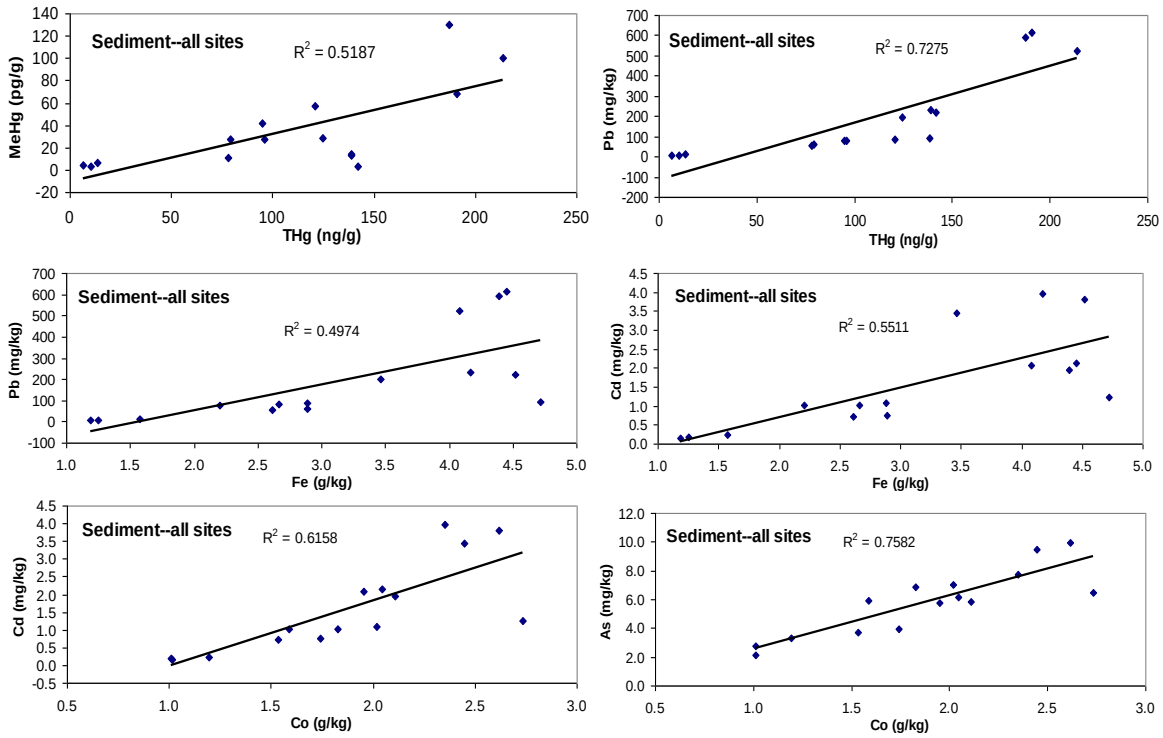


Figure 12. Significant ($p<0.01$) bivariate correlations involving selected trace elements in sediment.

4. Which chemical parameters show changes in concentration with time in surface water? Pore water?

Temporal changes were observed for some elements in surface water (both diel variations and seasonal changes) and pore water (seasonal changes only). Sediment samples were only collected during two consecutive months, and there is some spatial variability associated with these separate collections, so seasonal changes in sediment chemistry (if any occurred) cannot be distinguished with the current data. However, it seems unlikely that sediment chemistry would change during the summer and fall months when the ponds are still filled with water. Furthermore, little seasonal change occurred in pore water chemistry, as discussed below. Pond drainage likely affects sediment chemistry on an annual basis, but assessment of those changes is beyond the scope of this report.

4.1 Diel variations in surface water chemistry

Some elements/compounds show clear diel trends, despite samples being collected at only two times during each sampling date: early morning (AM) and afternoon (PM). Representative results are shown in Figure 13. The field parameters DO, pH, and conductivity were generally lower in the morning and higher in the afternoon at all sites; whereas, sites FB1 and FB2 displayed relatively weak diel variations in these parameters. Temperature was consistently higher during the afternoon at all sites. Similarly, the elements/compounds Se, Cu, V, Sb, and THg displayed elevated concentrations in afternoon relative to morning samples at some sites (consistent with pH-driven sorption-desorption to stationary iron oxyhydroxide phases). Diel variations in these elements/compounds were small, but still noticeable, compared to obvious diel swings in field parameters. Se and Cu had lower concentrations in morning relative to afternoon samples at most sites during July and August, but not during June. V had lower concentrations in morning samples at AM, N47, and PN, and Sb had lower concentrations in morning samples at N47 and FB2 during most months. THg concentrations were lower in morning relative to afternoon at PN during all months.

Mn, nitrite, HPO_4, F, and MeHg had higher concentrations in morning samples relative to afternoon samples at some sites. Mn concentrations were elevated in morning samples at all sites (except BR) during July and August (and this is also consistent with pH-driven sorption-desorption to stationary iron oxyhydroxide phases), but during June, the morning and afternoon samples had similar concentrations. Nitrite and HPO_4 were elevated in morning samples at AM and N47 (consistent with respiration-dominated sulfate- or iron-reducing chemistry during pre-dawn hours), and F was elevated in morning samples at AM, N47, FB1, and PN during most months. MeHg had higher concentrations in morning samples at FB2 and BR during all months (consistent with respiration-dominated sulfate- or iron-reducing chemistry during pre-dawn hours). However, measured sulfide concentrations were low in all samples at all sites, except for a sulfide spike measured at FB2 during July that was confirmed by a noticeable sulfide odor while collecting the sample. This suggests that the water column measurements may integrate a spectrum of aqueous chemistry conditions that overprint the iron- and sulfide-reducing microcosms (possibly at sediment/pore water interface).

4.2 Seasonal changes in surface water chemistry

Some elements showed a general increase in concentration throughout summer, while others displayed a general decrease in concentration. Representative plots showing element concentrations between June and September are shown in Figure 14. With some exceptions, the major elements, including Na, Cl, Mg, K, Li, SO_4, and alkalinity increased in concentration from June through September. These increases are attributed to summertime evaporation. Other seasonal increases were more site-specific: THg (Figure 13) and Sb concentrations increased throughout the summer at PN and FB2, respectively. A general summertime decrease in concentration was observed for dissolved organic carbon (DOC) at all sites excluding N47, for MeHg only at N47, and for Sb (Figure 13) at AM and N47.

4.3 Seasonal changes in pore water chemistry

In general, pore water chemistry showed very little change from June through September. Notable exceptions were the oxyanions As, V, and U, which showed decreasing concentrations throughout the summer at some sites (examples are shown in Figure 15).

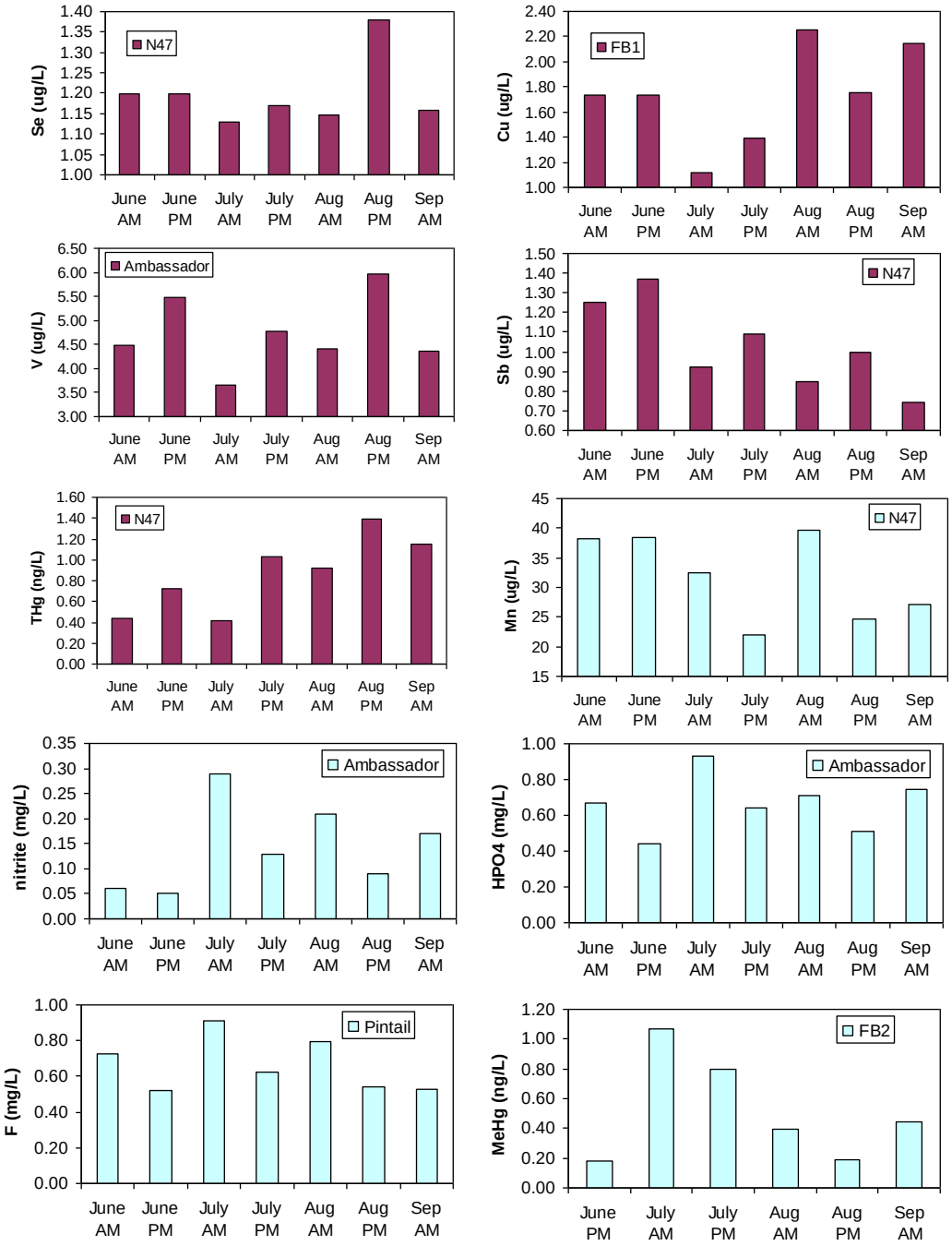


Figure 13. Diel varying elements in surface water. Se, Cu, V, Sb, and THg (top five charts with maroon bars) had elevated concentrations in PM samples, whereas Mn, nitrite, HPO_4, F, and MeHg (bottom five charts with blue bars) had elevated concentrations in AM samples.

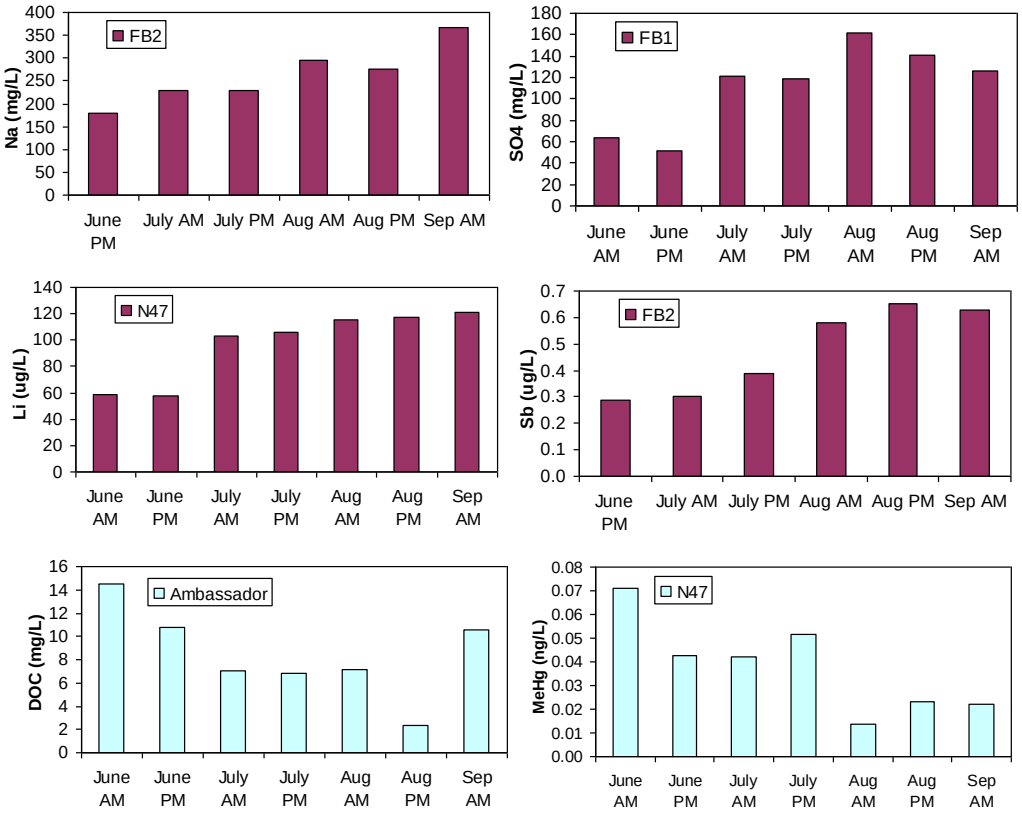


Figure 14. Surface water elements with a seasonal change in concentration. Na, SO_4, Li, and Sb (top four plots with maroon bars) showed a general increase in concentration throughout the summer months, whereas DOC and MeHg (bottom two plots with blue bars) showed a general decrease in concentration.

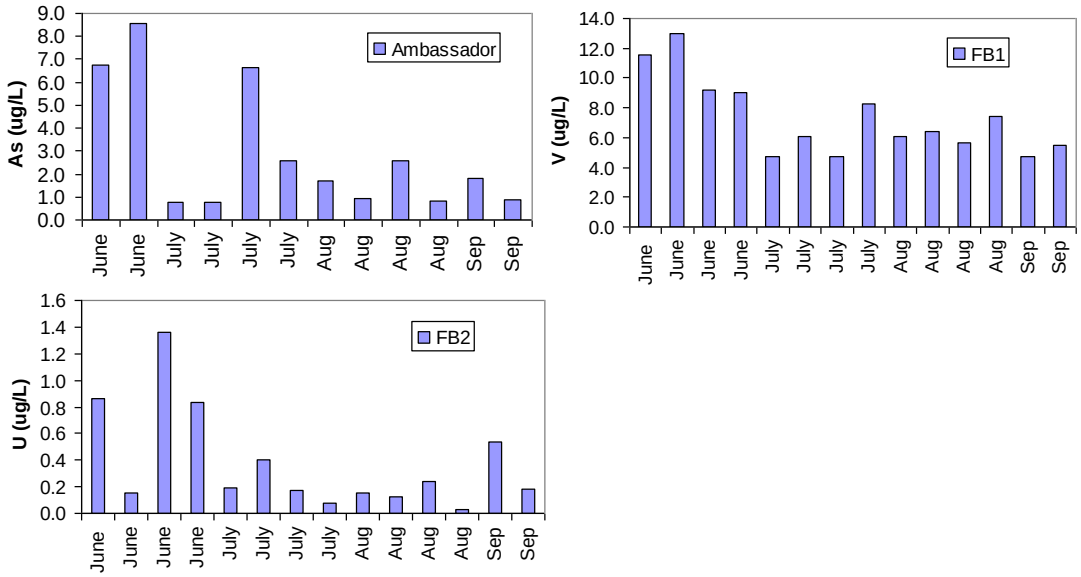
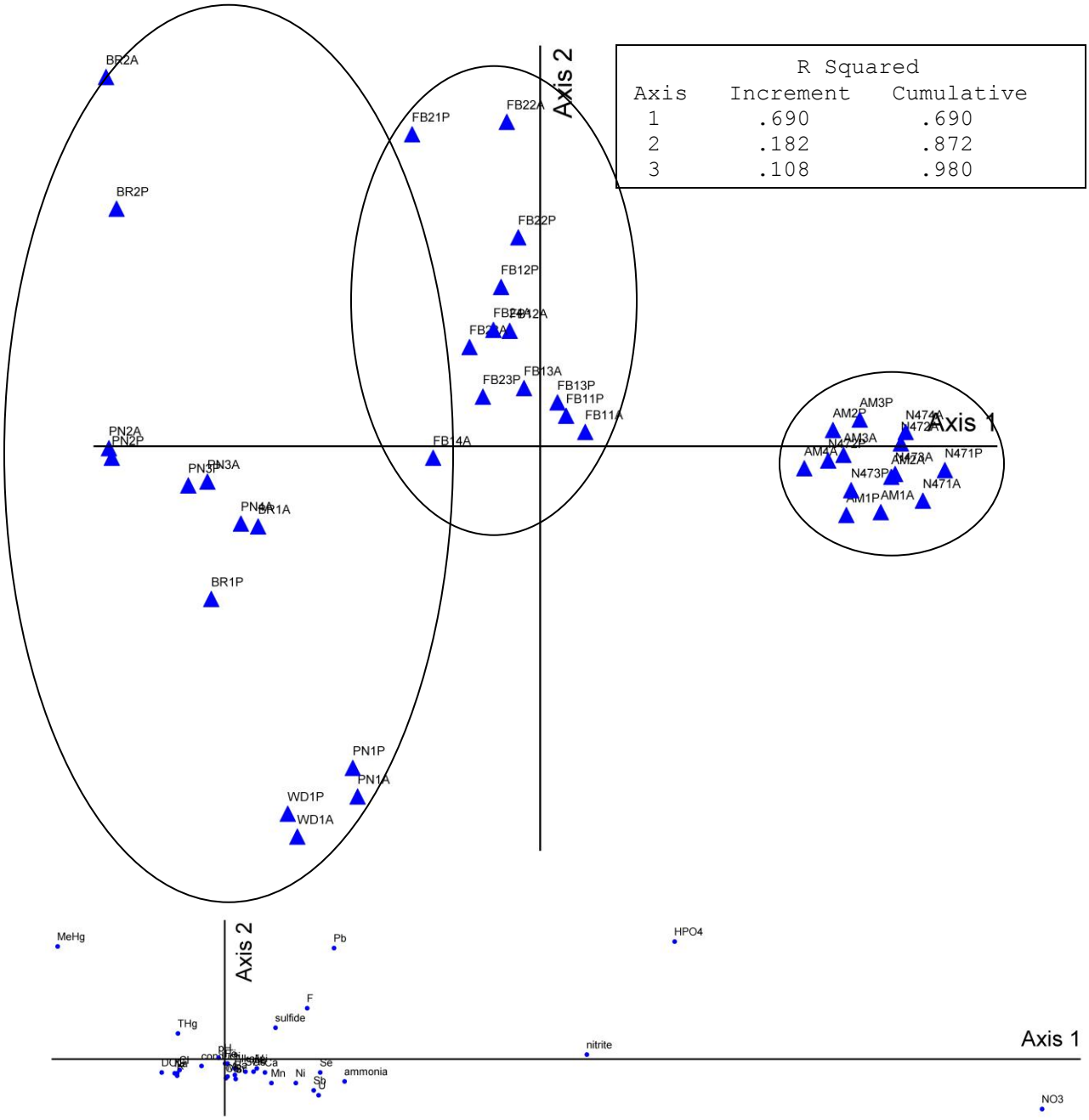
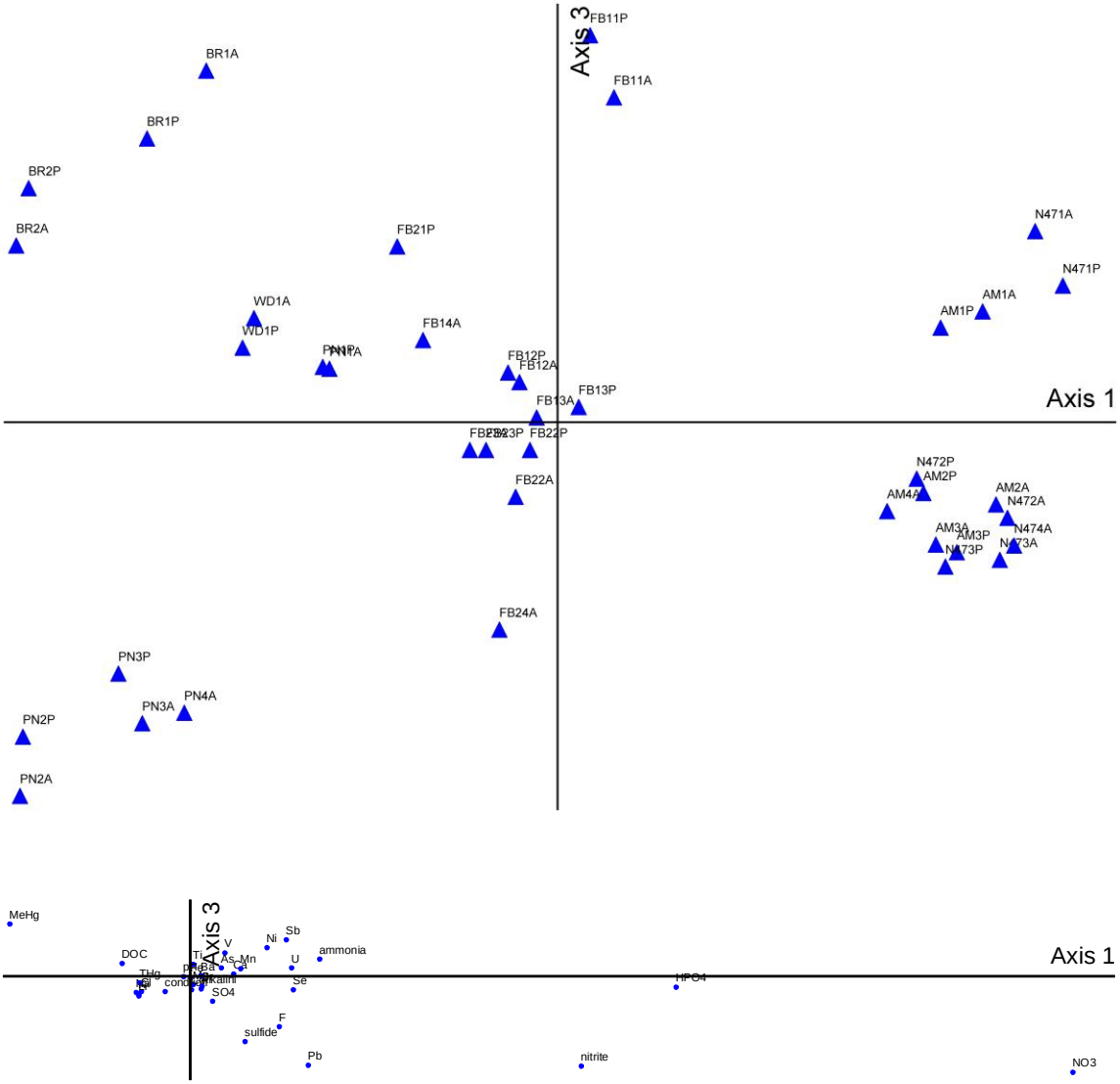


Figure 14. Pore water elements (the oxyanions As, V, and U) which had a seasonal decrease in concentration at some sites.

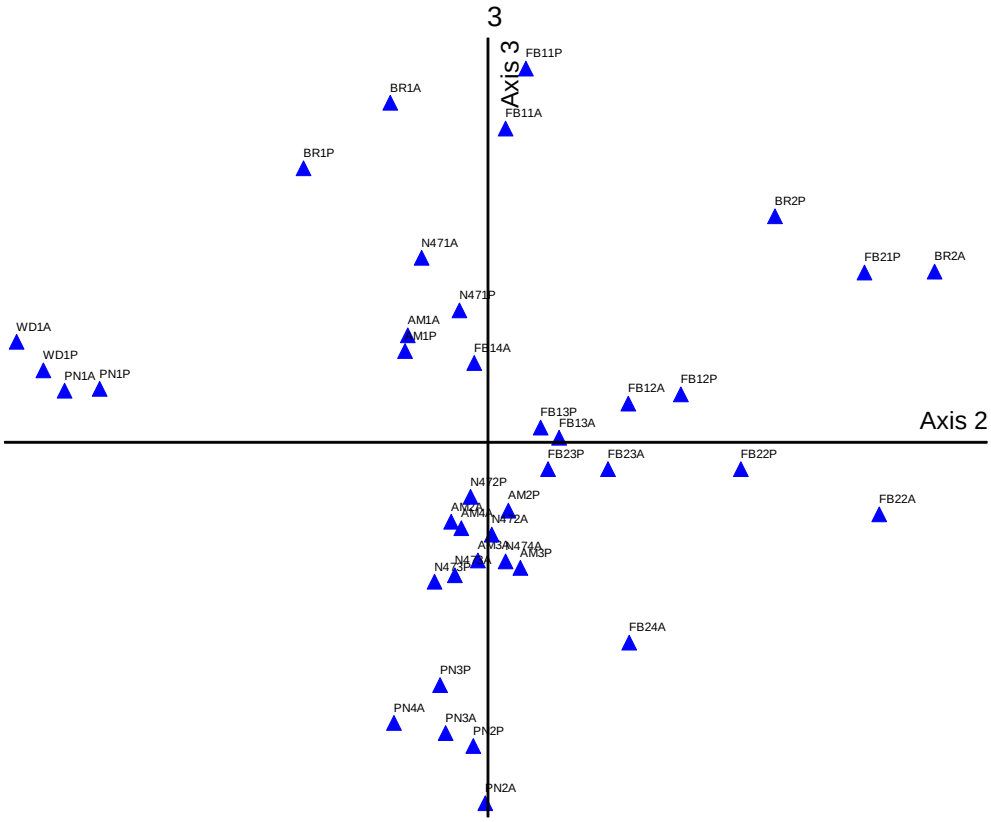
Appendix 1. Surface water ordination axes 1 and 2.

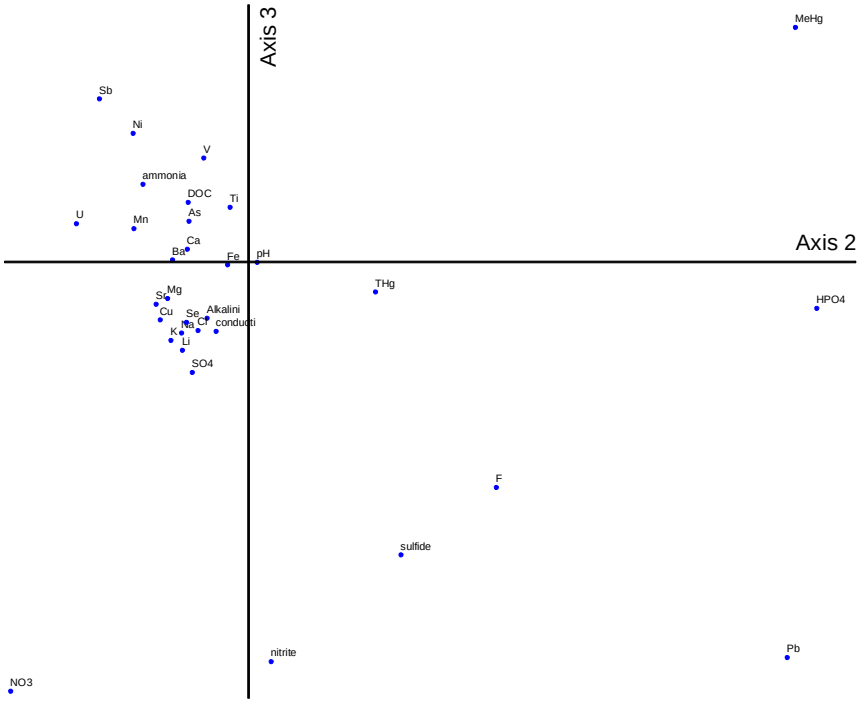


Appendix 1 continued. Surface water ordination axes 1 and 3.

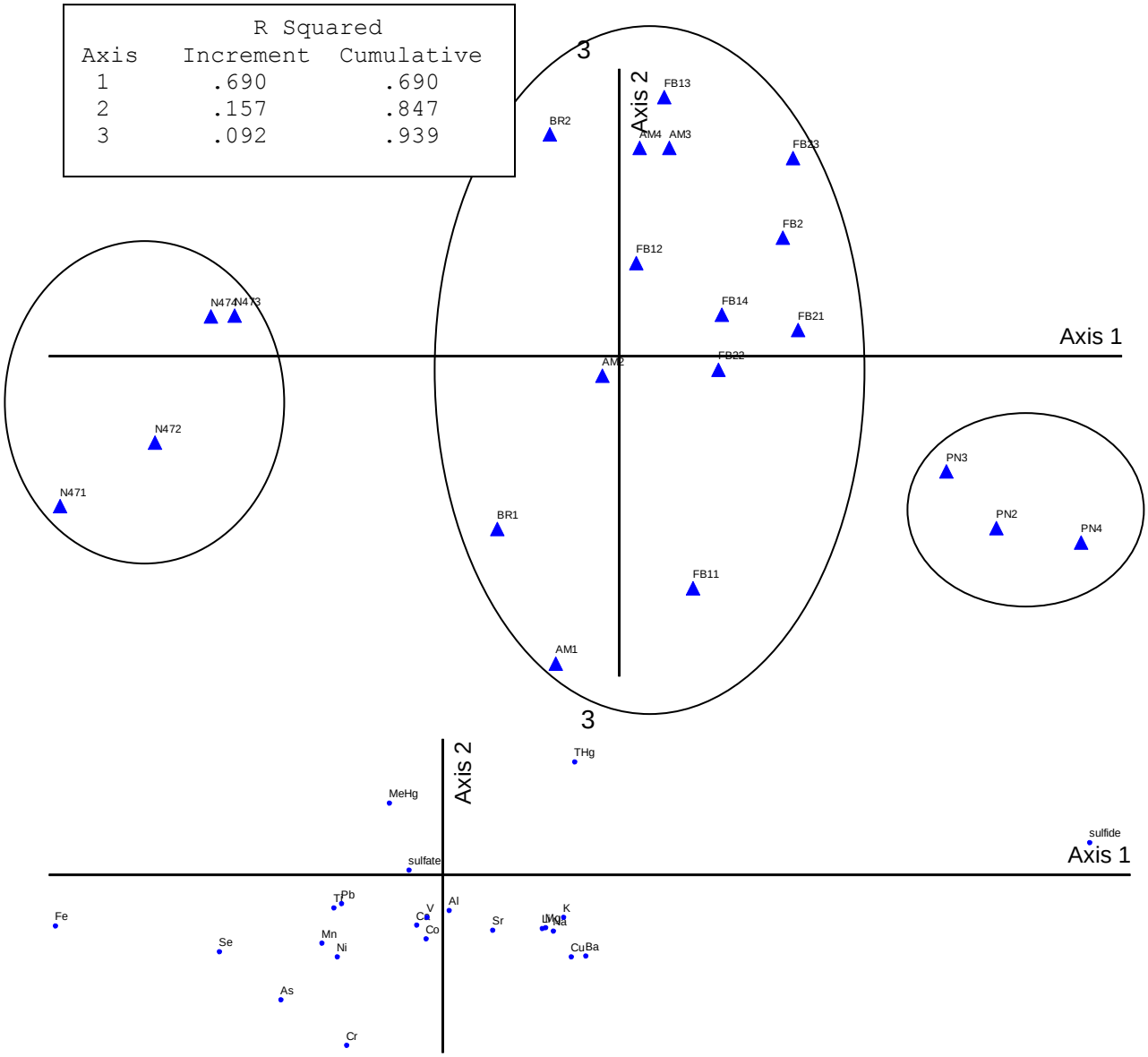


Appendix 1 continued. Surface water ordination axes 2 and 3.

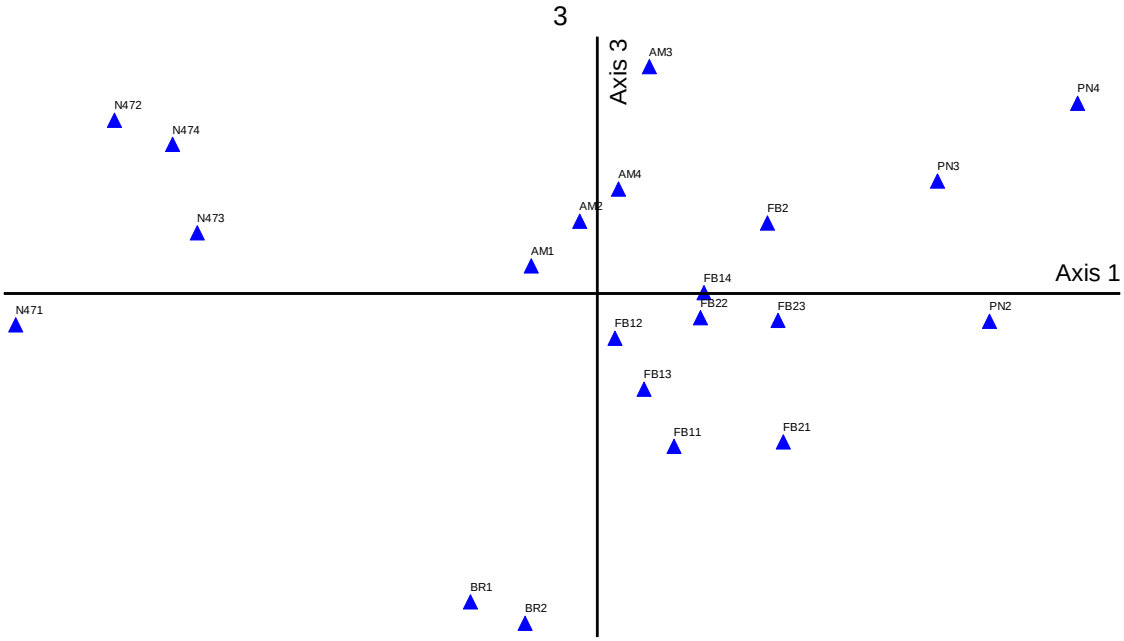


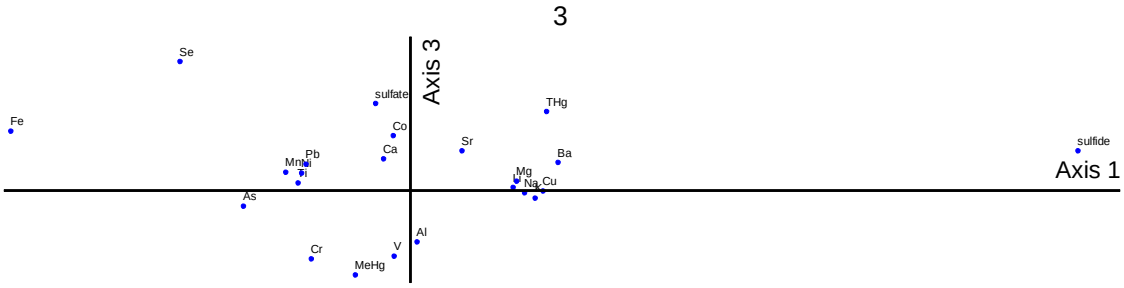
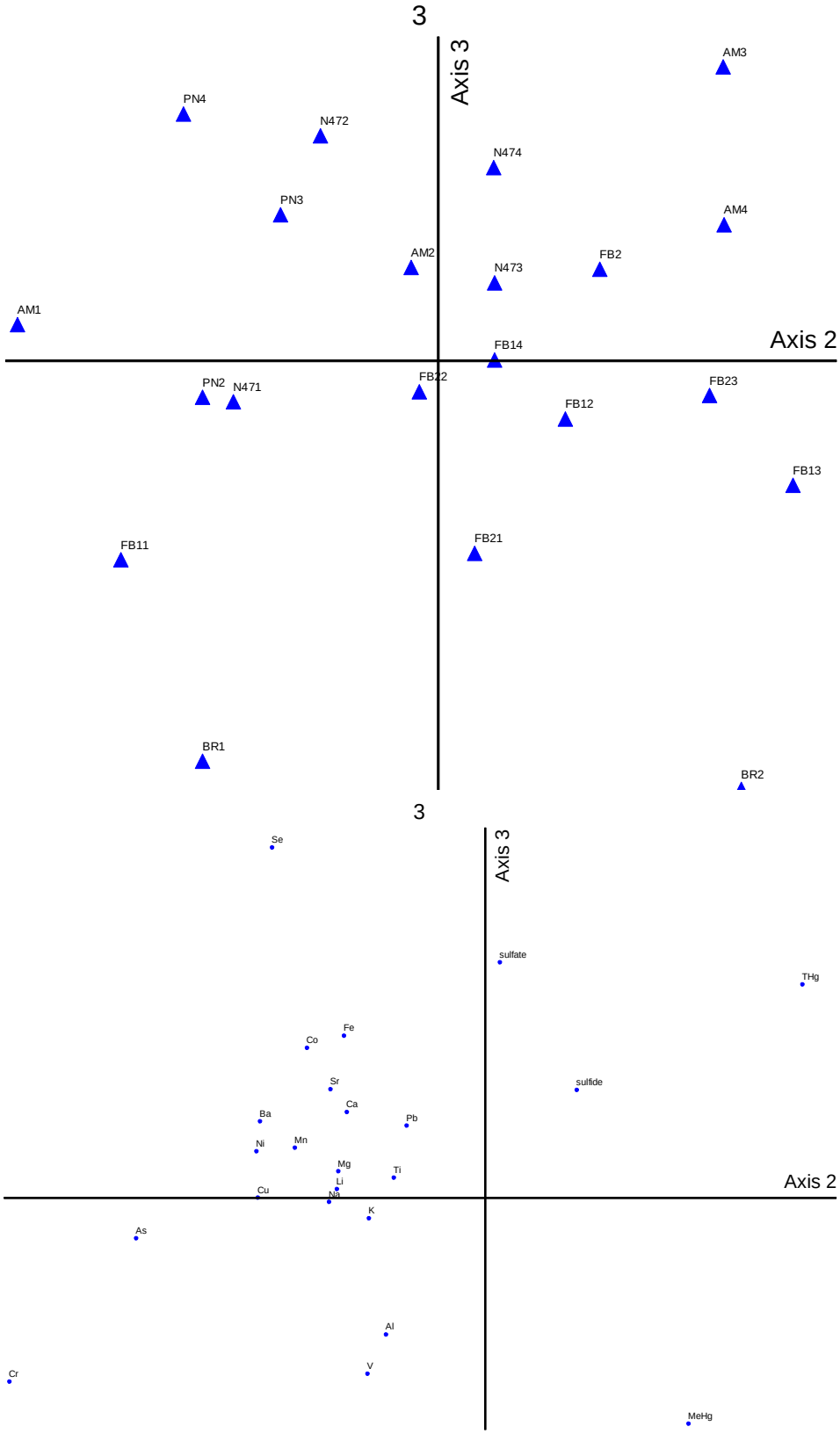


Appendix 2. Pore water ordination axes 1 and 2.



Appendix 2 continued. Pore water ordination axes 1 and 3.





Appendix 2 continued. Pore water ordination axes 2 and 3