Water Quality Assessment for the Earth Conservancy Phase II Wetland

January 2001 - November 2002

FINAL REPORT

21 May 2003

Prepared for the Earth Conservancy by the Wilkes University Wetland Technical Team

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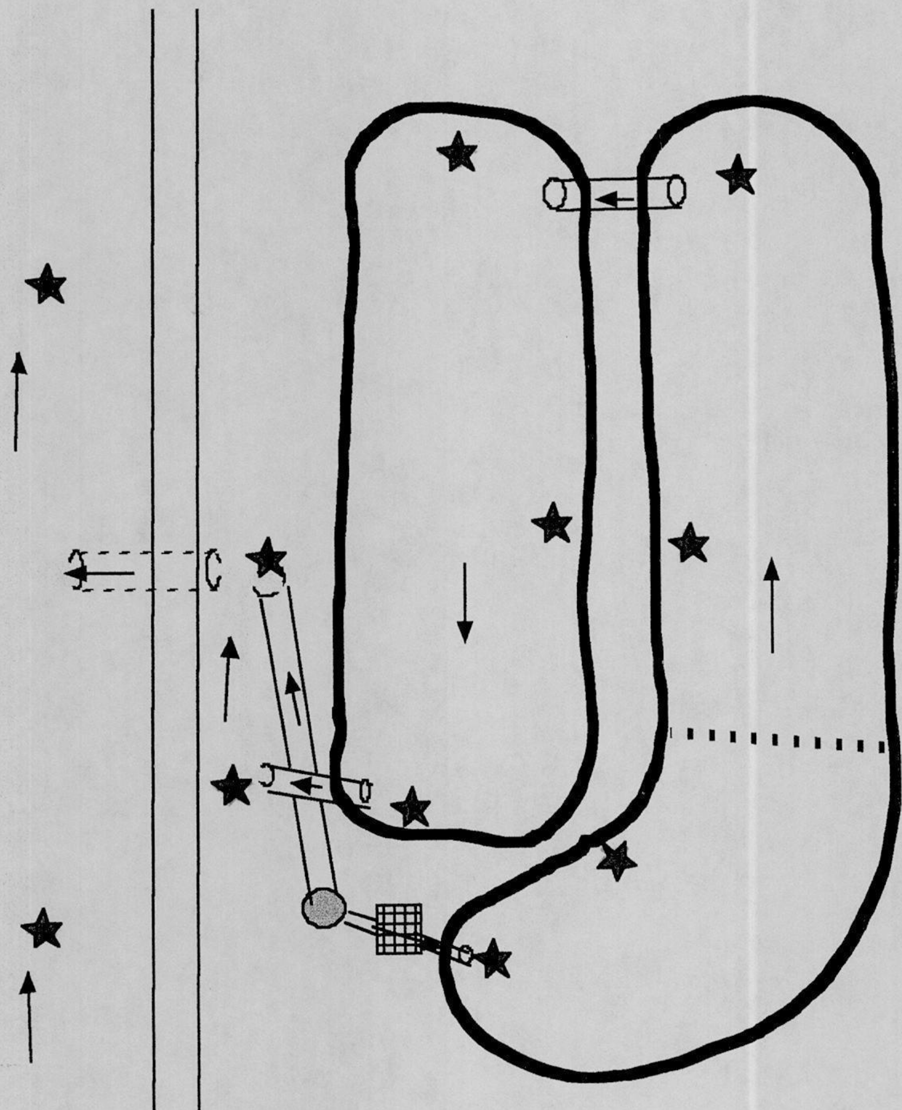

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I. SUMMARY

Water quality measurements were collected and analyzed from the Earth Conservancy's Phase II mine drainage treatment wetland system along Dundee Road in Hanover Township, Luzerne County, PA between January 2001 and November 2002. Key parameters were examined at nine locations in the wetland system, as well as at points above and below the wetland's discharge into Nanticoke Creek. This analysis was conducted by the Wilkes University Wetland Technical Team, supported by a grant provided by the Earth Conservancy.

Due to fluctuating hydrological conditions throughout the study, water was pumped into the wetland from the Askam Borehole during some months of the study, whereas no pumping as possible during other months because the elevation of the mine pool surface was below the pump intake. Those periods of inactivity occurred during the midsummer and fall of both years. Monthly water quality samples were collected as planned when the wetland flowed. Samples were taken only from the creek when no pumping occurred.

The analysis revealed that the minewater discharging from the borehole, and hence flowing through the wetland, was similar in composition to that found during an earlier assessment conducted between 1999 and 2000. The water had relatively high levels of alkalinity, leading to pH levels that averaged 6.3. The water had high levels of sulfate (average = 649 mg/L), iron (average = 35 mg/L), and specific conductance (average = 1156 μmho/cm).

Analyses of iron concentrations revealed that the wetland continued to successfully remove iron from the mine water that it received. Iron concentrations declined markedly from readings of 12-46 mg/L at the Askam Borehole to levels that were consistently under 1.6 mg/L at the system's outlet, and under 0.4 mg/L for eight of the months. Iron removal efficiency consistently exceeded 96%, and occasionally exceeded 99%. The system removed an average of 250 lbs iron per day, though the numbers varied depending on original loading levels.

As noted in previous years, the wetland slightly reduced sulfate and conductivity levels. No observable changes to alkalinity, acidity, or pH levels were noted.

Some accretion of iron hydroxides were noted in the system, especially in the upper cell. The wetlands appear capable of accepting more iron for at least two more years.

Despite the success of the Phase II wetland, Nanticoke Creek continued to be impacted by iron discharging from the Dundee Outfall because the Phase II system treats only a portion of the flow. To be sure, downstream iron levels were lower in 2002 than in previous years, suggesting that the wetland is indeed improving water quality in Nanticoke Creek.

While the Phase II wetland is functioning as designed, additional measures must be taken at the watershed level to completely address the AMD problem within the Nanticoke Creek drainage basin. Those solutions will require reconfiguration of the upstream reaches of the creeks to prevent their infiltration into the mine pool, as well as construction of additional wetlands below the outfall.

II. INTRODUCTION

Beginning in 1994, the Earth Conservancy (EC) of Ashley, PA has been involved in a program of remediating abandoned mine drainage (AMD) in the Wyoming Valley of northeastern Pennsylvania through the use of constructed wetlands. To date, the EC has been involved in two AMD-remediation wetland initiatives. The first, located along Espy Run in northwestern Hanover Township, involved the construction of a system comprised of two parallel cells initially sized at 0.26 acres each that treated water discharging from a seep alongside the creek. Construction of that wetland complex was completed in summer 1996. Technical assistance, in the form of initial site screening and site selection, design, site-specific environmental assessment, permitting, design, and monitoring of that system was provided by the Wilkes University Wetland Technical Team (WTT). Funding to underwrite costs associated with the creation of that wetland was provided though a grant from the Environmental Protection Agency to the EC. The performance of that wetland has been assessed by the WTT through November 2002. A report summarizing the findings of that assessment was provided to the EC in December 2002 (Klemow 2002a).

Beginning in 1996, the WTT and EC agreed to investigate the feasibility of creating a second wetland to follow up on the success of the Espy Run system. After a series of discussions between the EC and WTT concerning alternative sites, both parties agreed to locate the wetland near the Askam Borehole along Dundee Road, ca. 1 km southeast of the Espy Run site (Figure 1). The Askam Borehole was constructed by the Pennsylvania Department of Environmental Resources in 1974 as a means of relieving flooding caused by the inundation of the Truesdale mine pool two years earlier. The borehole consists of a vertical metal pipe ca. 35' deep that feeds a horizontal pipe that runs approximately 100' to the northwest. The end of that pipe is known as the Dundee Outfall and discharges fresh minewater into a culvert that passes under Dundee Road. Flow from that culvert enters Nanticoke Creek and usually provides most of the hydrology for that creek. Detailed studies by the WTT between 1993 and 2002 show that water quality within the creek is severely impacted by iron accumulation downstream of the outfall (Klemow 2002b). Though some improvement in water quality does occur downstream of the discharge, water emptying into the Susquehanna River, 9000' from the outfall, is still significantly impacted by AMD. That degraded water presumably impairs water quality within the river, especially during periods of high creekflow.

In order to streamline the permitting process, the EC and WTT agreed to locate the wetland east of Dundee Road, away from the creek corridor. That site consisted of sloping deciduous woodland, though the westernmost 100' was severely impacted by past disturbance. Detailed assessments of environmental conditions (especially existing wetlands) and substrate features were carried out in 1997. Concurrently, the WTT and EC examined the feasibility of incorporating a "Maxistripper" aeration device developed by Hazleton Environmental into the design.

A final design for the wetland system was developed by the WTT and approved by the EC in May 1998. That system incorporated five main design elements (Figure 2). The first was a pair of pumps, rated at 600 GPM, to lift water from the borehole. The second was the Maxistripper unit housed in a specially constructed shed to receive water pumped from the borehole. The third was an detention basin covering 0.69 acres that was able to hold 900,000 gallons, with a mean detention time of 30 hours. The fourth was an upper wetland cell sized at 0.71 acres to receive flow from the basin and effect initial removal of iron. The fifth was a lower wetland cell sized at 0.8 acres to receive water from the upper cell, provide final polishing, and carry it to an outlet pipe. The design called for cleaned water discharging from the outlet pipe to join the flow of the fresh minewater discharging from the outfall, and thus enter Nanticoke Creek.

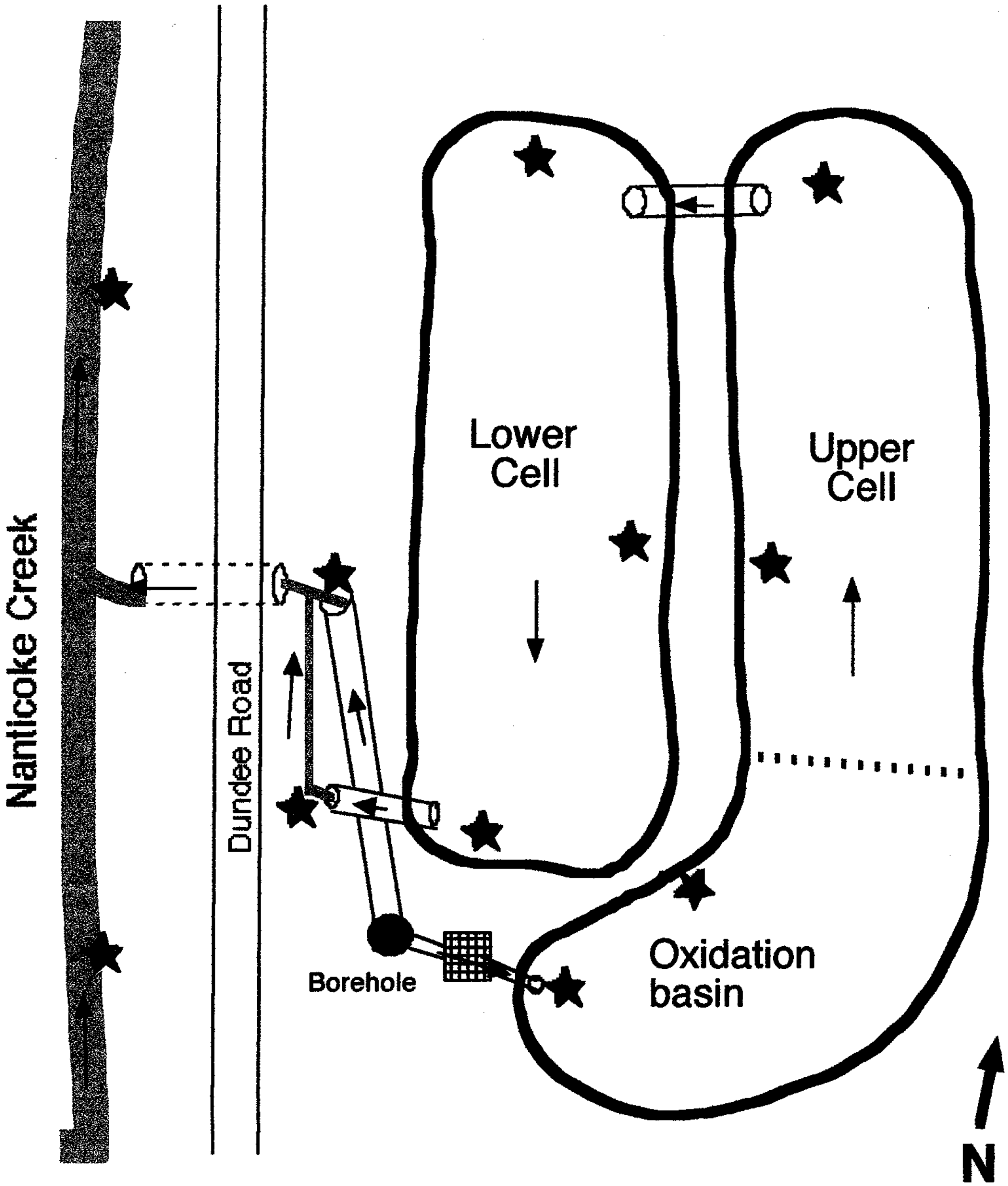
Previous determinations revealed that the Askam Borehole typically flows at a rate of 1000 - 8000 GPM. Limitations in pumping capacity, aeration capacity by the Maxistripper, and available land for

Figure 1 - Location of the Earth Conservancy Phase I Wetland
Nanticoke Creek, Hanover Township, Luzerne County, PA
Data from the USGS 7.5' Topographic Series, Wilkes-Barre West Quadrangle

Figure 2. Sampling Locations for Earth Conservancy Phase II Wetland

Dundee Road, Hanover Township, Luzerne County, PA

Stars denote sampling locations, arrows denote flow



wetland construction restricted the amount of water treated by the system as designed to 600 GPM. Thus, even under optimum conditions, the wetland treats only about half the minewater from the Dundee Outfall.

Construction of the Phase II system began in fall 1997. Final grading and planting was completed in November 1998. Operation began in late April 1999.

The WTT has been conducting an assessment of several key water quality parameters (including temperature, pH, conductivity, dissolved oxygen, iron, sulfate, alkalinity, and acidity) since the wetland was created. This report focuses on an analysis conducted by the WTT, funded by the EC, to monitor water quality for the period between January 2001 and November 2002. An interim report summarizing the wetland's performance for the 2001 calendar year was submitted to the EC on 5 June 2002. A second interim report, providing the findings for the assessment conducted between January and June 2002 was submitted on 19 August 2002. This final report covers the entire two-year period ending in November 2002.

III. METHODS

This assessment involved several components. Staff from the Wilkes University Water Quality Laboratory (WWQL) visited the wetland complex each month. Samples were taken at established locations throughout the wetland, as well as locations along Nanticoke Creek above and below the wetland's discharge. Some of the parameters were measured on site by field instruments. Other parameters were determined using equipment located in the WWQL via analysis of water samples that were transported to that facility. Data were collected by technical staff of the WWQL and subject to an initial quality assurance examination. Approved values were reported to the Project Principal Investigator who conducted a second quality assurance examination and added them to a master database. The data were then incorporated into figures that are included in this report.

A. Field Work

Water samples were collected at eleven different locations as depicted in Figure 2. Nine of the sites were located in the wetland complex east of Dundee Road. They included the outlet pipe from the Parshall flume (that received flow from the Maxistripper aeration unit), the detention basin, a point midway through the upper wetland cell, the outlet to the upper cell, the inlet, midpoint, and outlet to the lower wetland cell, the outflow from the lower cell, and the discharge from the Dundee Outfall (which carries overflow from the Askam Borehole). Two additional sites were located within the main stem of Nanticoke Creek, west of Dundee Road. One site was located under the PA 29 overpass, upstream of the outfall discharge into the creek, while the second site was located ca. 100' downstream of the outfall discharge.

Samples were taken whenever free water was present in the wetland or stream. Samples were not taken when the wetland was dry due to the cessation of pumping from the borehole.

1. Field sampling for chemical parameters

Water samples were taken using a plastic sampling cup that was rinsed with distilled water and then rinsed four times with water from the location that was to be sampled. The sample itself was taken from the free water in the wetland or stream, with care taken not to include sediment.

a. Determination of pH

Samples were measured in the field by a Fisher Scientific Accumet Portable AP 10 pH meter, standardized using pH buffers of 4.0, 7.0, and 10.0.

b. Determination of dissolved oxygen

Samples were measured in the field by a YSI Model 57 oxygen meter. The meter was calibrated at each site prior to measurement using the calibration functions of the machine. For this measurement, the probe was inserted into a sample cup immediately after the sample was withdrawn, and the measurement read directly off the meter.

c. Determination of temperature

Samples were measured in the field by the same YSI Model 57 oxygen meter used for the determination of dissolved oxygen. Temperature in °C was read from the scale after calibration, based on the same sample collected for the determination of dissolved oxygen.

d. Determination of specific conductance

Samples were measured in the field by a Cole Parmer Model 1500 conductivity meter standardized using a 1340 μmho/cm standard. For this measurement, the probe was inserted into a sample cup immediately after the sample was taken, and the measurement read directly off the meter.

2. Data recording

In all cases, readings taken from the sampling equipment were handwritten into a comprehensive dataform developed for this project. Separate dataforms were used for each sampling session.

3. Sampling for laboratory analysis

After the field measurements were taken, additional samples were collected for laboratory analysis. Two of the samples were placed into 20 ml scintillation vials for subsequent iron analysis. Of those, one sample (for total iron) was poured directly into the first vial. Water for the assessment of dissolved iron was passed through a 0.2 μm filter before being directed into the second vial. Five drops of concentrated hydrochloric acid were placed into each vial prior to sealing. Next, an 18 oz. Whirl-pak bag was filled with water for subsequent analysis of sulfate, alkalinity, and acidity in the lab. The two scintillation vials and the Whirl-pak bag were labeled with an indelible marker and placed into a container filled with ice.

Upon return to the Wilkes Water Quality Laboratory, samples were placed within the refrigerator located there and marked to designate the date and origin of the samples.

B. Laboratory work

In the lab, samples of water were subsequently withdrawn from the Whirl-pak bags for determination of sulfate, alkalinity, and acidity.

1. Determination of sulfate

Sulfate concentrations were determined using the Turbidimetric Method, as outlined in Standard Methods, 17th Edition (Method 4500 E, pp. 4-207). In that method, sulfate was combined with barium chloride in a buffer solution, forming a suspension of barium sulfate crystals. The density of the solution was determined by the spectrophotometer at the WWQL. Absorbence of diluted samples was compared to those of standards that were formulated in 5 ml increments from 0 to 40 mg / L.

2. Determination of alkalinity

Alkalinity was determined using the Potentiometric Method, as outlined in Standard Methods, 18th Edition (Method 2320 B, pp. 2-26). Phenolphthalein was used as a pH indicator, and standardized sulfuric acid solution was used for titration. The alkalinity of the individual samples was compared against blank and EPA samples. Standardization of the sulfuric acid solution to be used to titrate the unknown samples was done by back-titrating against a sodium carbonate solution.

3. Determination of acidity

Acidity was determined using the Potentiometric Method, as outlined in Standard Methods, 17th Edition (Method 2310 B, pp. 2-35). Phenolphthalein and methyl orange were used as pH indicators, and 0.02 N NaOH was used as the titrating solution. The acidity of the individual samples was compared against a blank sample.

4. Determination of total and dissolved iron

The vials containing the filtered and unfiltered water were removed from the refrigerator and arranged to reflect their origin. Next a series of iron solutions was formulated to provide a standard curve, using a 100 ppm stock solution previously formulated by the supervisor of the WWQL. The standards were 1 ppm, 3 ppm, 5 ppm, and 10 ppm.

The absorbence of each of the solutions was determined on a Perkin-Elmer 1100B atomic absorption spectrometer, using an iron-specific lamp. Each standard solution was introduced to the AA through the flexible plastic nebulizer tube that led into the unit, and the absorbence read from the digital display. The nebulizer tube was purged with deionized water between samples. A regression curve was developed in which concentration was given on the y-axis and absorbence was on the x-axis. From those data, a regression equation was developed using the linear regression model in Microsoft Excel.

Next, the samples within the vials were subject to AA analysis. In those instances where absorbence readings exceeded that of the 10 ppm standard solution, the sample was diluted and reanalyzed. Absorbence readings were converted to concentrations using the regression equation obtained from the standard solutions.

C. Data Management and Reporting

All of the values from both the field and laboratory measurements were entered into a comprehensive MS Excel workbook that was created for this project. The workbook consisted of individual worksheets, each of which corresponded to a particular sampling session. Thus, the workbook contained twenty-three worksheets. Each worksheet was arranged such that the rows denoted individual sample sites, while the columns denoted parameters. Above each cell was an expected range of data values for initial QA/QC purposes.

Once completed, the workbook was saved to a PC in the WWQL, and sent as an email attachment to the Project PI. After performing data quality assurance (see next section), the Project PI transcribed the data into a MS Excel master database enabling further analyses.

The raw data for each parameter at each site were then transcribed onto a series of schematic diagrams of the Phase II system to enable the visualization of spatial and temporal trends, especially as they relate to the impact of the wetland / borehole complex on Nanticoke Creek (Figures A1 - A16).

Time-series graphs of each of the parameters at the inlet and outlet weirs of each cell were generated using the graphing functions in Microsoft Excel. Raw graphs were copied and pasted into an AppleWorks file, and labels added, yielding the Figures 3-13.

To facilitate an understanding of the progression of water quality improvement within the wetland, as well as the impact of the outfall wetland complex on Nanticoke Creek, groups of data were averaged and their standard deviations were calculated. Data subjected to such analysis included those from the borehole (using the Dundee Outfall as a proxy), the pipe feeding the detention basin, the end of the upper cell, the end of the lower cell, Nanticoke Creek above the outfall, and Nanticoke Creek below the outfall. Temporally, data were grouped in various ways, including: all samples since the wetland began flowing in 1999, readings collected before vs after the January 2001 start of the study, and readings collected in each year. The results of that analysis are depicted in Tables 1-8.

The statistical significance of differences between means were determined by subjecting the raw population data to repeated Student t-tests using the algorithm present in MS Excel. The results of all statistical tests are depicted in Tables 1-8. Spatially, the following comparisons were made: borehole vs detention basin, detention basin vs end of upper cell, end of upper cell vs end of lower cell, borehole vs end of lower cell, and upstream vs downstream positions in Nanticoke Creek. Temporally, the means for samples collected in 1999 and 2000 were compared against those collected in 2001 and 2002. In addition, samples collected in 2001 were compared against those collected in 2002. To determine whether water quality in Nanticoke Creek was impacted by whether the creek was flowing, the data were also grouped according to whether water was discharging from the borehole, and the means were subjected to an Excel-based t-test. In all cases, data were not subjected to any kind of transformation. Nor were any Analyses of Variance applied to the data. Differences were viewed as being not significant when the P value exceeded 0.05. For tests yielding a P value below 0.05, the actual number was reported. The danger of using repeated t-tests is that Type I errors (resulting in a conclusion that two populations are significantly different when they are not) are additive. Therefore, P values between 0.01 and 0.05 should be viewed as weakly significant, at best.

D. Data Quality Assurance

Water quality data were collected in the field and laboratory using properly calibrated equipment, based on known standards. Periodic duplicate samples were taken to assure replicability. Water samples transported to the lab were placed in clearly marked containers. Procedures for storing and handling the samples followed those established by the WWQL. Samples were collected and analyses run by trained employees of the WWQL. All data were recorded on standard datasheets that were kept in a predetermined, secure location.

After the datafile was received from the WWQL, it was opened by the Project PI, who then scrutinized the numbers. Any values that appeared to deviate from the expected range for each parameter at each site were identified and reported back to the WWQL staff. The questionable data values were reassessed by reanalyzing the sample (whenever possible), or reevaluating the calculations that gave the anomalous number. The result of the reassessment was entered into a separate datasheet and emailed back to the Project PI for inclusion in the master database.

IV. RESULTS

A. Integrity of Wetland System

The construction of the Phase II system involved considerable earth moving to create a rather intricate system involving a series of pools with steep sides and flat bottoms. Moreover, a plant community was introduced into the two wetland cells to hold the soil in place, to facilitate the oxygenation of the water, to increase alkalinity levels, and to provide loci for iron to precipitate.

The recontoured banks and wetland bases remained largely intact throughout the two-year duration of this assessment. Some slumping was previously noted along the eastern edge of the detention basin and along the western edge of the lower cell. That slumping was still evident but did not appear to have progressed.

Both wetland cells continued to hold water, and flow patterns between the detention basin, upper wetland cell and lower wetland cell continued to function as designed. Minewater was noted in a swale immediately west of the lower cell, but its source was not ascertained. No short-circuiting or other hydrological problems were noted. The various structures including the pumps, Maxistripper, inlets and outlets, and ductwork all appeared to continue to function well. However, the WTT did not examine those structural components for evidence of iron buildup or other deterioration. Maintenance of those items is provided by staff from the Earth Conservancy.

The plant communities in both wetland cells filled in with a dense aggregation of hydrophytic plants. The upper cell became dominated by a dense community of cattail (*Typha latifolia*) and soft rush (*Juncus effusus*). The lower cell was a more diverse community of soft rush, bulrush (*Scirpus atrovirens*), and a variety of other broadleaf and graminoid plants common to wetlands in the region. The vegetation was apparently not harmed by the drawdowns that occurred after pumping ceased due to the lack of flow experienced both summers (see below).

In addition to the vegetation, the wetland appeared to act as habitat for a variety of wildlife. Several bird species including Canada geese, ducks, herons, and red-wing blackbirds were noted. Several frog species were also observed, as were populations of dragonflies and damselflies, especially in the summers. Thus, the system inarguably continued to function as a wetland ecosystem.

B. Seasonal Flow Patterns

In both years, precipitation levels were relatively normal in the periods between mid winter and early summer. As a result, the water levels in the mine pool were sufficiently high to allow pumping to occur, enabling water to flow through the wetland system. However, the mid-late summer and early fall of both years were dry and the mine pool level dropped below the intake of the pump. No water could be extracted to feed the wetland during those periods. While those periodic times of shutdown could be perceived as a shortcoming of the system, the Dundee Outfall also did not flow during those periods, and therefore no minewater was entering Nanticoke Creek.

In 2001, the dry period lasted between July and December. Some water samples were collected from pools of standing water within the wetland in July and August. In 2002, the lack of flow precluded sampling between August and November.

Some water was present in Nanticoke Creek during each month of the assessment. As a result, samples were collected at both creekside locations during all twenty-three sampling sessions. The one exception occurred in January of 2002 when the stream was frozen upstream of the outfall.

C. Measured Parameters

1. Temperature

In general, water temperatures discharging from the borehole were relatively constant, varying between 11 °C and 16 °C (Figures 3, A-1, A-2). Outliers were noted during the late spring of 2001, when temperatures of 18 - 23 °C were measured, as well as late November 2002, when the reading was 5.1 °C. In general, consistent temperatures would be expected for water coming to the surface from an underground mine pool. The outliers might have been caused by sampling error, specifically by the water being taken from the pool at the base of the outfall pipe, rather than from the discharge itself.

Water temperatures were measured in the first 6-7 months of each year because flow was available during those sampling sessions. The lack of discharge from the borehole in the late summer and fall precluded observations then. As expected, water temperatures in the wetland itself increased between January and late July during both years (Figures 3a, A-1, A-2). Lowest temperatures were found in January, generally being between 4 and 11 °C. Temperatures climbed throughout the spring, reaching in the 18 - 23 °C range in June. The temperature rise was more pronounced in 2001 (Figure 3a).

In both years, temperatures declined by 6 °C between the Maxistripper and outlet in January (Figures 3a, b), which would be expected due to the cooling of the minewater which came out of the ground warmer than the ambient. In contrast, temperatures increased by 4-5 °C in June and July; a rise that would be expected as the minewater is exposed to warmer air. Temperatures held relatively constant between February and May. During no time did the wetland freeze. Nor did temperatures exceed 28°C (Figures 3a,b).

Water temperatures within the two sites along Nanticoke Creek went through the expected seasonal progression each year. Both Januarys, the site upstream of the outfall discharge had readings of 3.0 °C or less (Figures A-1, A-2). Throughout each spring, temperatures increased to a peak in the 25-27 °C range in June, followed by a decline to 6-8°C in November and December. Flow from the outfall / wetland complex influenced water temperatures within the creek, which was expected because the complex is the creek's primary source of flow. The complex caused an increase in creek water temperatures between January and March, while a decrease was noted in June. Between August and November of each year, water temperatures at the two creekside locations were similar because the outfall / wetland complex was not flowing.

2. pH

As noted below, water discharging from the Askam Borehole has net alkalinity, making it different from acidic discharges found in most other abandoned mine drainage situations. As a result, pH levels were found to be higher than in other AMD treatment wetlands. Average pH readings at the borehole were 6.3 (Table 1a), though monthly values varied between 5.5 and 7.4 (Figures 4, A-3, A-4). No difference between the two years was noted. Likewise, the values observed during this study were statistically identical to those observed in 1999 and 2000 (Table 1a).

Some seasonal change was noted each year, though the patterns were contradictory in the two years (Figure 4a). In 2001, pH readings remained relatively constant between January and June, and increased by nearly one full unit between late June and late August. In 2002, pH readings declined markedly from 7.0 in January to 6.1 in July.

In the wetland complex, pH readings were mostly 6.0 - 6.8 (Figures 4, A-2), averaging 6.4 - 6.5 (Table 1a). In general, pH remained relatively constant as water passed through the wetland (Figures 4b-4d), though a slight increase of 0.2 units was noted on average.

In Nanticoke Creek, pH readings averaged 6.8 above the discharge and 6.6 below; a difference that was not significant (Table 2b). Readings collected in the upstream location were a bit higher during this study than those collected in 1999 / 2000 (Table 1b). Likewise, readings taken in 2002 were slightly higher than those collected in 2001. pH readings were similar regardless of whether the creek flowed (Table 2b).

3. Specific conductance

Water discharging from the Askam Borehole had a specific conductance that averaged 1156 μmho/cm throughout the duration of this study (Table 2a). Average conductance was nearly identical in 2001 and 2002 (Table 2a). Likewise, the values observed in this study were similar to those observed in the previous two years. Monthly readings varied from 824 μmho/cm in January 2002 to 1420 μmho/cm in April 2002 (Figures A-5, A-6). No clear seasonal trends were noted in either year (Figure 5a).

Water passing through the wetland showed a slight decrease in conductance, dropping to an average of 1077 μmho/cm by the end of the upper cell (Table 2a). Most of that decline occurred in the upper cell, rather than in the detention basin. The lower cell did not effect any decrease in conductance (Figures 5b-5d). Overall, values in the two years included in this study were similar to those observed in 1999/2000 (Table 2a).

In Nanticoke Creek, conductance readings averaged 483 μmho/cm above the discharge, which was significantly less than the 814 μmho/cm observed in 1999 / 2000 (Table 2b). In both years, the discharge from the borehole / wetland complex caused conductance to increase in the creek by a factor of two to three downstream (Table 2b, Figures A-5, A-6). When the discharge flowed, conductance increased from 664 to 1151 μmho/cm upstream to downstream. When it did not, a smaller increase was observed (509 to 829 μmho/cm) (Table 2b).

4. Dissolved oxygen (DO)

Water discharging from the Dundee Outfall averaged 4.7 mg/L dissolved O_2 (Table 3a). Though average DO readings were 4.1 mg/L in 2001 and 5.1 mg/L in 2002, the difference was not significant. Monthly DO readings at the outfall varied between 2.0 and 9.2 mg/L (Figures A-7, A-8). A value of 15.0 mg/L observed in January 2002 was seen as anomalous. Average readings observed in this study were statistically similar to those observed in 1999/2000 (Table 3a).

As expected, the Maxistripper caused a marked, statistically significant increase in DO, so that the water entering the pond averaged 6.9 mg/L (Table 3a, Figure 6). DO levels increased slightly to an average of 7.1 mg/L in the upper wetland, and to 8.9 mg/L in the lower wetland. The difference between the discharges to the upper and lower wetlands were both significant. The patterns observed were similar between the two years, and to those in 1999 / 2000 (Table 3a).

On a seasonal basis, levels were highest each February, decreasing throughout the spring and summer, and increasing to the fall reading (Figure 6). That seasonal pattern likely results from the fact that cold water holds more oxygen than warm water.

DO levels averaged 8.2 mg/L in Nanticoke Creek above the discharge, increasing only slightly to 8.7 mg/L downstream (Table 3b). That increase was not significant. As noted within the wetland, DO levels were typically lower during the warmer months than cooler months, though that seasonal trend was not as clear in 2002 (Figures A-7, A-8). For those months in which the wetland was flowing, DO increased from 7.1 to 8.4 mg/l, though that difference was not significant (Table 3b). When the discharge was dry, DO increased significantly from 6.1 to 10.3 mg/L.

5. Iron

The Phase II treatment wetland was designed primarily to remove iron from the minewater that it receives. To that end, iron dynamics were studied intensively and data are expressed in terms of measured concentrations for total and dissolved iron, iron loading at each sampling location, and iron removal both in terms of total iron removed and percent removed as a function of starting load.

a. Total and dissolved iron concentrations

Iron concentrations in the fresh minewater discharging from the Dundee Outfall averaged 33.9 mg/L throughout the two year duration of the study (Table 4a). No significant differences between the two years of this study were noted. Nor were the values obtained in 2001 / 2002 significantly different from the previous two year period (Table 4a). Some month-to-month variability was noted such that a few months gave readings in the 20-30 mg/l range, whereas other months had readings in the 45 - 60 mg/L range (Figures 7, A-9, A-10). In 2001, iron concentrations at the outfall increased from 27 mg/L in January to 59 mg/L in March (Figure 6a). They subsequently declined to 12 mg/L in late July before the discharge stopped flowing due to the drought. In 2002, iron concentrations fluctuated between 43 and 46 mg/L during the first four months of the year (Figure A-10). They were much lower (22-29 mg/L) between May and July, before the discharge stopped flowing. A concentration of 20 mg/L was recorded when flow resumed in November 2002 (Figures 7, A-10). Throughout the period of this analysis, the percentage of iron that was dissolved generally exceeded 89%, which would be expected for fresh mine water.

Throughout its progression through the wetland system, iron concentrations showed two clear and consistent patterns noted in previous years. The first was that the concentration of total iron dropped markedly. Concentrations averaged 19.9 mg/L at the Maxistripper, 3.3 mg/L at the end of the upper cell, and 0.4 mg/L at the outflow from the lower cell (Table 4, Figures 7b, 7c). Each decrease was significantly significant. No clear and consistent differences in the pattern of iron removal were noted between the two years of this study, or between the two years encompassed by this study and the prior two years (Table 4). Second, the percentage of dissolved iron typically dropped markedly, with values <10% being common (Figure A-9. A-10). That trend would be expected in view of the normal oxidation, hydrolysis, and coagulation processes that iron undergoes in an aerobic wetland system.

b. Iron loading

The loading of iron (expressed as lbs/day) was estimated from the concentration data, assuming a 600 GPM pump output. For the two year duration of the study, loading averaged 255 lbs / day (Table 5). Individual values ranged from 89 lbs / day in July 2001 to 425 lbs / day in March 2001. Loading rates were not significantly different between 2001 and 2002 (Figures A-9, A-10). The rates observed in this study were significantly lower than the loading in 1999 / 2000 (327 lbs / day) (Table 5).

Loading values within the wetland averaged 256 lbs/day at the borehole, 143 lbs/day at the inlet to the detention basin, 24 lbs/day at the end of the upper wetland, and 2.8 lbs / day at the outlet to the lower wetland. No clear seasonal trend was noted, though some month-to-month variability was detected, especially at the Maxistripper and detention basin (Figure 8).

c. Iron removal

Cumulative iron removal graphs revealed a saturation-type pattern where most (240 lbs.) of the iron was actively removed between the borehole and end of the upper wetland cell. Some additional iron removal (ca. 15-40 lbs) occurred in the lower cell (Figures 9b - 9d). In each month, nearly all of the removal occurred before the end of the upper wetland cell. No clear seasonal pattern for removal was noted (Figure 9a)

On a percentage basis, over half of the iron entering the system was removed in the detention basin on average (Figure 10b - 10d). About 90% was removed by the end of the upper cell, and in most months that value exceeded 95%. By the end of the lower cell and outlet, iron removal rates averaged 98.3% (Table 5). On a weight basis, an average of 254.3 lbs/day was observed for the period of this assessment. However, in most months in which normal levels of flow entered the wetland, more than 300 lbs of iron were removed each day (Figures A-9, A-10). Thus, the wetland continued to remove iron as designed.

Iron removal was effected by particles adhering to roots and submerged stems of plants in each cell. The proportion being incorporated into plant tissue was probably low relative to the total amount being removed.

d. Impacts on Nanticoke Creek

As noted by Klemow (2002) the Dundee Outfall has been, and continues to be, the primary source of iron pollution into the Nanticoke Creek watershed. The examination of iron concentration patterns in the area above and below the Dundee Outfall discharge into the creek can reveal much about the impact of the wetland in treating its AMD problem.

Iron concentrations in the creek above the wetland discharge averaged 2.7 mg/L for the two year duration of this study (Table 4b). Individual monthly readings were mostly under 6 mg/L, though a few samples had 15-18 mg/L, possibly due to backwash from the outfall. No statistical difference was noted between the two years of the study, though the values obtained were significantly lower than those observed in 1999 and 2000 (average of 20.0 mg/L) (Table 4b). Interestingly, the average upstream iron concentration was significantly higher when the outfall was flowing than when it was not (11.4 vs 3.4 mg/L) (Table 4b).

Iron concentrations below the outfall's confluence with Nanticoke Creek averaged 17.3 mg/L during the study (Table 4b). That value was significantly higher than the value observed above the discharge (Figures A-9, A-10). Monthly readings varied from under 5 to over 40 mg/L. Much of that variability can no doubt be traced to the fact that iron concentrations downstream of the outfall varied greatly depended on whether the outfall was flowing. When the outfall was dry, average concentrations were 8.3 mg/L, much lower than the 31.4 mg/L observed when the outfall yielded water (Table 4b).

Thus, Nanticoke Creek continued to be contaminated by AMD, despite the Phase II wetland's success at removing iron. As observed in previous years, the wetland treats only part of the water discharging from the borehole. Flow of untreated water emanating the borehole apparently continued to contaminate the treated water discharging from the wetland outlet.

Superimposed on that general pattern is a more subtle one that can be discerned by comparing the data from most of the late winter / early spring measurements (February through April) to those obtained between May and July (Figure A-9, A-10). Flows from the outfall were rather heavy in late winter and early spring, and only an estimated 10-25% of the flow was treated. During those months, iron concentrations increased from less than 1 mg/L above the discharge to 30-40 mg/L below. By May and June of each year, water levels within the mine pool had dropped, and the discharge from the outfall had decreased substantially. The amount of water that was being treated was estimated to be 25-40% of the total. During those months, iron concentrations in the creek below the outfall discharge was 5-25 mg/L, much less than the values found when the had higher discharge rates (Figures A-9, A-10). If the flow estimates are correct, they would indicate that the Phase II wetland indeed has some measurable effect on ameliorating iron loading into Nanticoke Creek, especially during periods of reduced AMD discharge from the outfall.

6. Sulfate

Previous investigations of minewater discharging from the Dundee Outfall complex revealed it to contain high levels of dissolved sulfate. That pattern continued throughout this study as sulfate levels averaged ca. 649 mg / L at the outfall (Table 6a). Average sulfate was higher in 2001 than in 2002 (684 vs 620 mg/l), though that difference was not significant. Readings during individual months varied from 446 to 958 mg/L, though that latter reading might have been anomalous. The values observed in this study were nearly identical to those observed in 1999 / 2000 (Table 6a).

Though sulfate removal was not a key outcome of the Phase II wetland, a slight removal was noted between the borehole and outlet from the lower wetland (Figure 11). Average concentrations at the wetland discharge were 597 mg/L (Table 6a). An examination of sulfate concentrations in individual sampling dates revealed the decline to be more evident during some months than others (Figures A-11, A-12). Trends observed throughout the wetland were similar between the two years of the study, and between those observed in 1999 / 2000 (Figure 11).

On a seasonal basis, sulfate concentrations tended to decline in both years between February and June (Figure 11a). In most months, month-to-month variability tended to be larger than site-to-site variability (Figure 11b). Since sulfate is one of the primary ions within the minewater being treated at Phase II, it is not surprising that its seasonal and site-related patterns were similar to those noted for conductivity (see above).

As true of conductivity and iron, the discharge of minewater from the borehole / wetland complex caused a significant increase in sulfate within Nanticoke Creek between the upstream and downstream locations. Sulfate levels upstream of the discharge during this study averaged 147 mg/L, while those downstream averaged 483 mg/L (Table 6b). Those levels were similar from one year to the next, and to those measured in 1999 / 2000. The upstream - downstream increase was more statistically significant when the wetland was flowing than when it was not (Table 6b).

7. Alkalinity

Alkalinity levels from the Dundee Outfall averaged ca. 89.3 mg $CaCO_3$ / L during the two year duration of the study (Table 7a; Figures 12). Monthly readings varied from 40 to 130 mg $CaCO_3$ / L (Figures A-13, A-14). The latter reading came in late January 2002, after a five-month period in which the wetland did not flow. The high January readings may have resulted from a flushing effect following the low mine pool elevations throughout the latter half of 2002. Overall, alkalinity levels in water discharging from the outfall were statistically similar in the two years of the study, and to those measured in 1999 / 2000.

In general, alkalinity levels remained constant within the wetland complex, with readings mostly holding to within 15-20 units of those noted in the outfall (Figures 12b, 12c). No real removal or addition of alkalinity were noted during the two-year duration of the study. Nor were any seasonal fluctuations in alkalinity noted (Figure 12a).

In Nanticoke Creek, alkalinity levels averaged 86.1 upstream of the outfall discharge. No difference between years was noted, though the alkalinity was found to be significantly higher than that observed in 1999 and 2000 (Table 7b). No clear seasonal trends in alkalinity were noted. Alkalinity levels downstream of the discharge were statistically the same as those upstream (Table 7b).

8. Acidity

Levels of acidity were consistently lower than those of alkalinity throughout the study. Water discharging from the Dundee Outfall averaged acidity levels of 7.0 mg $CaCO_3$ / L (Table 8a). Individual monthly readings varied considerably, from 1 to 24 mg $CaCO_3$ / L (Figures 13, A-8), and no seasonal patterns were noted (Figure 13a).

Acidity levels within the wetland were typically under 16 mg $CaCO_3$ / L, with those in 2002 being mostly under 8 mg $CaCO_3$ / L (Figures A-15, A-16). Values did fluctuate from site to site and date to date, in no real pattern. Mean acidity did not appear to increase or decline appreciably as water passed through the wetland (Figure 13b, 13d).

Acidity levels in Nanticoke Creek averaged 4.9 mg $CaCO_3$ / L, with individual monthly readings generally being 0-8 mg $CaCO_3$ / L (Figures A-15, A-16). Those values were significantly less than the 9.1 mg $CaCO_3$ / L noted in 1999-2000 (Table 8b). No significant difference was observed comparing values taken in 2001 and 2002. Acidity levels were significantly higher downstream of the discharge.

IV. CONCLUSIONS

Water quality parameters were analyzed at the Earth Conservancy's Phase II mine drainage treatment wetland along Dundee Road in Hanover Township, Luzerne County, PA throughout 2001 and 2002. In general, the findings revealed that the wetland continued to function well during the period of investigation. However, flow within the wetland system during the second half of each year was curtailed because seasonal droughts caused the water table in the mine pool to drop below the intake for the pump.

Water quality parameters in the water entering the system were similar to those noted in previous years. The water had a relatively high pH (average = 6.3) because alkalinity exceeded acidity (89 vs 7 mg $CaCO_3$ / L). Due to relatively high concentrations of sulfate (average = 649 mg / L) and iron (average = 35 mg / L), the water had high conductance (average = 1156 μmho/cm). As expected for fresh minewater, dissolved oxygen levels were low, averaging 4.7 mg/L.

When the borehole flowed, minewater was pumped into the wetland at an estimated rate of 600 GPM. Iron loading averaged 255 lbs/day, ranging from 85 lbs/day in July 2002 to 422 lbs/day in April 2002. Essentially all of the iron entering the wetland system was in the dissolved form. As water passed through the system, the iron went through the oxidation - hydrolysis - flocculation reactions as designed. Iron concentrations dropped to 10% of their original levels by the end of the upper wetland cell, and to 0.5 - 2% by the end of the lower cell. Visually, the clarity of the minewater improved greatly as it passed from the detention basin to the end of the lower wetland. Most of the removal appeared to result from the adhesion of iron particles to the roots and submerged stems of the vegetation in each cell.

The wetland slightly reduced sulfate and conductivity levels. No observable changes to alkalinity, acidity, or pH levels were noted.

Since the wetlands are successfully removing iron, the possibility exists that the wetland cells will fill with iron hydroxide sludge. Some accumulation of iron solids was noted in the system especially in the upper wetland cell. However, the amount of freeboard space appears more than sufficient to allow the system to accept more iron for at least the next two years.

Despite the excellent iron-removal ability of the Phase II wetland, Nanticoke Creek continued to be impacted by iron loading from the untreated portion of the discharge from the Dundee Outfall. Concentrations increased from an average of 2.7 mg/L above the discharge to 17 mg/L below. Significantly, downstream concentrations were typically much lower when the borehole was dry, indicating the potential for an improvement of water quality should the loading of minewater cease.

The Earth Conservancy's Phase II wetland is effective at removing iron from the water that it receives, but is far from solving the mine drainage problem in the Nanticoke Creek watershed. The wetland should be able to treat greater volumes of water, though pursuing that option would require the EC to pump more water at a greater cost. Effecting a complete solution to the AMD problem will require that headwater streams do not lose flow to the underground mine pool. In addition, creation of more wetland acreage is possible downstream of the outfall - especially alongside Nanticoke Creek above Loomis Park. Thus, the Phase II wetland should be viewed as being an important, successful first step in a larger program of AMD remediation within the Nanticoke Creek watershed.

Tables

Table 1 - Summary of pH Trends in the Earth Conservancy Phase II Wetland

Nanticoke Creek, Hanover Township, Luzerne County, PA

Values given as arithmetic mean ± 1 standard deviation. Data collection and analysis by the Wilkes University Wetland Technical Team

a. Trends in the Wetland

Study period	**Borehole** Mean ± 1 SD	**Basin feed** Mean± 1 SD	**End U Cell** Mean± 1 SD	**End L Cell** Mean± 1 SD	Bore. v. Basin	Basin v UCell	UCell v LCell	Bore v LCell
All samples (8/99-11/02)	**6.4** ± 0.4	**6.6** ± 0.4	**6.5** ± 0.4	**6.6**± 0.4	0.018	n.s.	n.s.	0.004
1999	**6.6** ± 0.2	**6.9** ± 0.2	**6.4** ± 0.2	**6.7**± 0.3				
2000	**6.3** ± 0.2	**6.6** ± 0.2	**6.9** ± 0.7	**6.8**± 0.4				
Prior studies (1999/2000)	**6.5** ± 0.2	**6.8** ± 0.2	**6.7** ± 0.6	**6.7**± 0.4	0.012	n.s.	n.s.	n.s.
2001	**6.2** ± 0.4	**6.4** ± 0.5	**6.4** ± 0.3	**6.3**± 0.3				
2002	**6.5** ± 0.5	**6.4** ± 0.4	**6.4** ± 0.3	**6.7**± 0.4				
This study (2001/2002)	**6.3** ± 0.5	**6.4** ± 0.4	**6.4** ± 0.3	**6.5**± 0.4	n.s.	n.s.	n.s.	0.006
Prior studies vs this study	n.s.	0.019	n.s.	n.s.				
2001 vs 2002	n.s.	n.s.	n.s.	n.s.				

b. Trends in Nanticoke Creek

Study period	**Above** Mean ± 1 SD	**Below** Mean± 1 SD	Above v. below
All samples (8/99-11/02)	**6.7** ± 0.6	**6.5** ± 0.6	n.s.
1999	**6.5** ± 0.3	**6.5** ± 0.4	
2000	**6.3** ± 0.7	**6.3** ± 0.3	
Prior studies (1999/2000)	**6.4** ± 0.6	**6.4** ± 0.4	n.s.
2001	**6.3** ± 0.7	**6.3** ± 0.3	
2002	**6.6** ± 0.6	**6.5** ± 0.7	
This study (2001/2002)	**6.8** ± 0.5	**6.6** ± 0.7	n.s.
Prior studies vs this study	0.037	n.s.	
2001 vs 2002	0.015	n.s.	
Flow	**6.6** ± 0.6	**6.4** ± 0.5	n.s.
No flow	**6.9** ± 0.4	**6.7** ± 0.6	n.s.
Flow vs no flow	n.s.	n.s.	

Table 2 - Summary of Conductivity Trends in the Earth Conservancy Phase II Wetland

Nanticoke Creek, Hanover Township, Luzerne County, PA

Values given as arithmetic mean ± 1 standard deviation. Data collection and analysis by the Wilkes University Wetland Technical Team

a. Trends in the Wetland

Study period	**Borehole** Mean + 1 SD	**Basin feed** Mean+ 1 SD	**End U Cell** Mean+ 1 SD	**End L Cell** Mean+ 1 SD	Bore. v. Basin	Basin v UCell	UCell v LCell	Bore v LCell
All samples (8/99-11/02)	**1191** ± 164	**1166** ± 188	**1110** ± 207	**1112** ± 201	n.s.	0.001	n.s.	0.008
1999	**1189** ± 192	**1190** ± 197	**1230** ± 174	**1204** ± 161				
2000	**1300** ± 62	**1276** ± 74	**1117** ± 249	**1090** ± 233				
Prior studies (1999/2000)	**1240** ± 153	**1233** ± 148	**1162** ± 219	**1148** ± 203	n.s.	0.029	n.s.	n.s.
2001	**1153** ± 133	**1083** ± 254	**1015** ± 224	**1045** ± 186				
2002	**1159** ± 196	**1166** ± 137	**1139** ± 159	**1121** ± 223				
This study (2001/2002)	**1156** ± 166	**1124** ± 202	**1077** ± 198	**1088** ± 204	n.s.	0.013	n.s.	n.s.
Prior studies vs this study	n.s.	n.s.	n.s.	n.s.				
2001 vs 2002	n.s.	n.s.	n.s.	n.s.				

b. Trends in Nanticoke Creek

Study period	**Above** Mean ± 1 SD	**Below** Mean± 1 SD	Above v. below
All samples (8/99-11/02)	**612** ± 305	**1052** ± 287	<0.001
1999	**1005** ± 354	**1110** ± 413	
2000	**671** ± 335	**1107** ± 274	
Prior studies (1999/2000)	**814** ± 372	**1109** ± 325	0.007
2001	**509** ± 188	**944** ± 291	
2002	**452** ± 110	**1097** ± 213	
This study (2001/2002)	**483** ± 157	**1017** ± 263	<0.001
Prior studies vs this study	0.006	n.s.	
2001 vs 2002	n.s.	n.s.	
Flow	**664** ± 330	**1151** ± 218	<0.001
No flow	**508** ± 222	**829** ± 304	0.003
Flow vs no flow	n.s.	0.014	

Table 3 - Summary of Dissolved Oxygen Trends in the Earth Conservancy Phase II Wetland

Nanticoke Creek, Hanover Township, Luzerne County, PA

Values given as arithmetic mean ± 1 standard deviation. Data collection and analysis by the Wilkes University Wetland Technical Team

a. Trends in the Wetland

Study period	Borehole Mean ± 1 SD	Basin feed Mean ± 1 SD	End U Cell Mean ± 1 SD	End L Cell Mean ± 1 SD	Bore. v. Basin	Basin v UCell	UCell v LCell	Bore v LCell
All samples (8/99-11/02)	4.3± 2.8	7.2± 1.9	7.2± 1.9	8.8± 2.2	<0.001	n.s.	<0.001	<0.001
1999	4.8± 2.6	7.9± 0.4	7.1± 0.7	9.1± 1.4				
2000	2.4± 0.2	7.7± 0.4	7.7± 1.6	8.4± 1.2				
Prior studies (1999/2000)	3.7± 2.2	7.8± 0.4	7.5± 1.3	8.7± 1.3	<0.001	0.020	0.050	<0.001
2001	4.1± 0.9	7.5± 1.9	7.2± 1.5	8.2± 2.3				
2002	5.1± 4.2	6.2± 2.6	7.0± 2.9	9.5± 3.1				
This study (2001/2002)	4.7± 3.2	6.9± 2.3	7.1± 2.2	8.9± 2.8	0.031	n.s.	0.003	<0.001
Prior studies vs this study	n.s.	n.s.	n.s.	n.s.				
2001 vs 2002	n.s.	n.s.	n.s.	n.s.				

b. Trends in Nanticoke Creek

Study period	Above Mean ± 1 SD	Below Mean ± 1 SD	Above v. below
All samples (8/99-11/02)	7.4± 2.8	7.1 ± 3.2	n.s.
1999	4.9± 0.8	5.1 ± 1.4	
2000	7.2± 3.0	4.0 ± 1.0	
Prior studies (1999/2000)	6.2± 2.5	4.5 ± 1.3	0.033
2001	8.7± 3.0	8.6 ± 3.5	
2002	7.7± 2.5	8.9 ± 2.3	
This study (2001/2002)	8.2± 2.7	8.7 ± 2.9	n.s.
Prior studies vs this study	0.033	<0.001	
2001 vs 2002	n.s.	n.s.	
Flow	7.1± 2.8	6.1± 2.8	0.021
No flow	8.4± 2.8	10.3± 1.9	0.035
Flow vs no flow	n.s.	<0.001	

Table 4 - Summary of Total Iron Trends in the Earth Conservancy Phase II Wetland

Nanticoke Creek, Hanover Township, Luzerne County, PA

Values given as arithmetic mean ± 1 standard deviation. Data collection and analysis by the Wilkes University Wetland Technical Team

a. Trends in the Wetland

Study period	Borehole Mean ± 1 SD	Basin feed Mean± 1 SD	End U Cell Mean± 1 SD	End L Cell Mean± 1 SD	Bore. v. Basin	Basin v UCell	UCell v LCell	Bore v LCell
All samples (8/99-11/02)	37.5 ± 13.1	28.0 ± 17.0	4.4 ± 4.3	1.6± 2.7	<0.001	<0.001	<0.001	<0.001
1999	38.2 ± 19.4	39.9 ± 22.8	8.3 ± 7.7	5.0± 5.1				
2000	42.0 ± 3.8	41.9 ± 4.9	4.6 ± 2.5	1.3± 0.9				
Prior studies (1999/2000)	40.0 ± 14.1	40.9 ± 15.6	6.1 ± 5.2	3.0± 3.8	n.s.	<0.001	0.002	<0.001
2001	36.3 ± 14.1	22.9 ± 17.1	3.9 ± 4.3	0.5± 0.4				
2002	32.0 ± 14.2	16.9 ± 4.6	2.7 ± 2.2	0.6± 0.5				
This study (2001/2002)	35.5 ± 12.3	19.9 ± 12.5	3.3 ± 3.3	0.4± 0.4	<0.001	<0.001	0.007	<0.001
Prior studies vs this study	n.s.	0.002	n.s.	n.s.				
2001 vs 2002	n.s.	n.s.	n.s.	n.s.				

b. Trends in Nanticoke Creek

Study period	Above Mean ± 1 SD	Below Mean± 1 SD	Above v. below
All samples (8/99-11/02)	9.4 ± 13.7	25.8 ± 18.7	<0.001
1999	29.4 ± 17.5	42.3 ± 23.3	
2000	12.9 ± 12.5	38.0 ± 7.3	
Prior studies (1999/2000)	20.0 ± 16.5	39.8 ± 15.5	<0.001
2001	4.3 ± 5.8	17.5 ± 17.0	
2002	0.8 ± 0.4	17.1 ± 13.6	
This study (2001/2002)	2.7 ± 4.6	17.3 ± 15.1	<0.001
Prior studies vs this study	0.002	<0.001	
2001 vs 2002	n.s.	n.s.	
Flow	11.4 ± 15.1	31.4 ± 16.9	<0.001
No flow	3.4 ± 4.7	8.3 ± 12.6	n.s.
Flow vs no flow	0.021	<0.001	

Table 5 - Summary of Iron Trends in the Earth Conservancy Phase II Wetland

Nanticoke Creek, Hanover Township, Luzerne County, PA

Values given as arithmetic mean ± 1 standard deviation. Data collection and analysis by the Wilkes University Wetland Technical Team

a. Trends in the Wetland

Study period	Iron Concentration (mg/L) Borehole Mean ± 1 SD	Iron Concentration (mg/L) Outlet Mean± 1 SD	Iron Loading (lbs/day) Borehole Mean± 1 SD	Iron Loading (lbs/day) Outlet Mean± 1 SD	Borehole v. Outlet	Percent Fe Removal Mean± 1 SD
All samples (8/99-11/02)	37.3 ± 13.3	1.2 ± 1.8	268.8 ± 95.8	8.3 ± 12.3	<0.001	97.2± 4.0
1999	37.6 ± 21.1	2.7 ± 3.7	270.4 ± 152.3	19.2 ± 26.7		94.3± 8.3
2000	42.0 ± 3.8	1.3 ± 0.9	302.5 ± 27.6	9.0 ± 6.2		97.1± 1.9
Prior studies (1999/2000)	39.8 ± 14.7	1.9 ± 2.5	286.4 ± 105.7	13.6 ± 18.2	<0.001	95.8± 5.6
2001	36.3 ± 11.3	0.5 ± 2.2	261.5 ± 81.7	3.9 ± 15.5		98.4± 4.8
2002	34.6 ± 11.2	0.6 ± 0.5	249.0 ± 80.6	4.3 ± 3.4		98.2± 1.4
This study (2001/2002)	35.5 ± 12.3	0.6 ± 0.4	255.3 ± 88.0	4.2 ± 3.1	<0.001	98.3± 1.5
Prior studies vs this study	n.s.	n.s.	n.s.	n.s.		n.s.
2001 vs 2002	n.s.	n.s.	n.s.	n.s.		n.s.

Table 6 - Summary of Sulfate Trends in the Earth Conservancy Phase II Wetland

Nanticoke Creek, Hanover Township, Luzerne County, PA

Values given as arithmetic mean ± 1 standard deviation. Data collection and analysis by the Wilkes University Wetland Technical Team

a. Trends in the Wetland

Study period	Borehole Mean ± 1 SD	Basin feed Mean ± 1 SD	End U Cell Mean ± 1 SD	End L Cell Mean ± 1 SD	Bore. v. Basin	Basin v UCell	UCell v LCell	Bore. v LCell
All samples (8/99-11/02)	**647** ± 158	**652** ± 132	**600** ± 167	**597** ± 173	n.s.	0.044	n.s.	0.004
1999	**669** ± 262	**835** ± 158	**745** ± 190	**663** ± 306				
2000	**615** ± 54	**593** ± 100	**513** ± 166	**543** ± 175				
Prior studies (1999/2000)	**644** ± 190	**700** ± 175	**606** ± 204	**597** ± 238	n.s.	n.s.	n.s.	n.s.
2001	**684** ± 167	**627** ± 106	**587** ± 193	**620** ± 131				
2002	**620** ± 108	**621** ± 94	**606** ± 92	**580** ± 90				
This study (2001/2002)	**649** ± 137	**624** ± 97	**597** ± 146	**597** ± 107	n.s.	n.s.	0.021	0.010
Prior studies vs this study	n.s.	n.s.	n.s.	n.s.				
2001 vs 2002	n.s.	n.s.	n.s.	n.s.				

b. Trends in Nanticoke Creek

Study period	Above Mean ± 1 SD	Below Mean ± 1 SD	Above v. below
All samples (8/99-11/02)	**223** ± 211	**525** ± 213	<0.001
1999	**519** ± 187	**617** ± 278	
2000	**250** ± 188	**575** ± 193	
Prior studies (1999/2000)	**353** ± 226	**593** ± 224	<0.001
2001	**154** ± 199	**454** ± 217	
2002	**138** ± 116	**516** ± 185	
This study (2001/2002)	**147** ± 163	**483** ± 200	<0.001
Prior studies vs this study	n.s.	n.s.	
2001 vs 2002	n.s.	n.s.	
Flow	**264** ± 219	**588** ± 178	<0.001
No flow	**107** ± 137	**330** ± 204	0.012
Flow vs no flow	0.020	0.005	

Table 7 - Summary of Alkalinity Trends in the Earth Conservancy Phase II Wetland

Nanticoke Creek, Hanover Township, Luzerne County, PA

Values given as arithmetic mean ± 1 standard deviation. Data collection and analysis by the Wilkes University Wetland Technical Team

a. Trends in the Wetland

Study period	Borehole Mean + 1 SD	Basin feed Mean+ 1 SD	End U Cell Mean+ 1 SD	End L Cell Mean+ 1 SD	Bore. v. Basin	Basin v UCell	UCell v LCell	Bore v LCell
All samples (8/99-11/02)	83.5± 28.4	75.1± 16.9	77.3± 26.3	72.9± 19.4	n.s.	n.s.	n.s.	0.014
1999	77.2± 30.8	59.00± 11.8	57.5± 17.7	66.4± 22.0				
2000	73.3± 18.3	78.0± 15.5	85.4± 36.8	67.5± 9.1				
Prior studies (1999/2000)	75.4± 24.9	68.5± 16.4	74.3± 32.6	67.0± 15.3	n.s.	n.s.	n.s.	0.030
2001	76.6± 27.7	72.5± 10.5	69.0± 13.7	68.6± 15.3				
2002	99.5± 29.1	85.9± 18.9	89.4± 25.7	84.1± 23.8				
This study (2001/2002)	89.3± 30.0	79.2± 16.3	79.2± 22.5	77.5± 21.4	n.s.	n.s.	n.s.	n.s.
Prior studies vs this study	n.s.	n.s.	n.s.	n.s.				
2001 vs 2002	n.s.	n.s.	n.s.	n.s.				

b. Trends in Nanticoke Creek

Study period	Above Mean ± 1 SD	Below Mean± 1 SD	Above v. below
All samples (8/99-11/02)	78.4± 23.4	82.4± 25.3	n.s.
1999	69.7± 15.9	86.0± 38.4	
2000	64.0± 23.2	87.6± 33.8	
Prior studies (1999/2000)	66.4± 19.9	86.9± 34.4	n.s.
2001	89.5± 22.1	72.1± 16.5	
2002	81.9± 23.7	88.1± 16.8	
This study (2001/2002)	86.1± 22.6	79.7± 18.2	n.s.
Prior studies vs this study	0.010	n.s.	
2001 vs 2002	n.s.	0.031	
Flow	74.9± 21.7	84.9± 26.7	n.s.
No flow	89.0± 26.5	74.7± 19.8	n.s.
Flow vs no flow	n.s.	n.s.	

Table 8 - Summary of Acidity Trends in the Earth Conservancy Phase II Wetland

Nanticoke Creek, Hanover Township, Luzerne County, PA

Values given as arithmetic mean ± 1 standard deviation. Data collection and analysis by the Wilkes University Wetland Technical Team

a. Trends in the Wetland

Study period	Borehole Mean + 1 SD	Basin feed Mean+ 1 SD	End U Cell Mean+ 1 SD	End L Cell Mean+ 1 SD	Bore. v. Basin	Basin v UCell	UCell v LCell	Bore v LCell
All samples (8/99-11/02)	8.0± 5.5	11.4± 9.1	9.3± 6.3	7.0± 3.9	n.s.	n.s.	n.s.	n.s.
1999	7.4± 2.6	8.7± 4.6	11.6± 2.8	6.0± 3.2				
2000	12.1± 2.5	16.5±12.1	9.6± 5.1	10.8± 3.8				
Prior studies (1999/2000)	9.5± 3.4	12.6± 9.5	10.4± 4.3	8.6± 4.2	n.s.	n.s.	n.s.	n.s.
2001	7.4± 8.1	12.6± 8.7	10.8± 6.7	7.7± 3.2				
2002	6.6± 5.4	8.6± 9.4	6.3± 7.7	4.3± 2.5				
This study (2001/2002)	7.0± 6.5	10.6± 9.0	8.5± 7.3	5.7± 3.2	n.s.	n.s.	n.s.	n.s.
Prior studies vs this study	n.s.	n.s.	n.s.	n.s.				
2001 vs 2002	n.s.	n.s.	n.s.	n.s.				

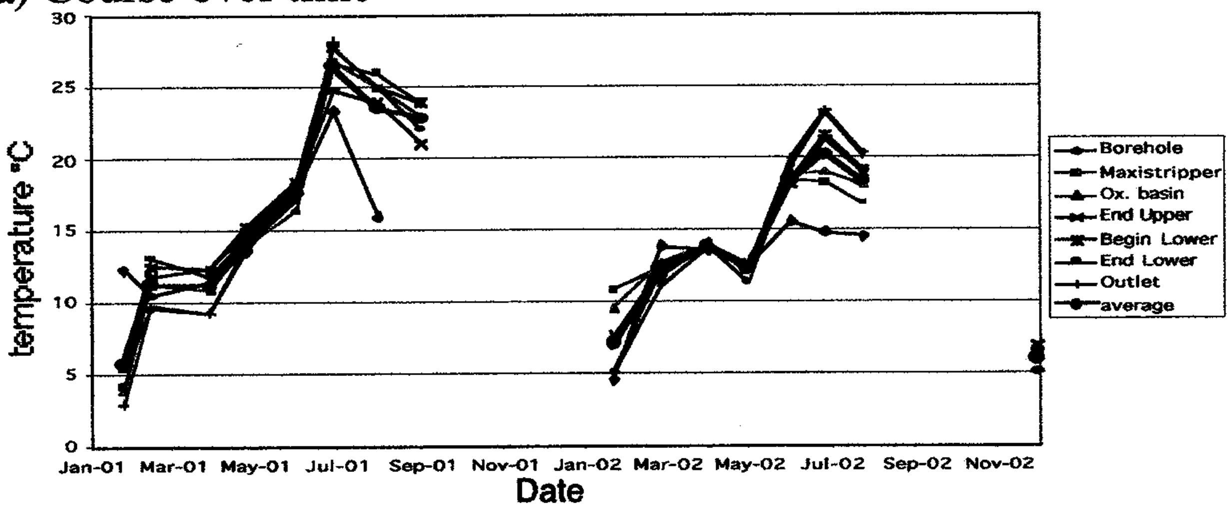
b. Trends in Nanticoke Creek

Study period	Above Mean ± 1 SD	Below Mean± 1 SD	Above v. below
All samples (8/99-11/02)	6.5± 5.3	8.9 ± 8.5	n.s.
1999	7.8± 2.0	6.9 ± 2.7	
2000	10.1± 5.8	9.8 ± 5.9	
Prior studies (1999/2000)	9.1± 4.6	8.5 ± 4.9	n.s.
2001	4.3± 4.2	9.0 ±10.8	
2002	5.6± 6.2	9.3 ± 9.8	
This study (2001/2002)	4.9± 5.1	9.2 ±10.1	0.019
Prior studies vs this study	0.015	n.s.	
2001 vs 2002	n.s.	n.s.	
Flow	7.0± 5.2	9.7± 8.9	n.s.
No flow	5.2± 5.6	6.4± 6.7	n.s.
Flow vs no flow	n.s.	n.s.	

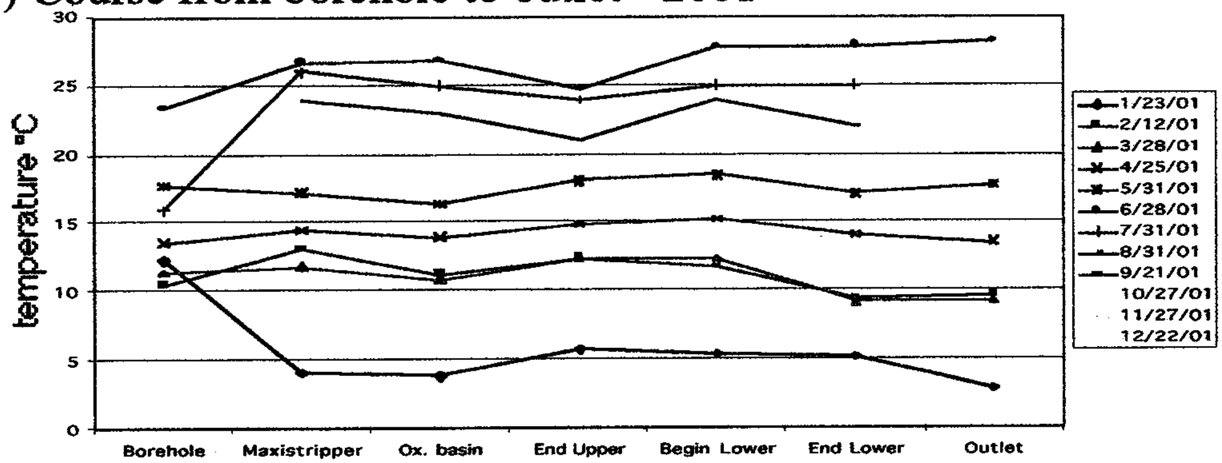
Performance Figures

Figure 3 - Course of Temperature
Dundee Road Wetland, Hanover Twp., PA
Data from Wilkes University Wetland Team. 2001 - 2002

(a) Course over time



(b) Course from borehole to outlet - 2001



(c) Course from borehole to outlet - 2002

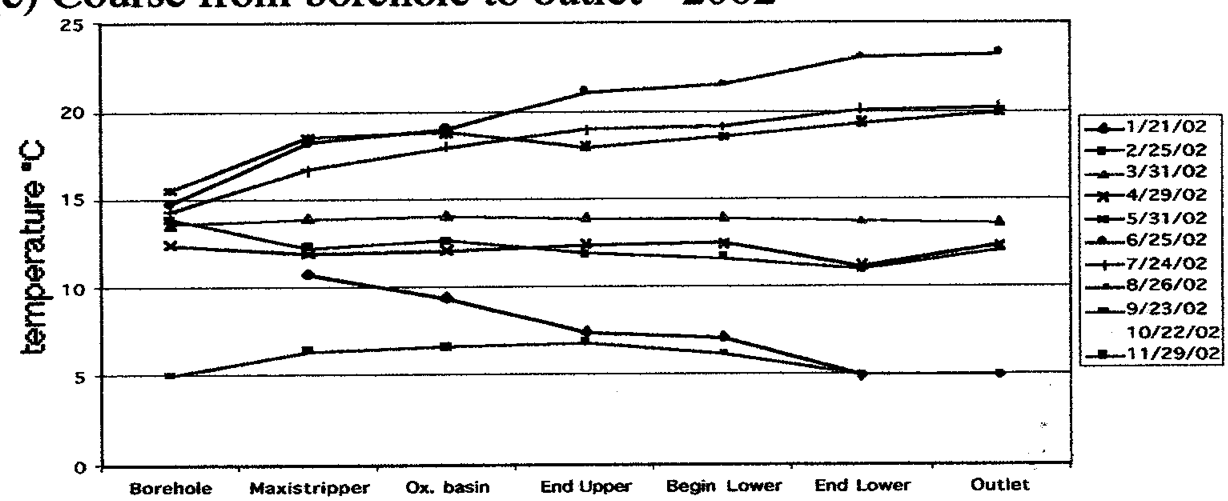
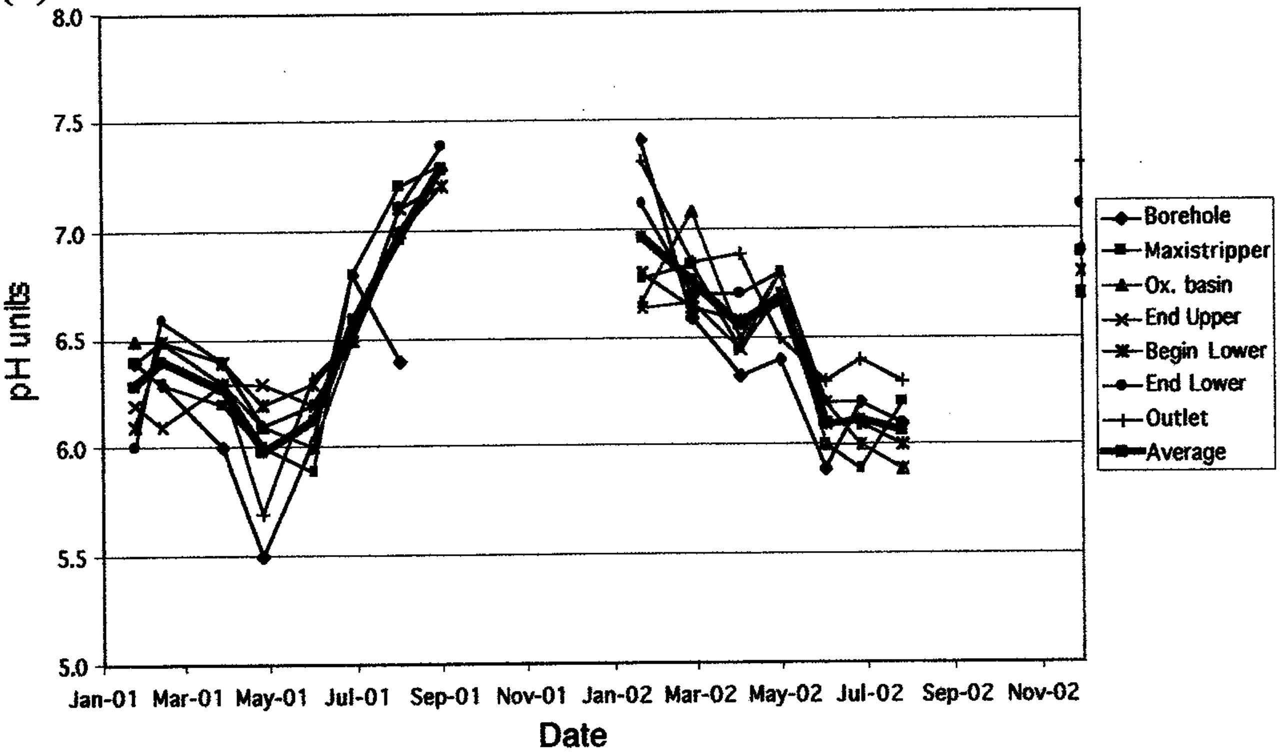


Figure 4 - Course of pH

Dundee Road Wetland, Hanover Twp., PA

Data from Wilkes University Wetland Team. 2001 - 2002

(a) Course over time



(b) Course from borehole to outlet - 2001

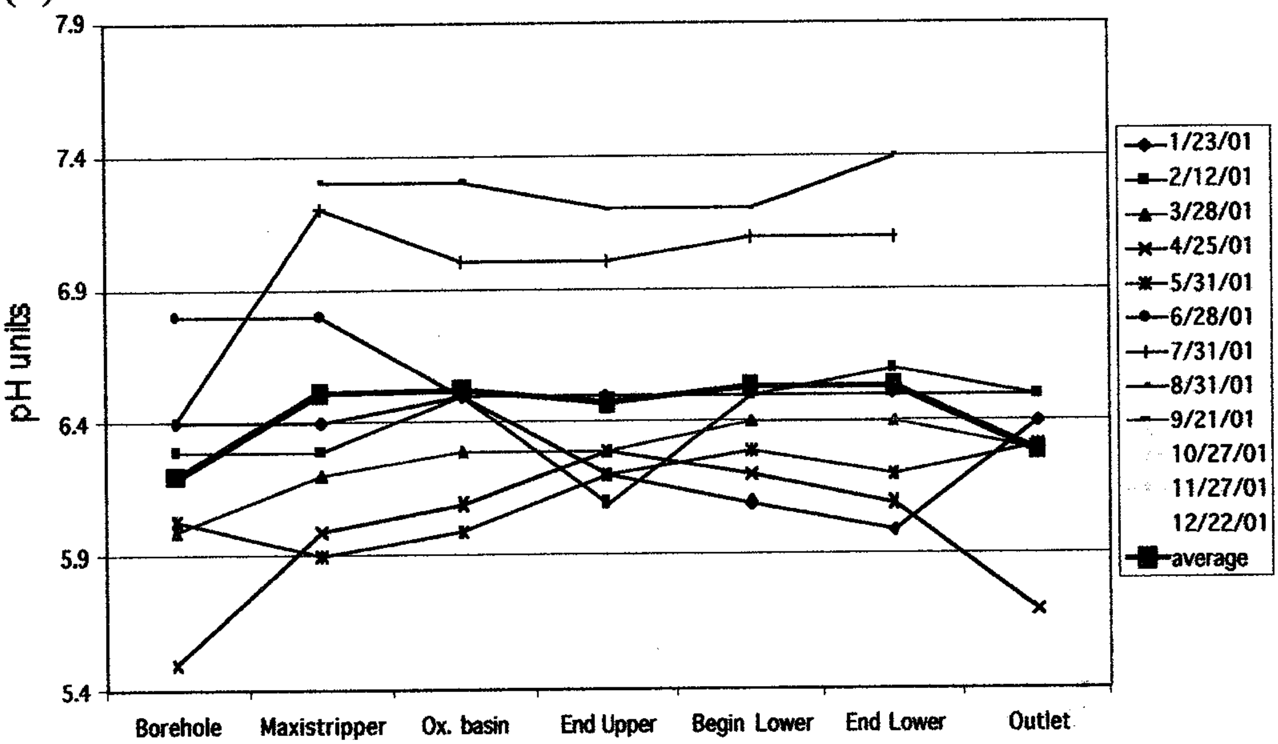
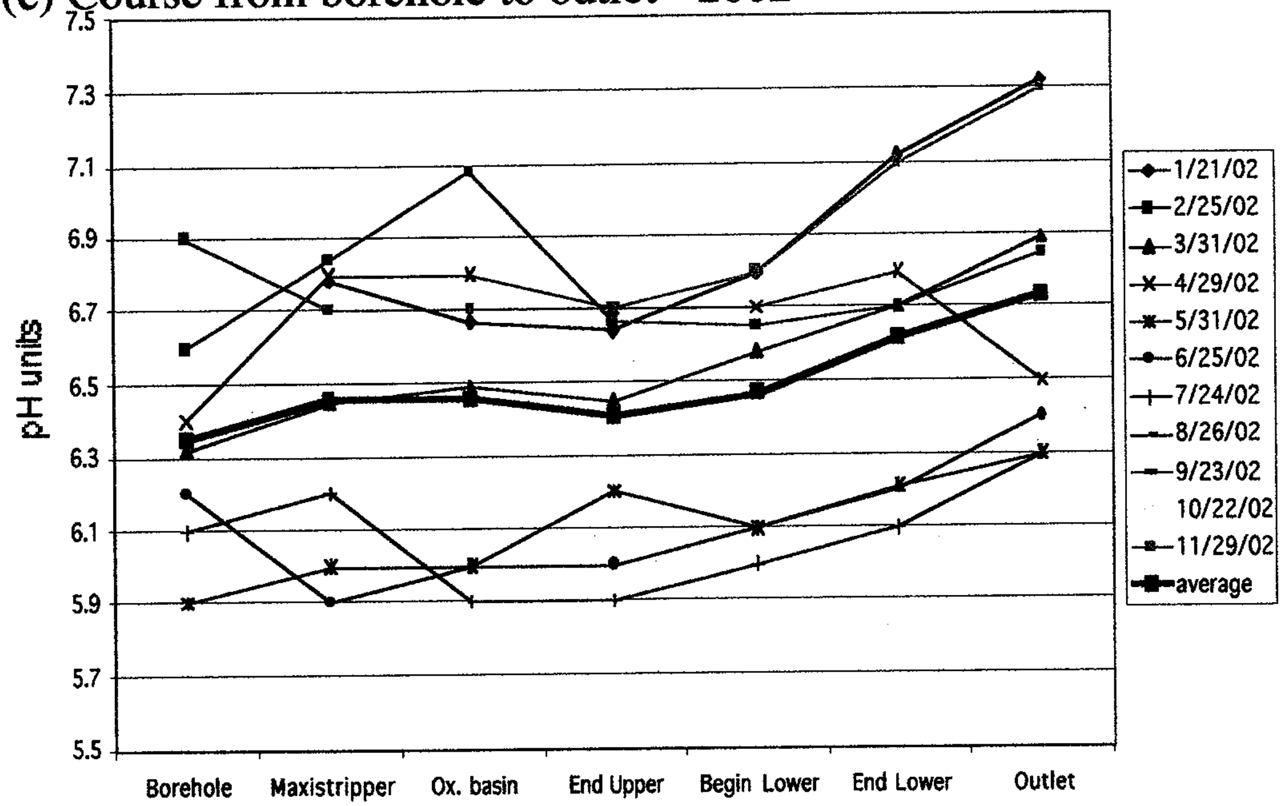


Figure 4 - Course of pH

Dundee Road Wetland, Hanover Twp., PA

Data from Wilkes University Wetland Team. 2001 - 2002

(c) Course from borehole to outlet - 2002



(d) Course from borehole to outlet - averages 1999 - 2002

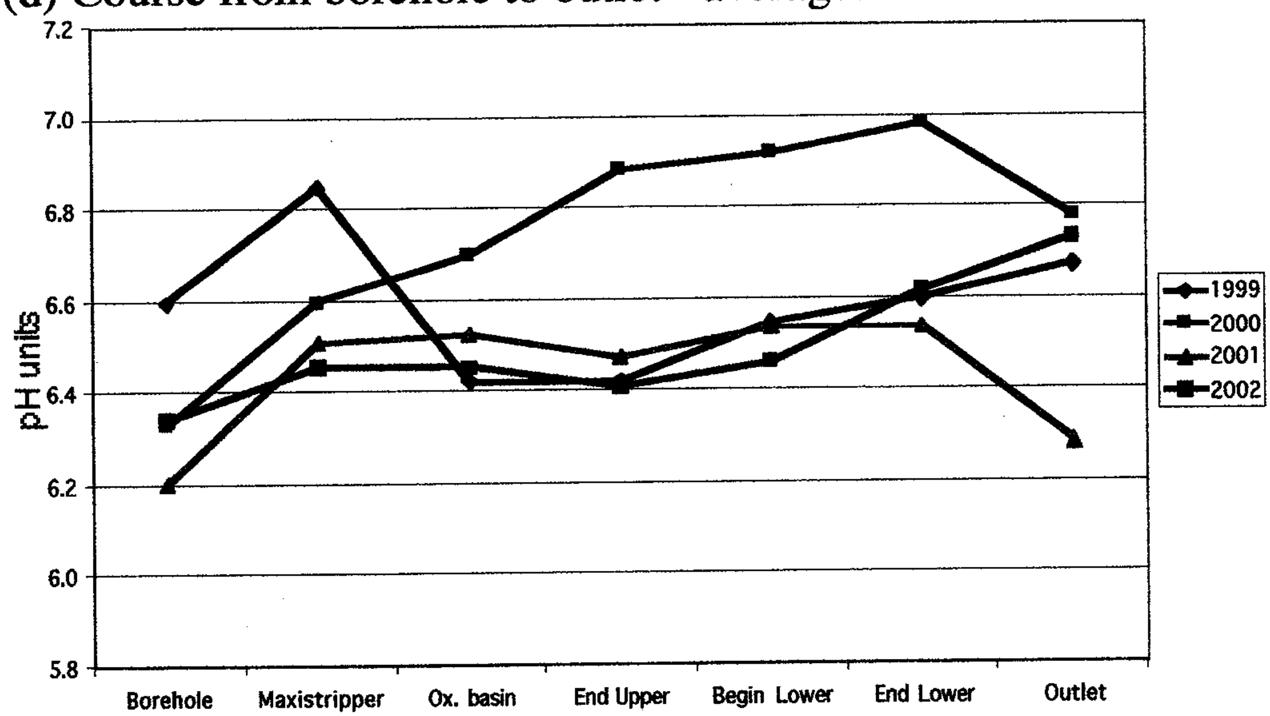
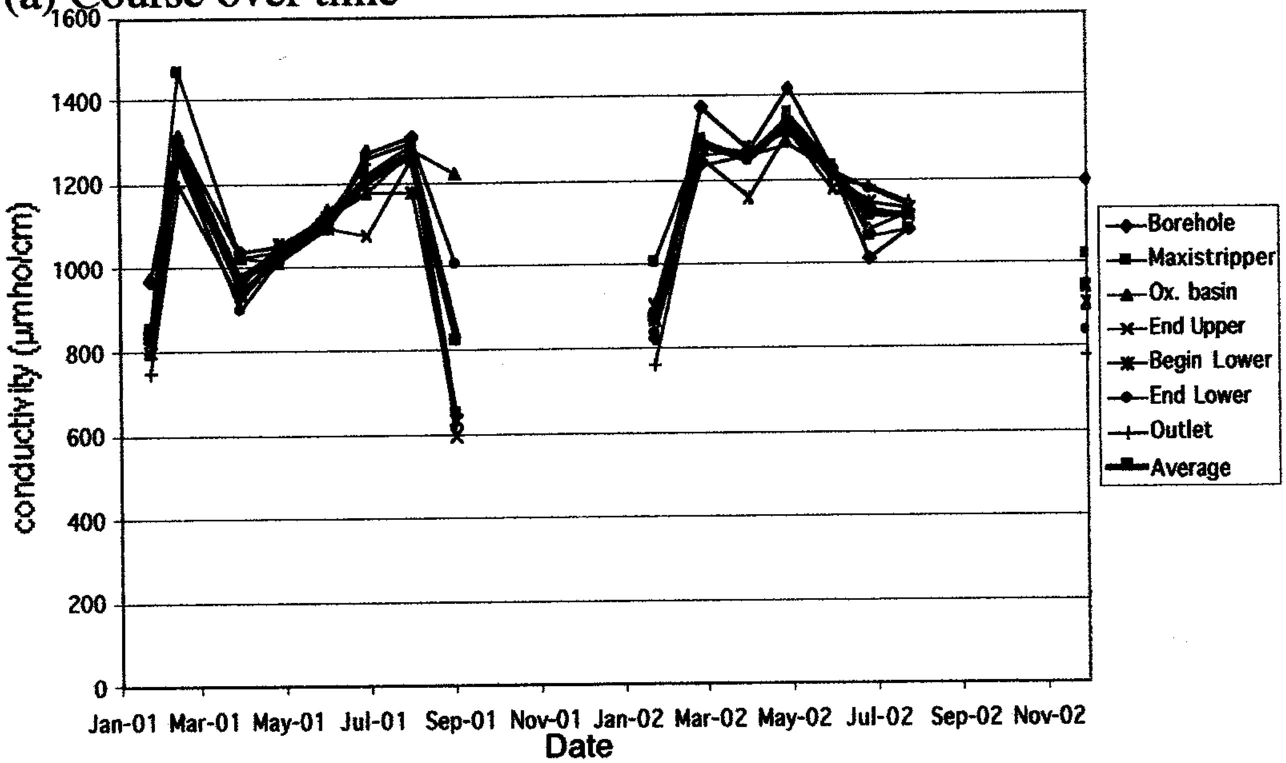


Figure 5 - Course of Conductivity

Dundee Road Wetland, Hanover Twp., PA

Data from Wilkes University Wetland Team. 2001 - 2002

(a) Course over time



(b) Course from borehole to outlet - 2001

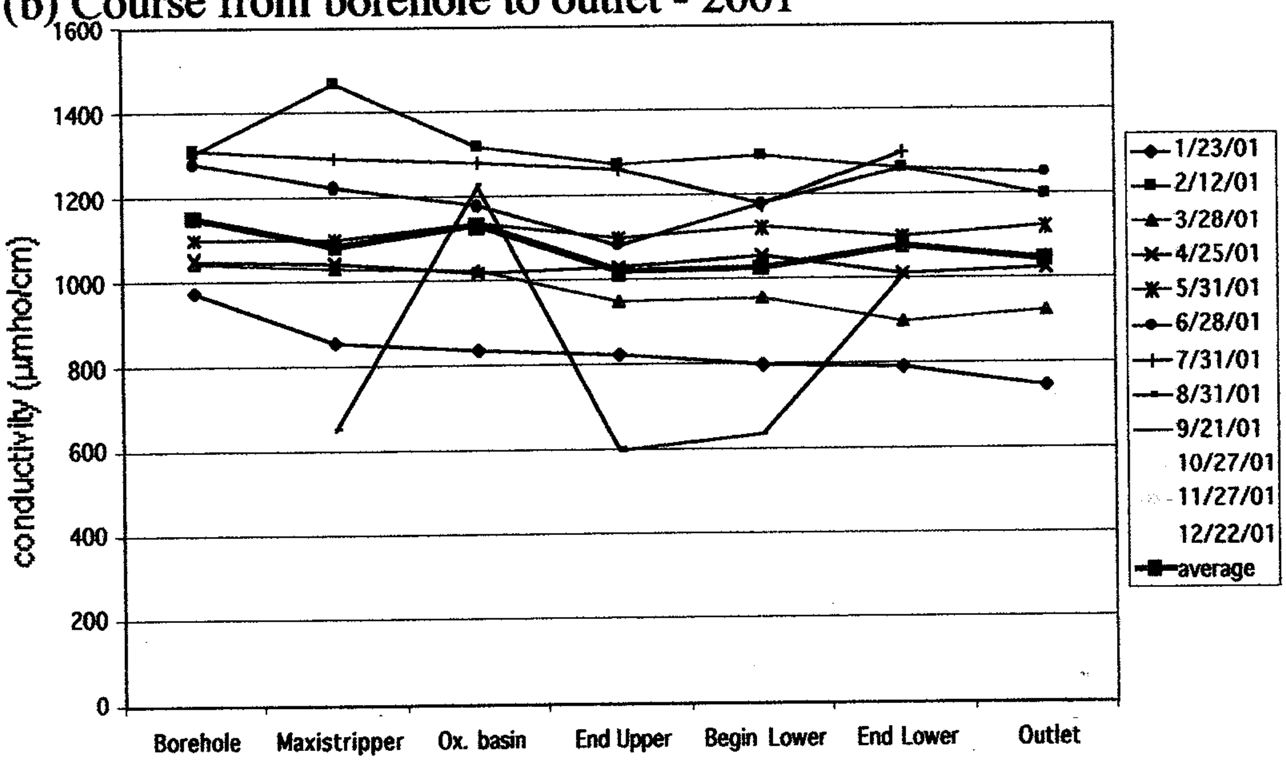
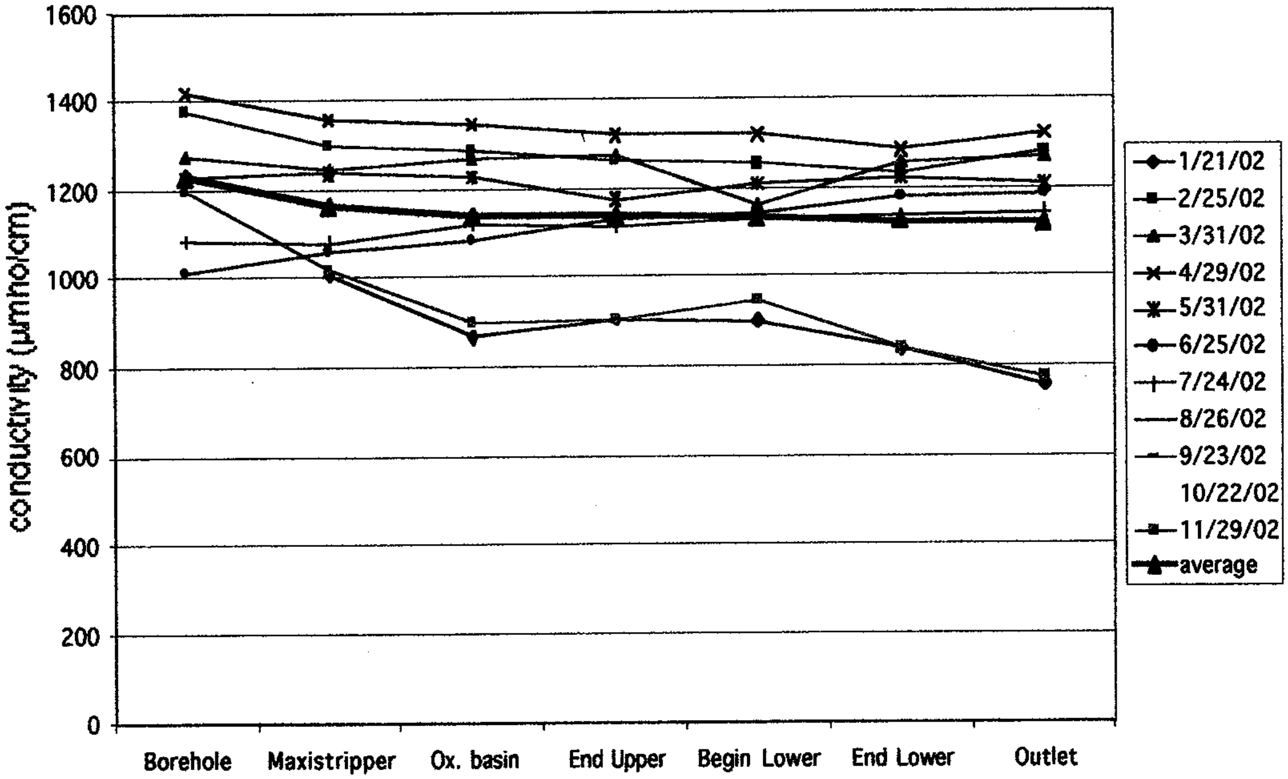


Figure 5 - Course of Conductivity

Dundee Road Wetland, Hanover Twp., PA

Data from Wilkes University Wetland Team. 2001 - 2002

(c) Course from borehole to outlet - 2002



(d) Course from borehole to outlet - averages 1999 - 2002

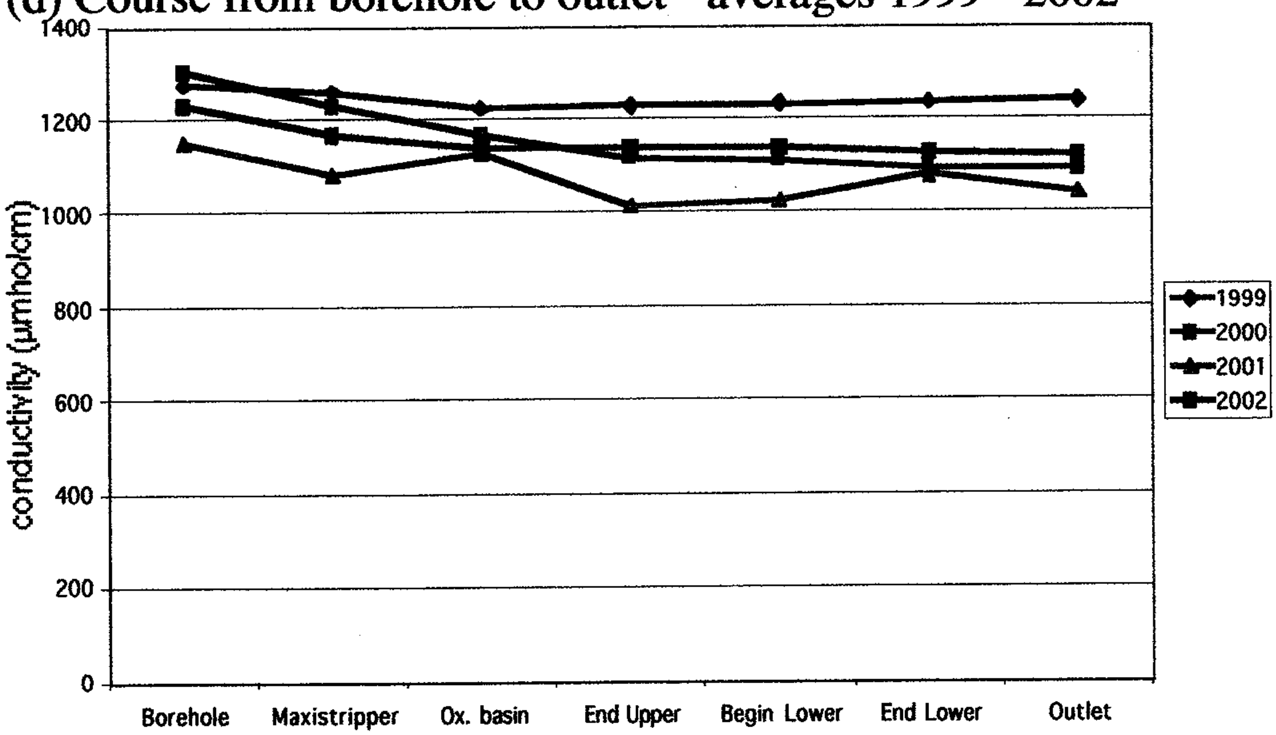
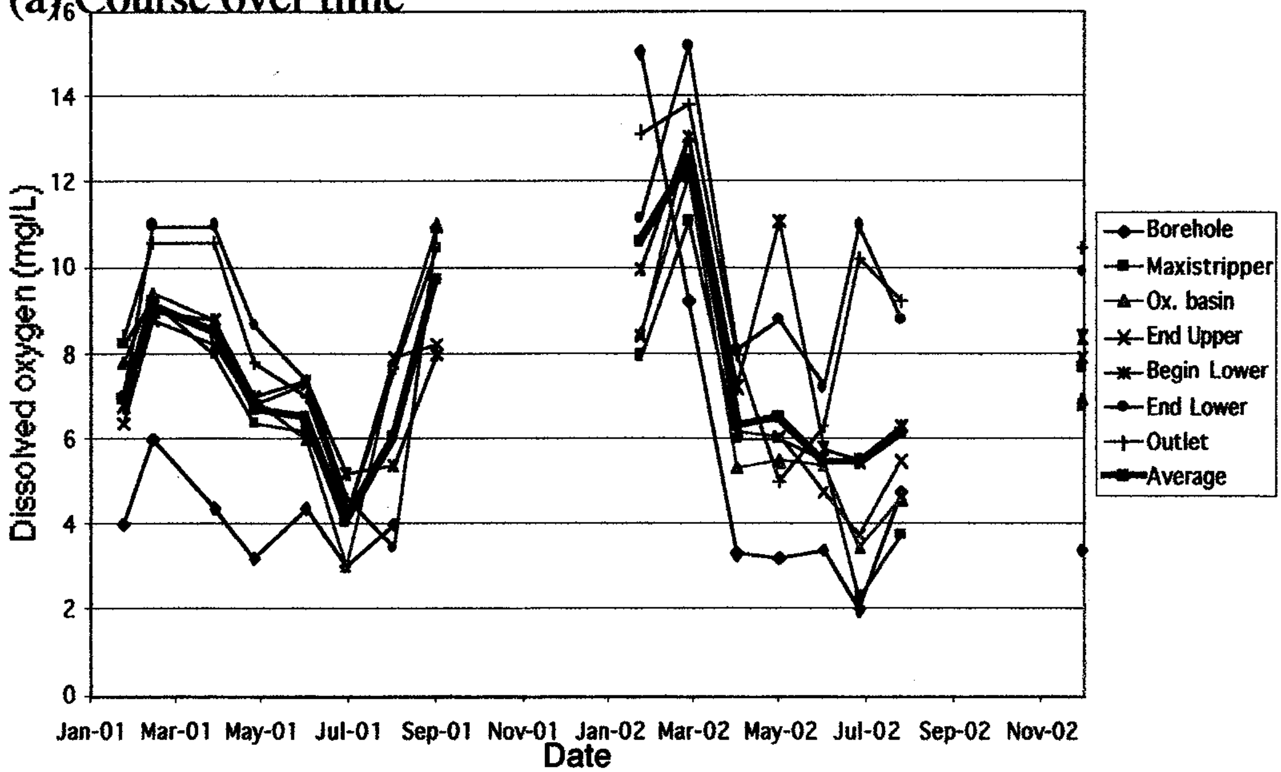


Figure 6 - Course of Dissolved Oxygen

Dundee Road Wetland, Hanover Twp., PA

Data from Wilkes University Wetland Team. 2001 - 2002

(a) Course over time



(b) Course from borehole to outlet - 2001

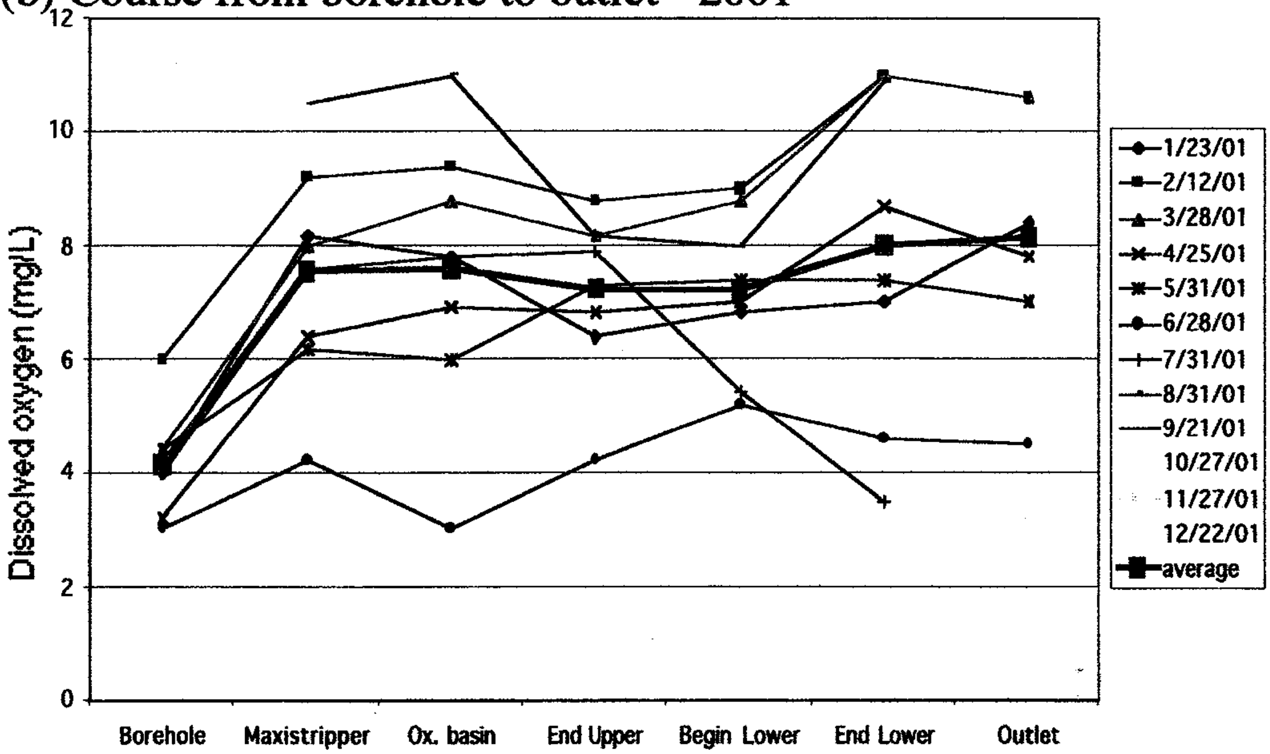
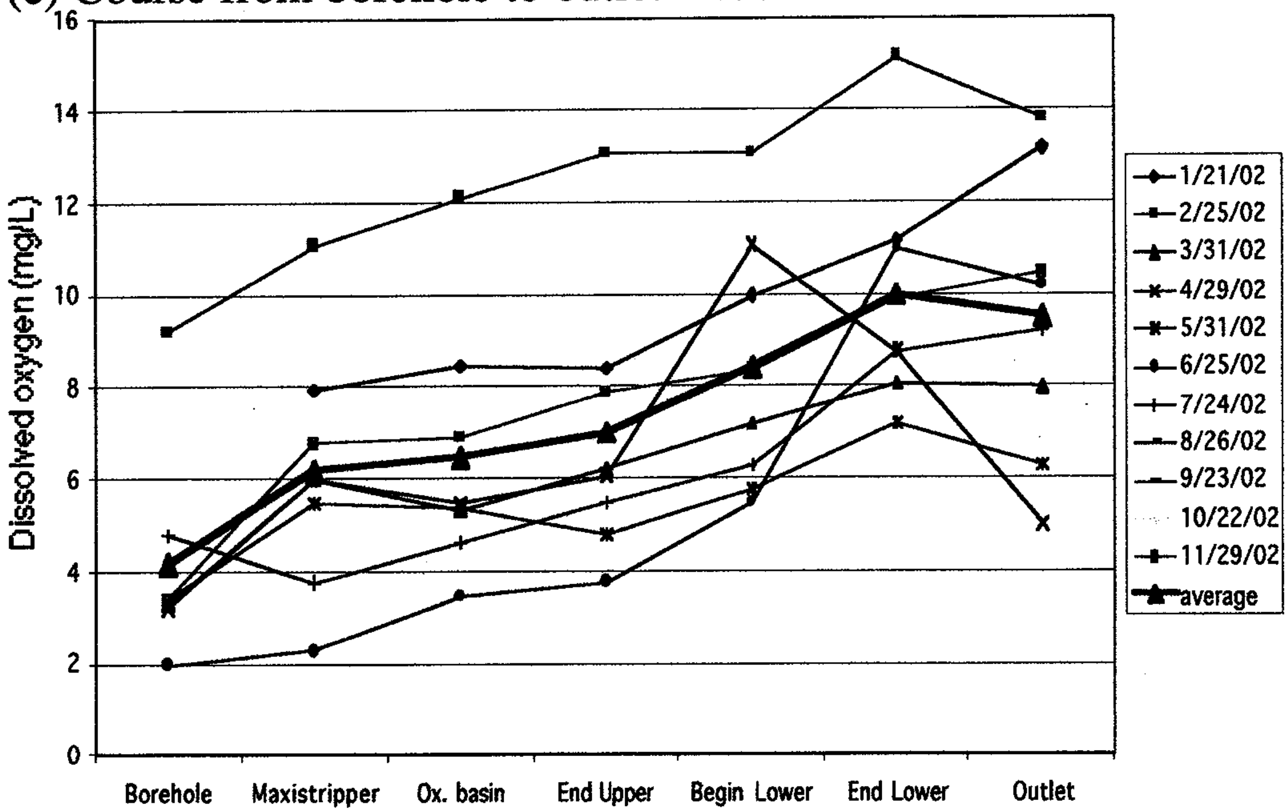


Figure 6 - Course of Dissolved Oxygen

Dundee Road Wetland, Hanover Twp., PA

Data from Wilkes University Wetland Team. 2001 - 2002

(c) Course from borehole to outlet - 2002



(d) Course from borehole to outlet - averages 1999 - 2002

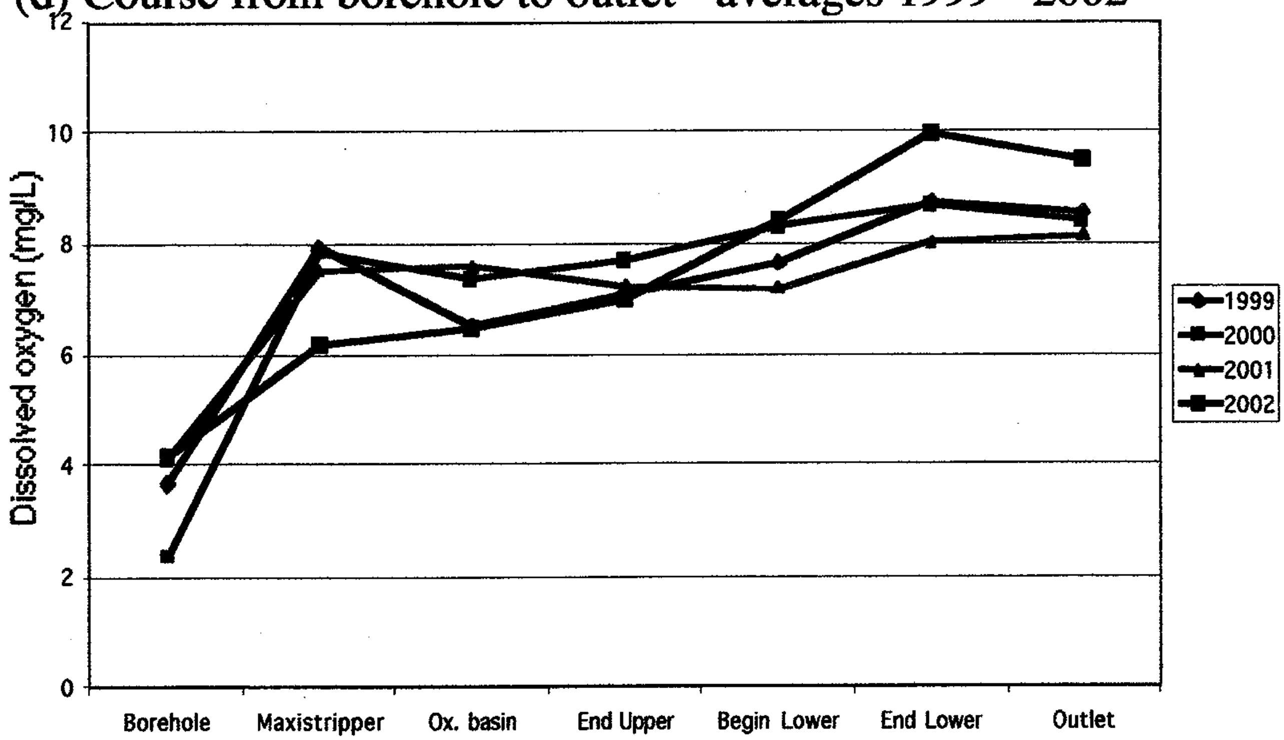
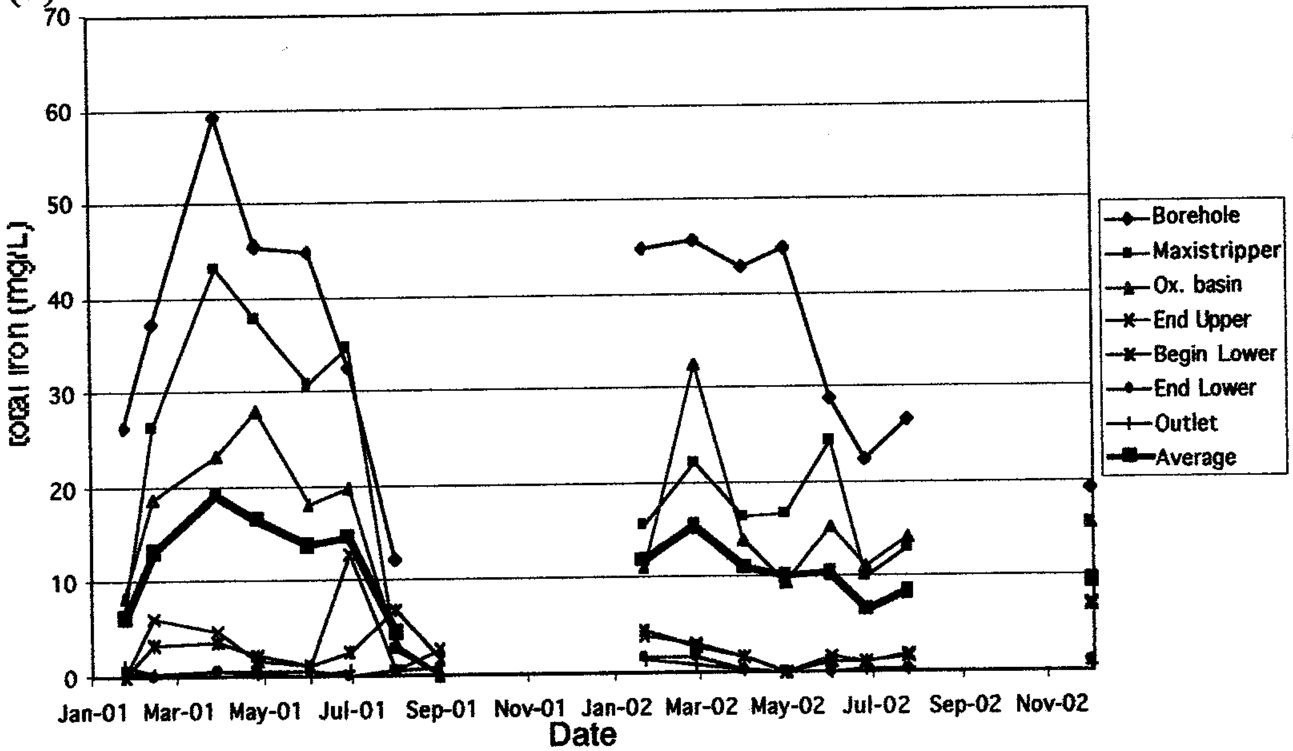


Figure 7 - Course of Total Iron Concentrations

Dundee Road Wetland, Hanover Twp., PA

Data from Wilkes University Wetland Team. 2001 - 2002

(a) Course over time



(b) Course from borehole to outlet - 2001

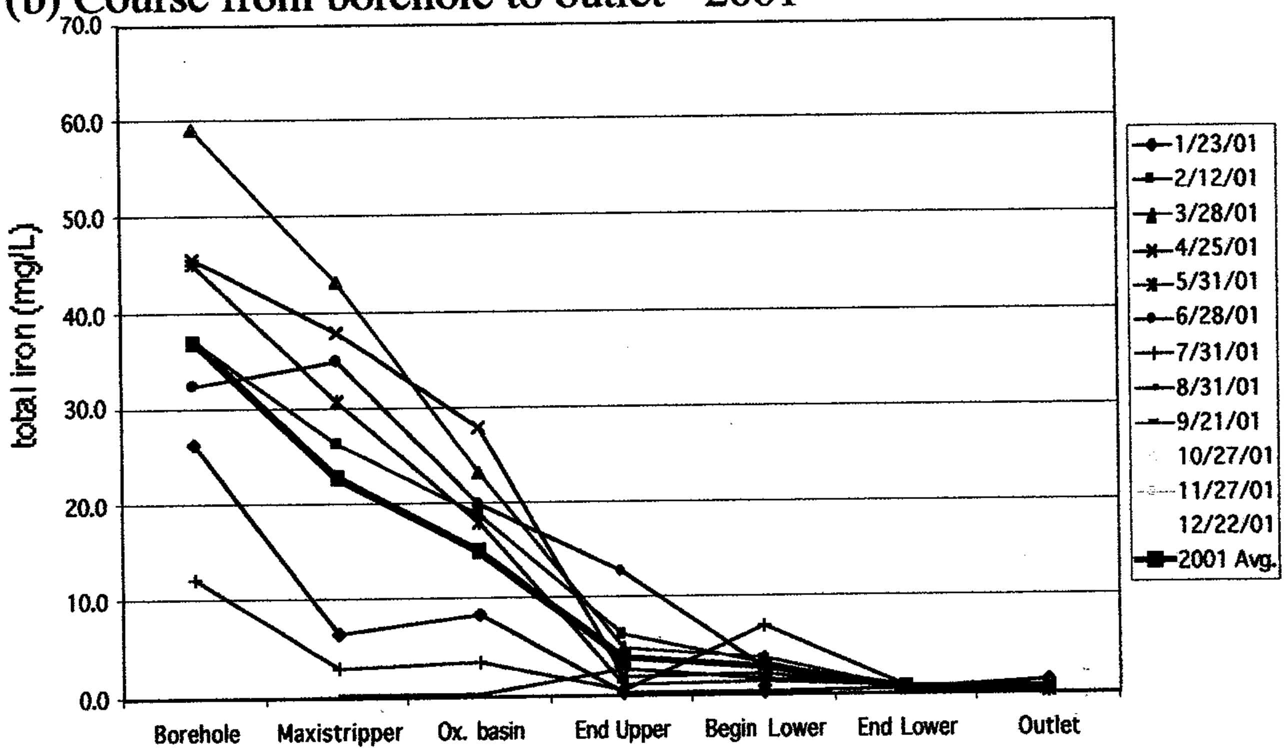
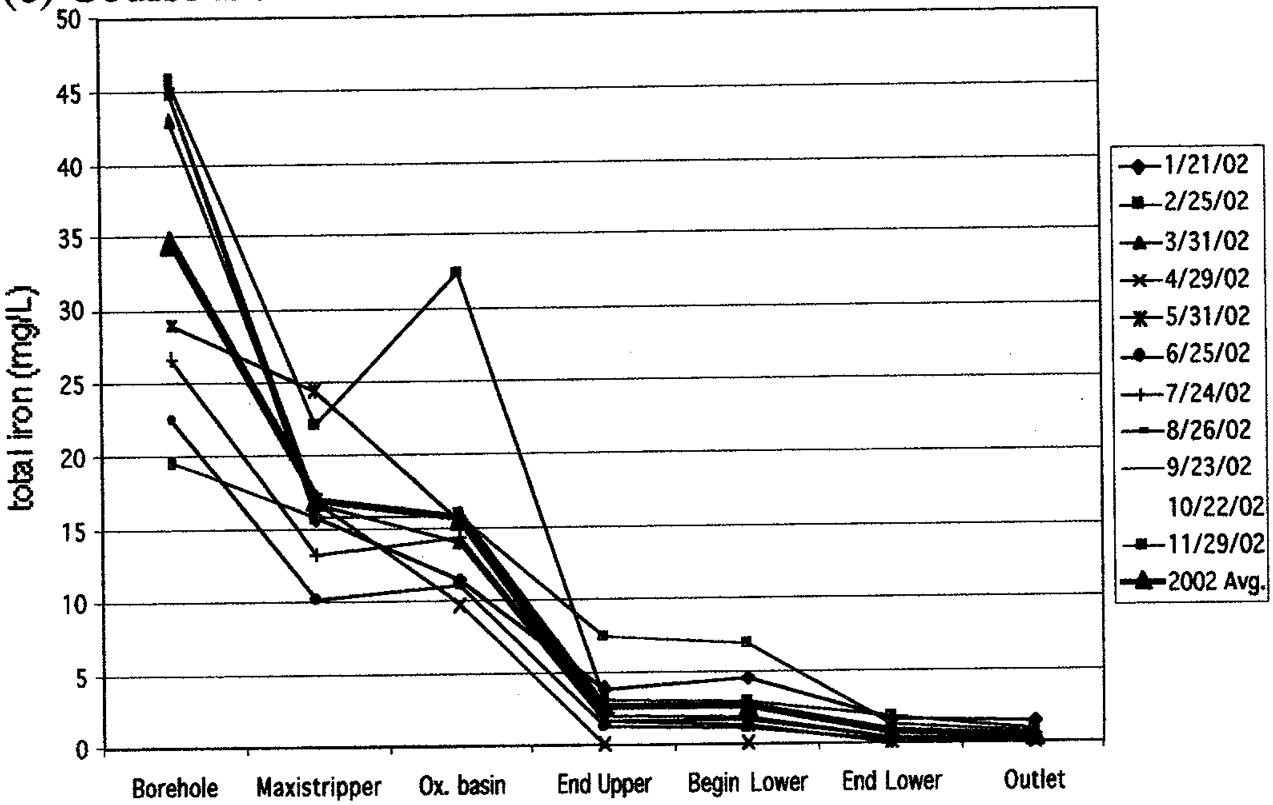


Figure 7 - Course of Total Iron Concentrations

Dundee Road Wetland, Hanover Twp., PA

Data from Wilkes University Wetland Team. 2001 - 2002

(c) Course from borehole to outlet - 2002



(d) Course from borehole to outlet - averages 1999 - 2002

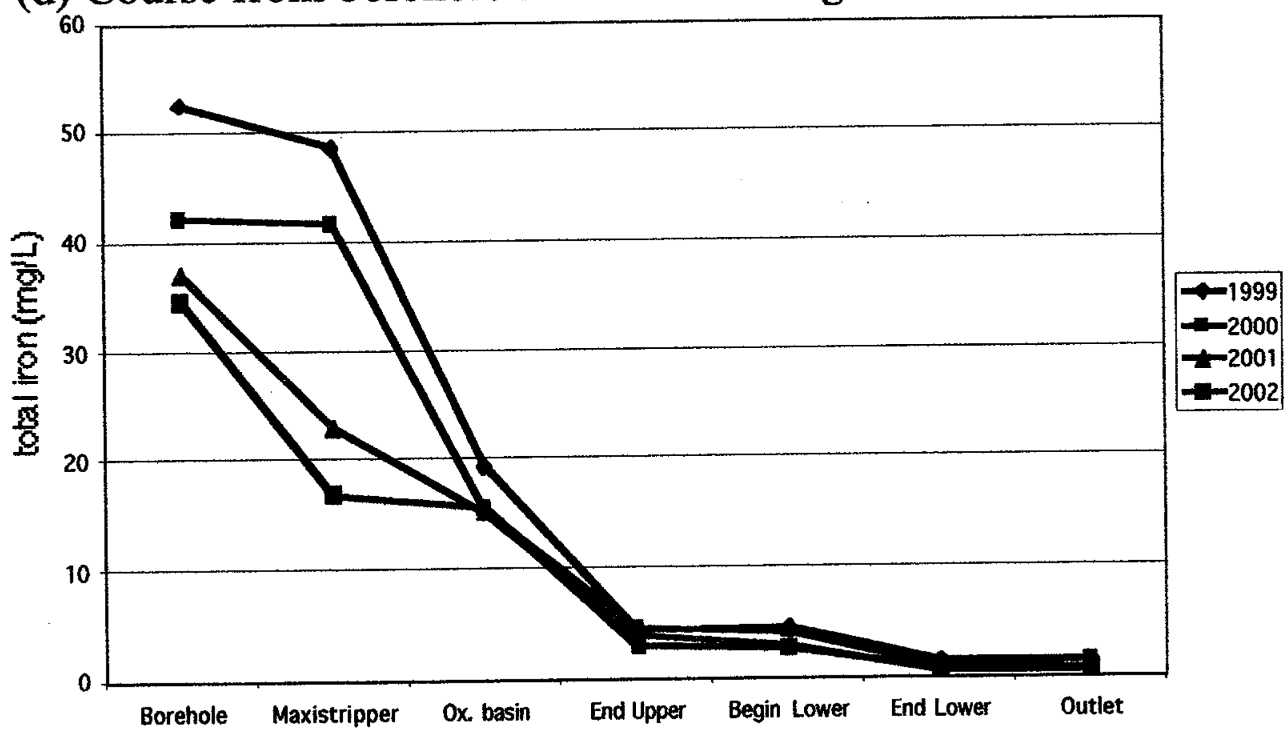
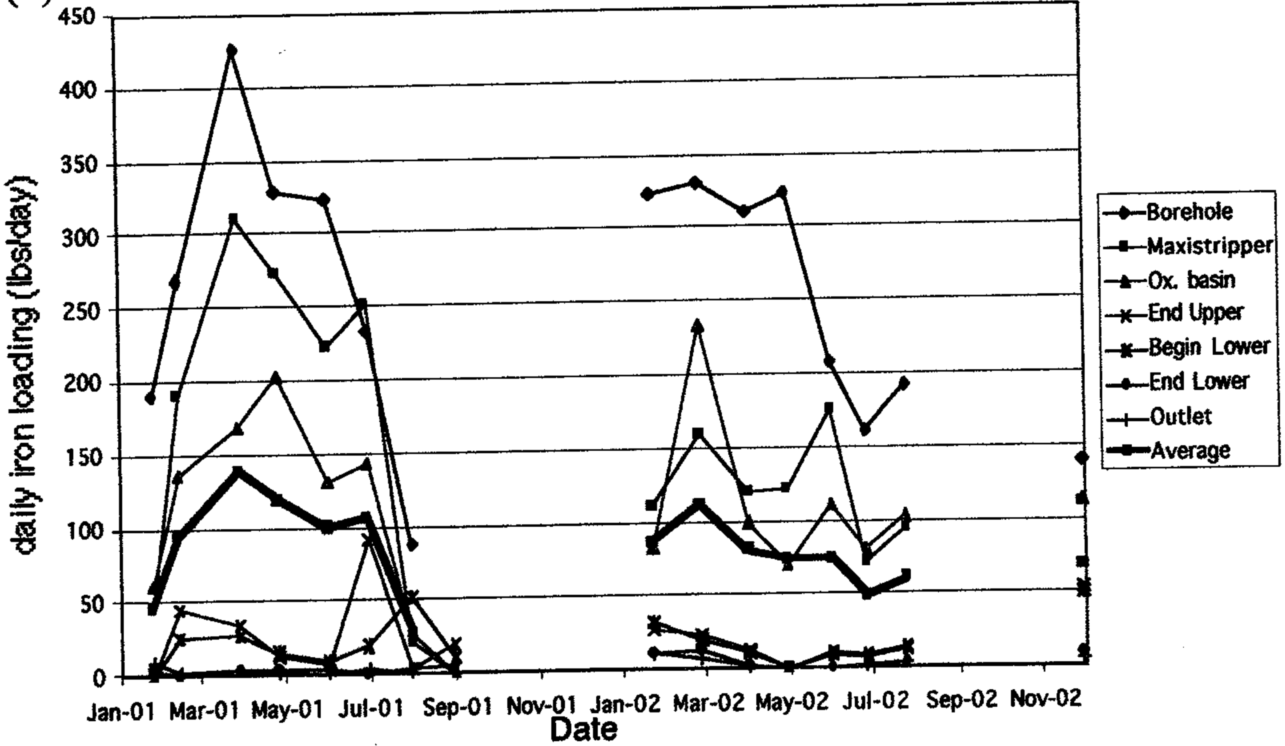


Figure 8 - Course of Iron Loading

Dundee Road Wetland, Hanover Twp., PA

Data from Wilkes University Wetland Team. Jan. - June 2002

(a) Course over time



(b) Course from borehole to outlet - 2001

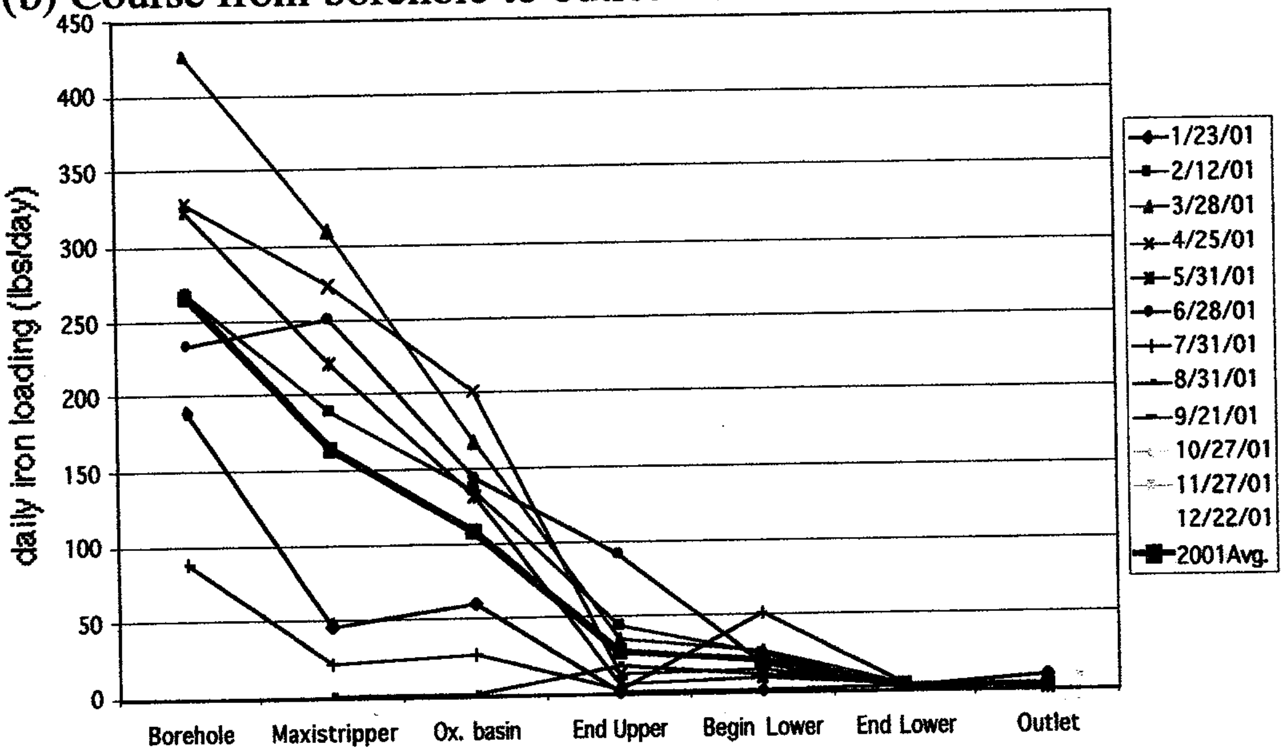
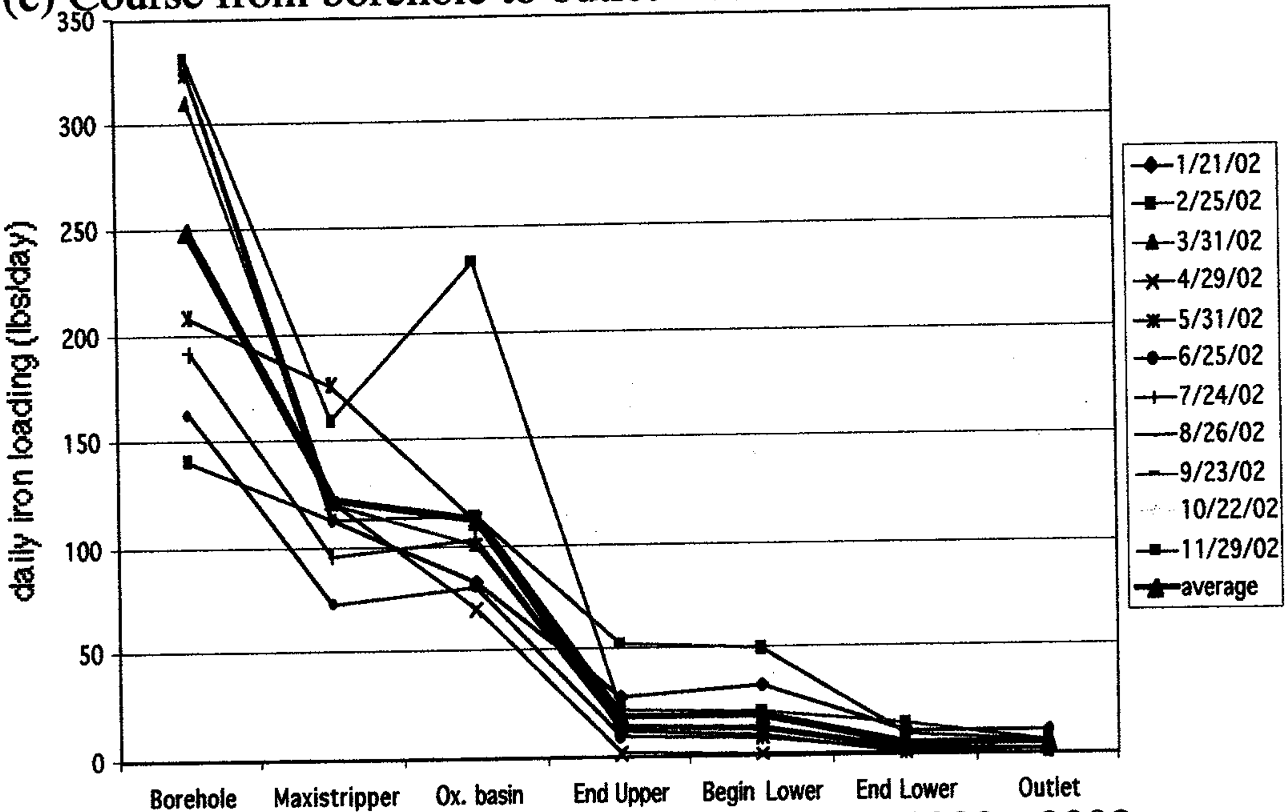


Figure 8 - Course of Iron Loading
Dundee Road Wetland, Hanover Twp., PA
Data from Wilkes University Wetland Team. Jan. - June 2002

(c) Course from borehole to outlet - 2002



(d) Course from borehole to outlet - averages 1999 - 2002

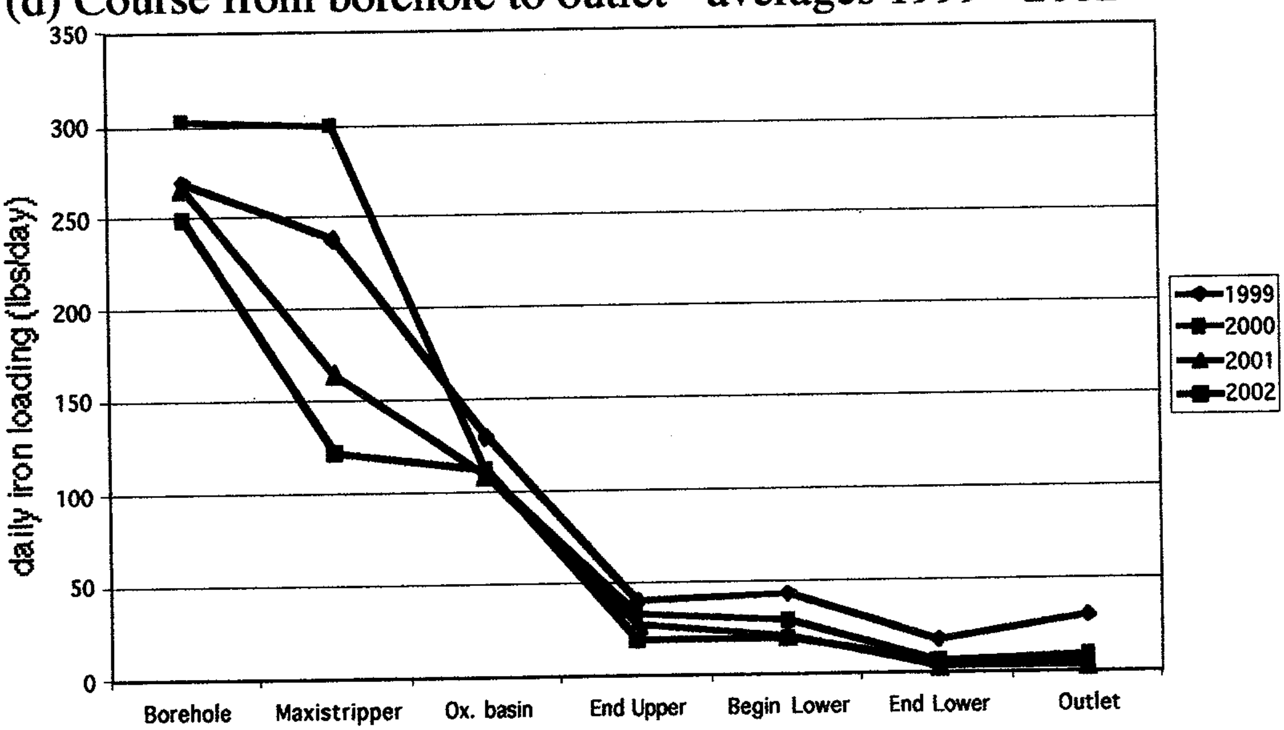
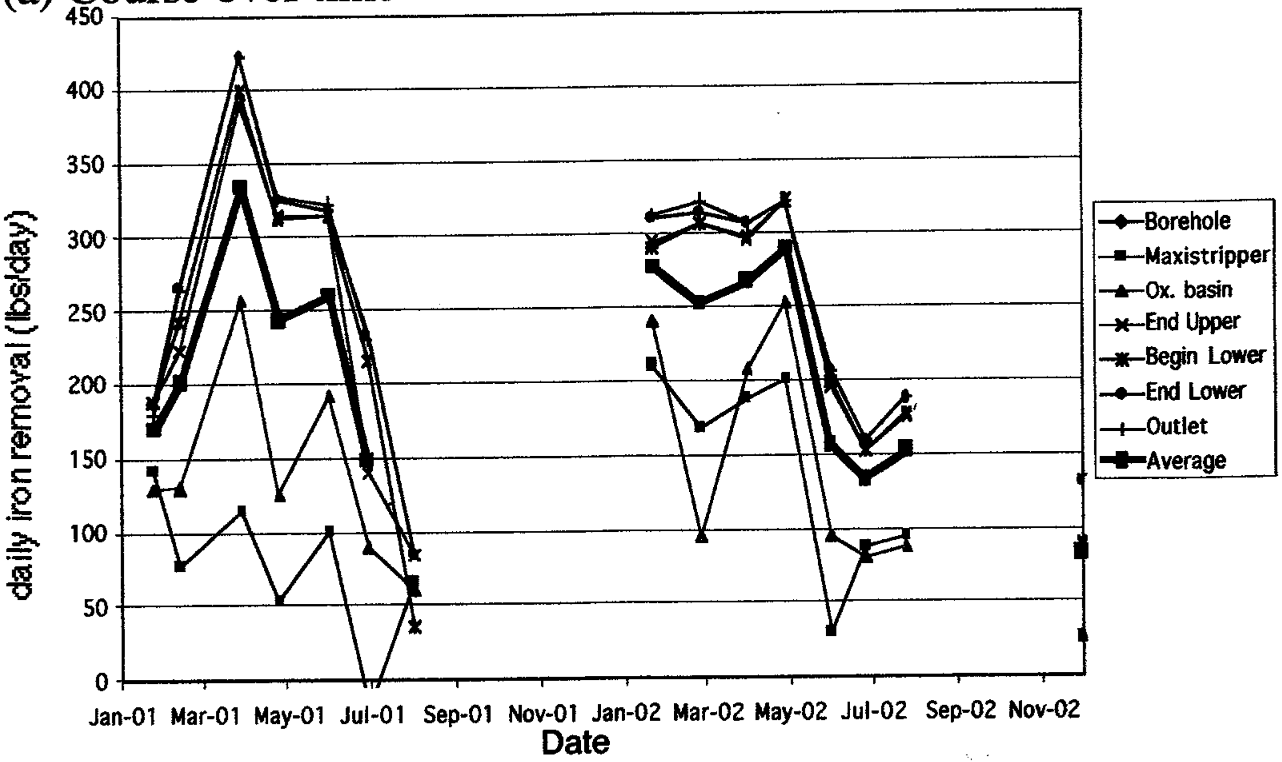


Figure 9 - Cumulative Iron Removal

Dundee Road Wetland, Hanover Twp., PA

Data from Wilkes University Wetland Team. 2001 - 2002

(a) Course over time



(b) Course from borehole to outlet - 2001

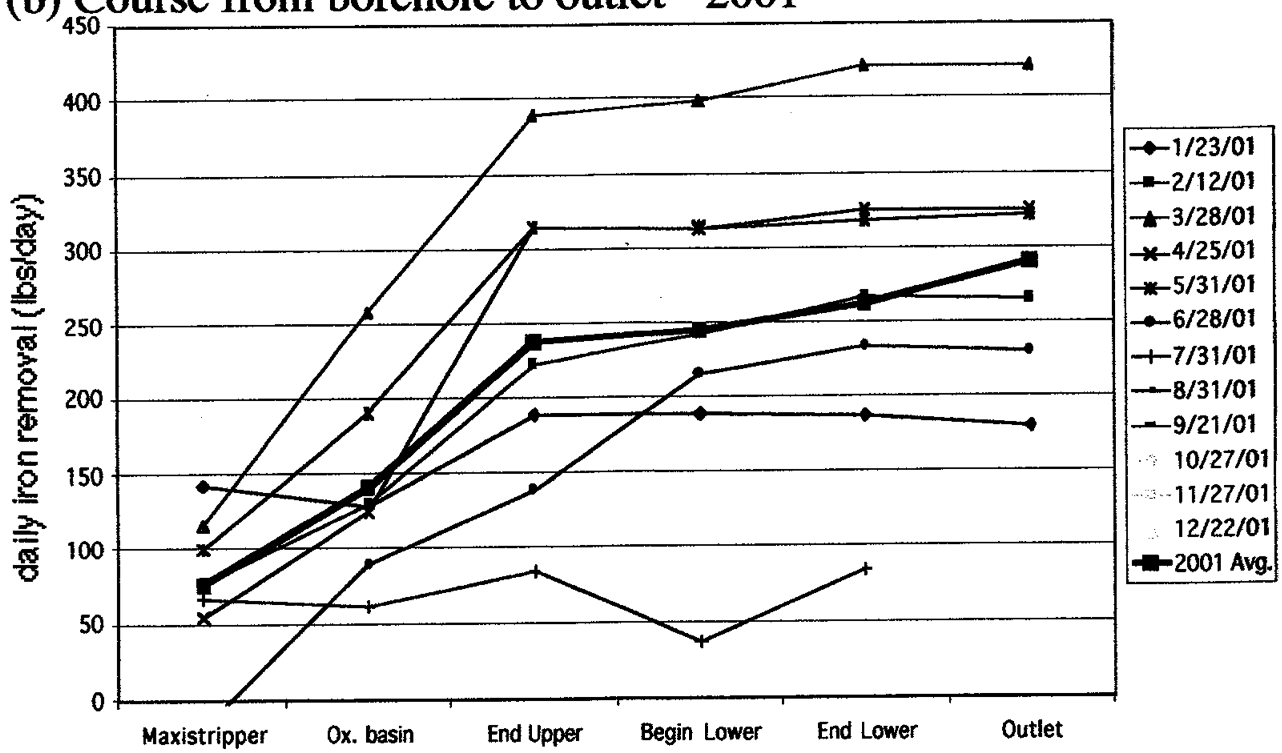
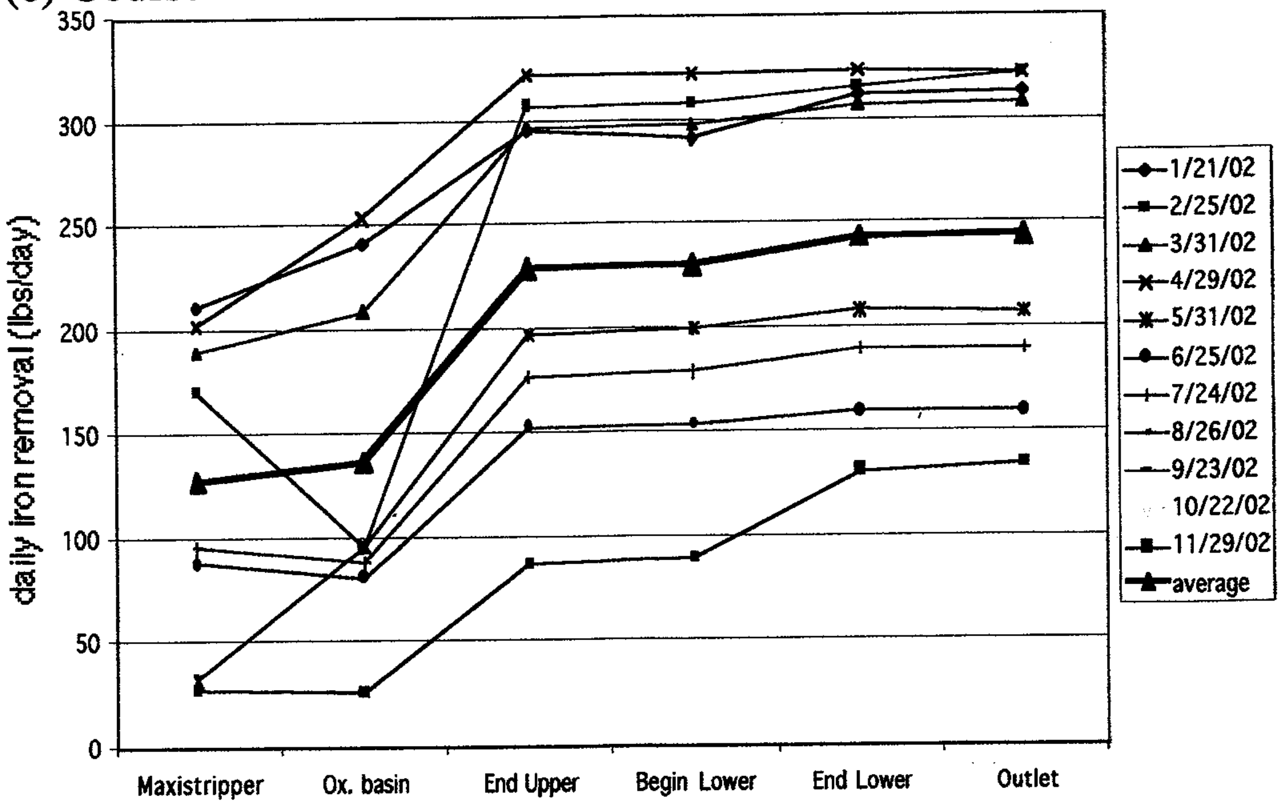


Figure 9 - Cumulative Iron Removal
Dundee Road Wetland, Hanover Twp., PA
Data from Wilkes University Wetland Team. 2001 - 2002

(c) Course from borehole to outlet - 2002



(d) Course from borehole to outlet - averages 1999 - 2002

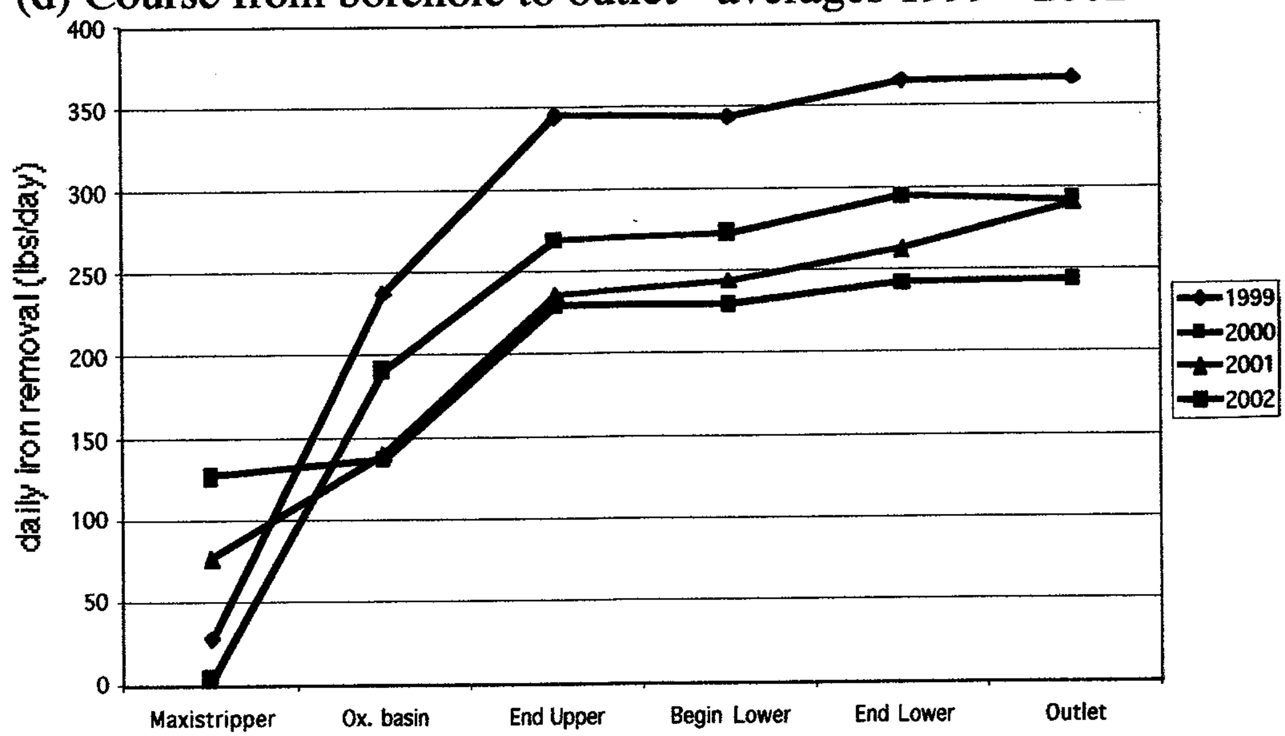
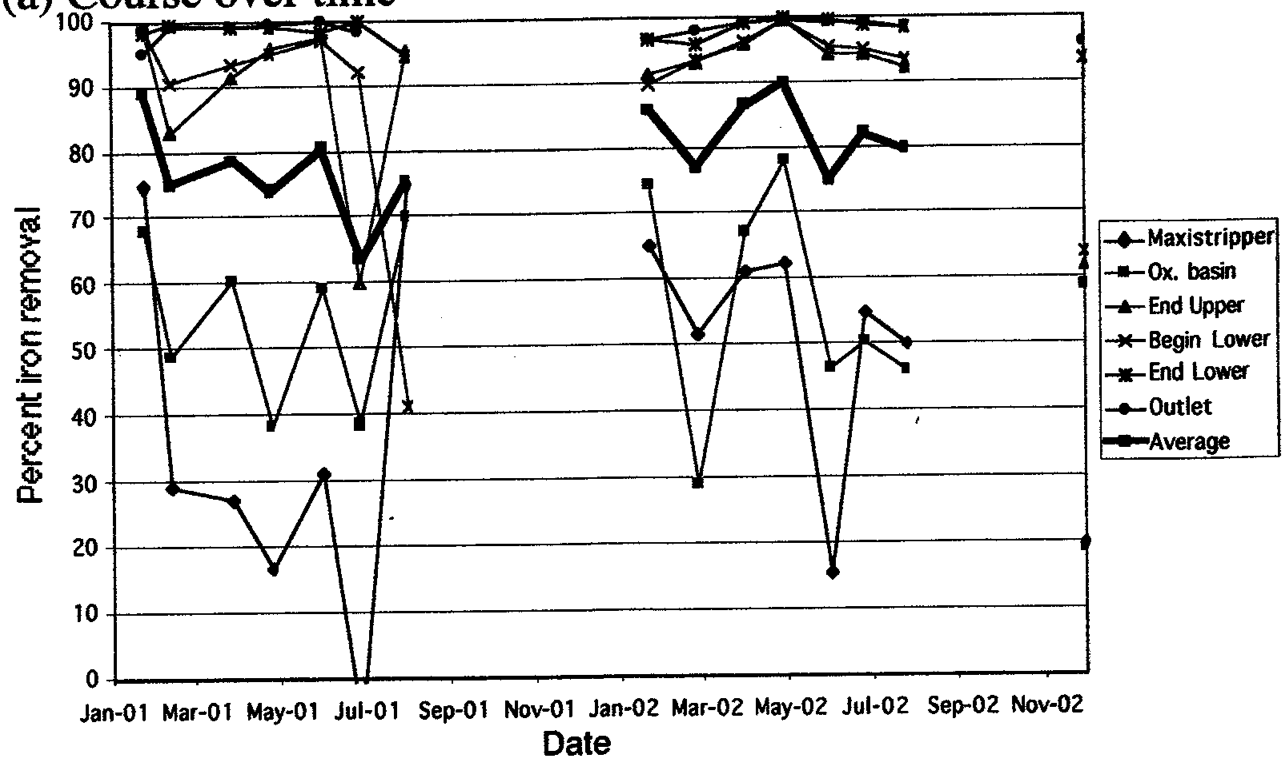


Figure 10 - Cumulative Percent Iron Removal

Dundee Road Wetland, Hanover Twp., PA

Data from Wilkes University Wetland Team. 2001 - 2002

(a) Course over time



(b) Course from borehole to outlet - 2001

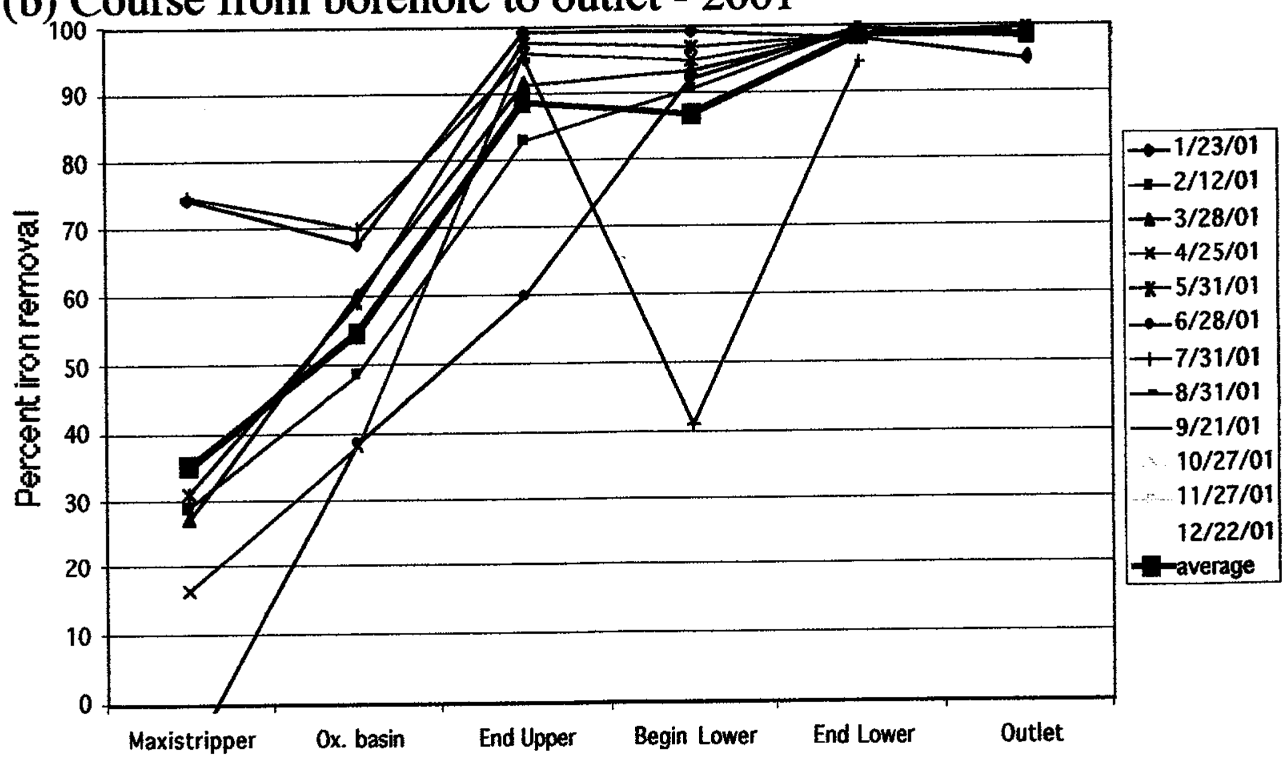
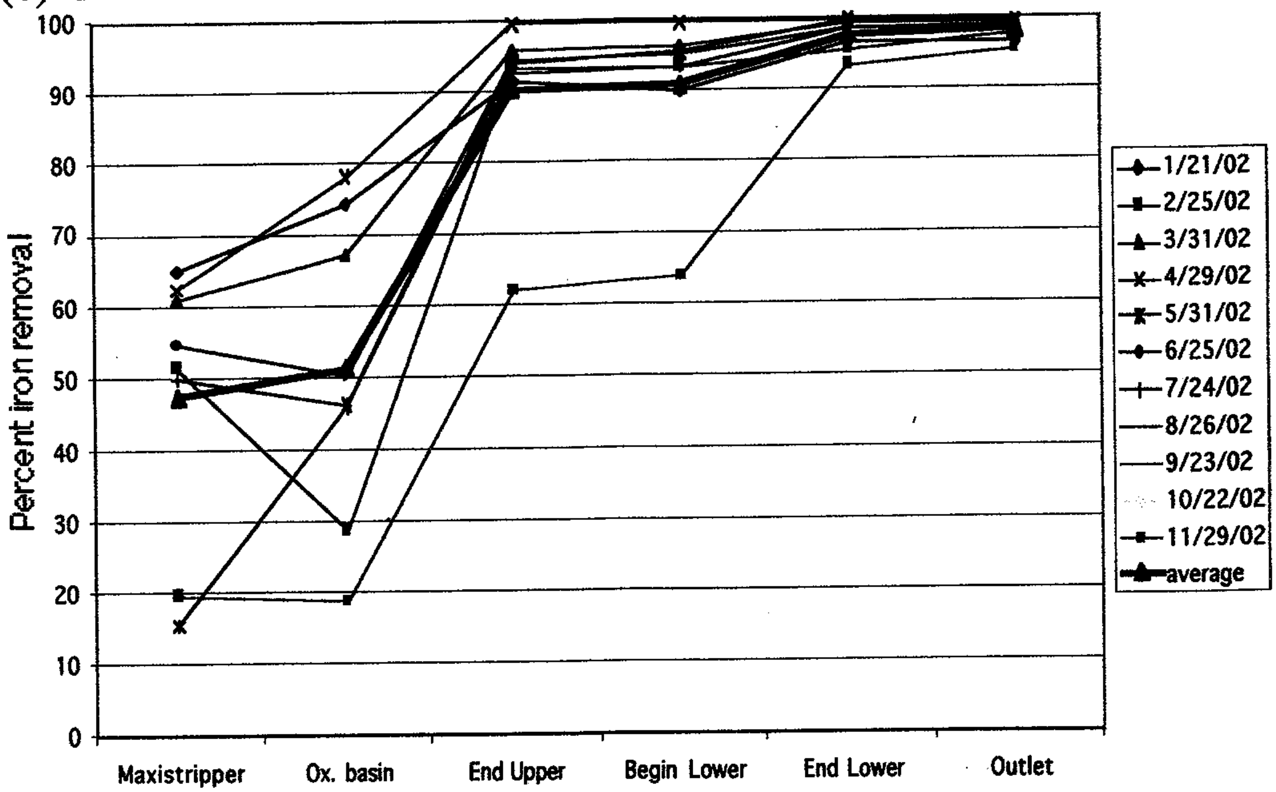


Figure 10 - Cumulative Percent Iron Removal

Dundee Road Wetland, Hanover Twp., PA

Data from Wilkes University Wetland Team. 2001 - 2002

(c) Course from borehole to outlet - 2002



(d) Course from borehole to outlet - averages 1999 - 2002

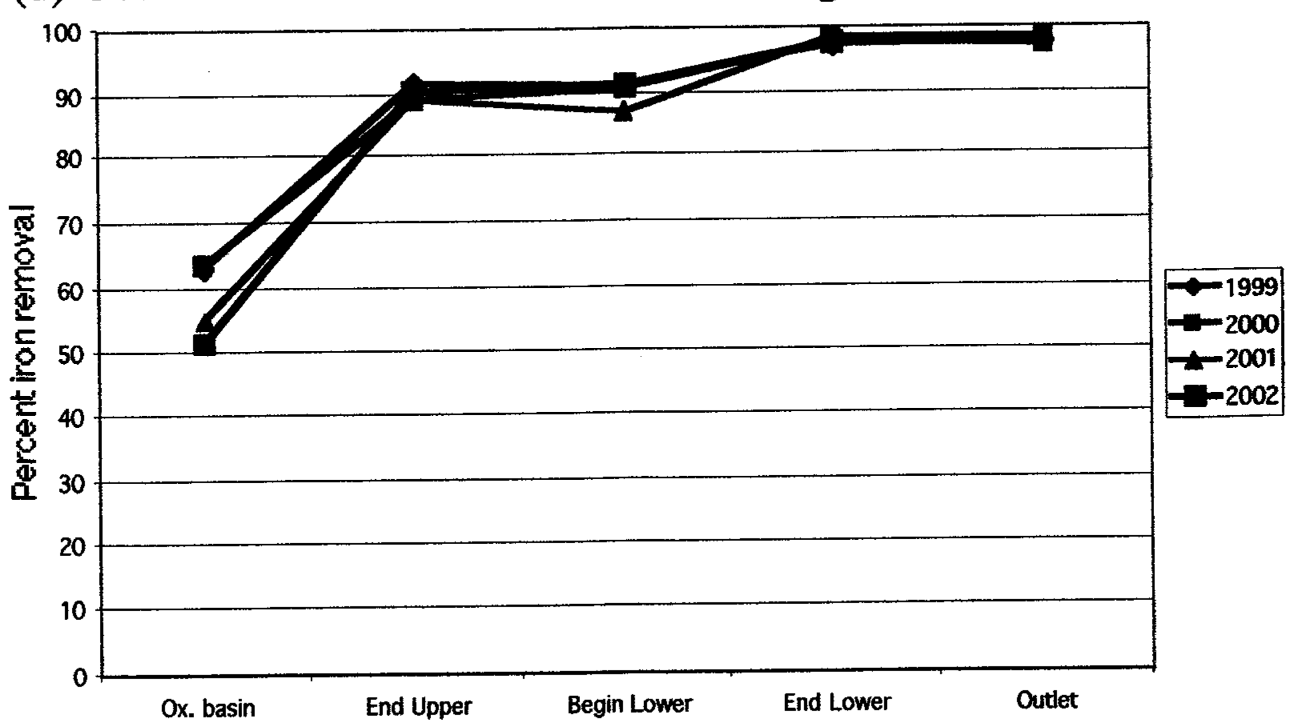
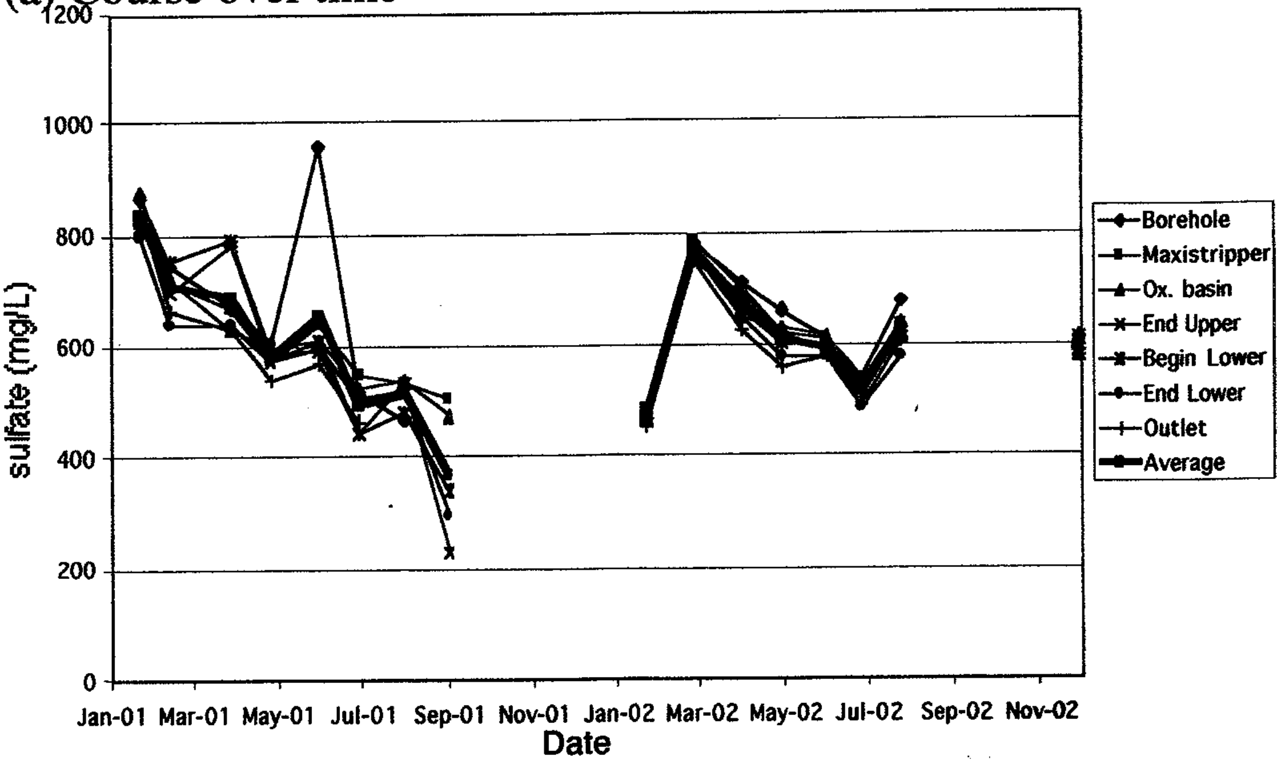


Figure 11 - Course of Sulfate
Dundee Road Wetland, Hanover Twp., PA
Data from Wilkes University Wetland Team. 2001 - 2002

(a) Course over time



(b) Course from borehole to outlet - 2001

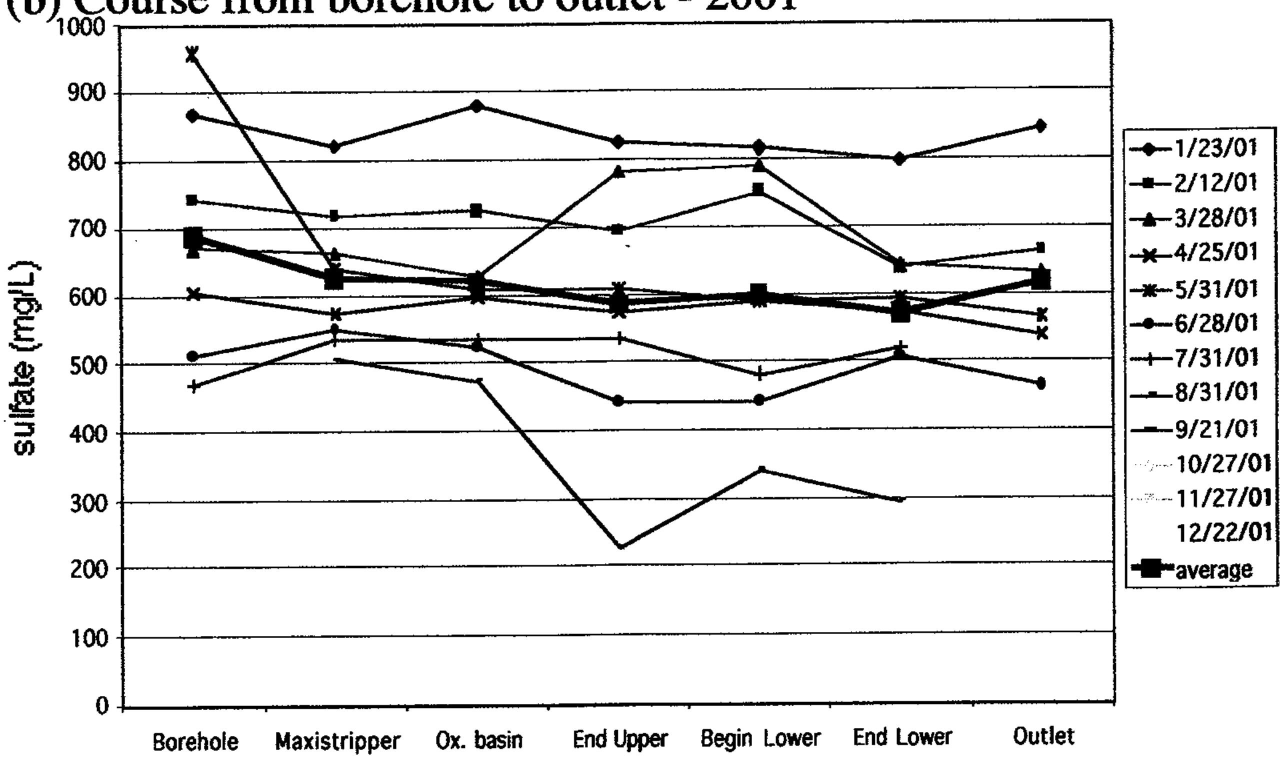
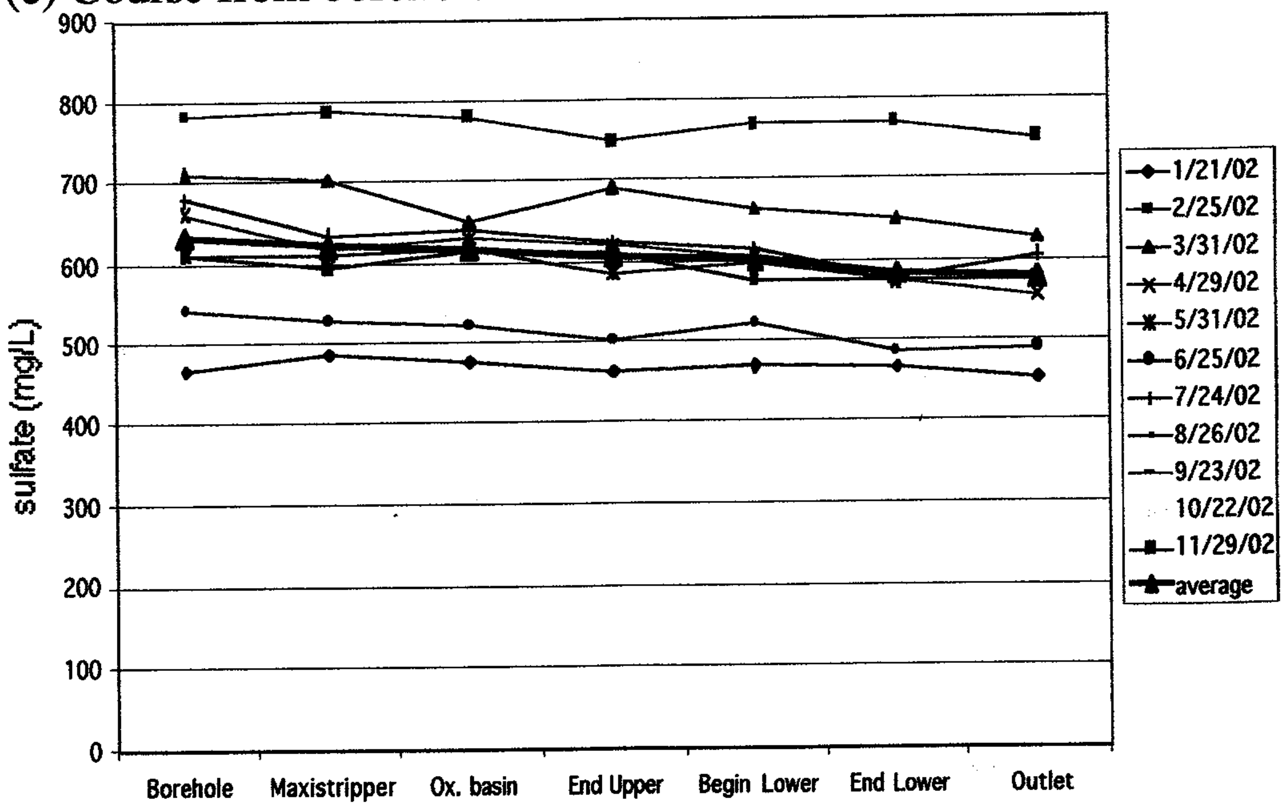


Figure 11 - Course of Sulfate

Dundee Road Wetland, Hanover Twp., PA

Data from Wilkes University Wetland Team. 2001 - 2002

(c) Course from borehole to outlet - 2002



(d) Course from borehole to outlet - averages 1999 - 2002

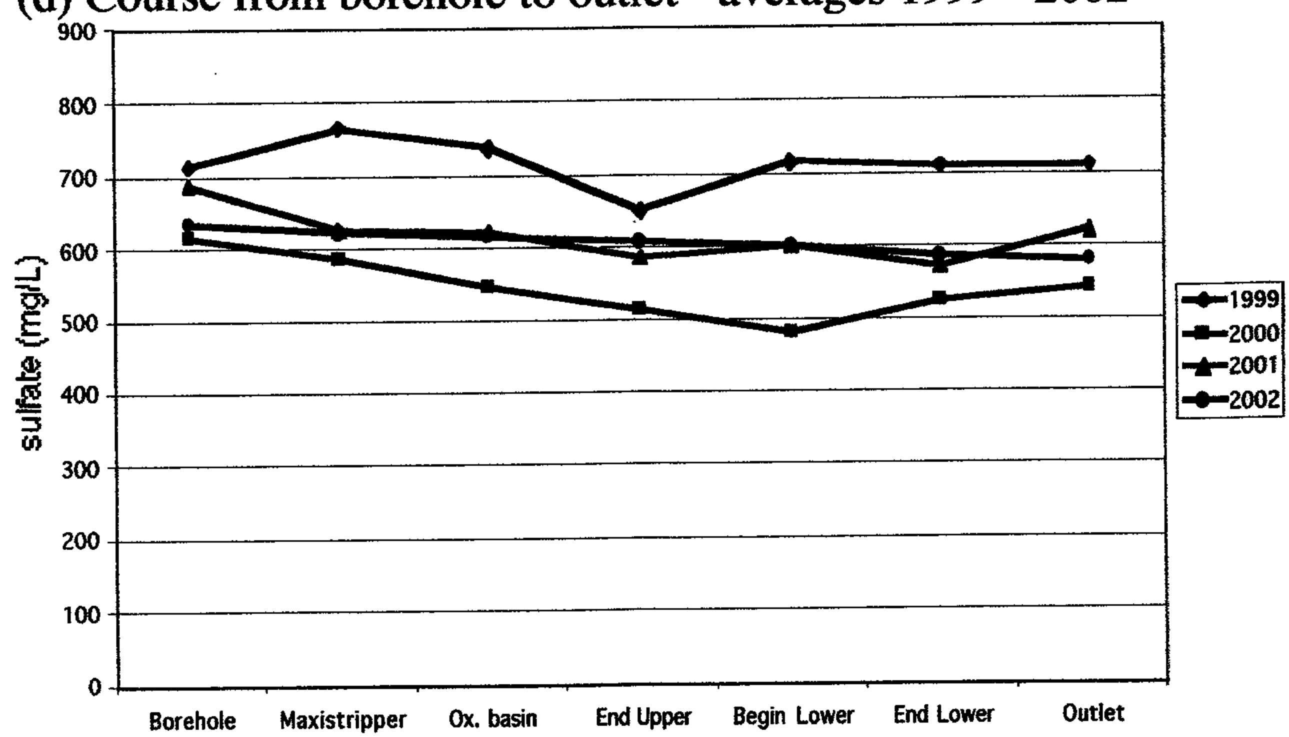
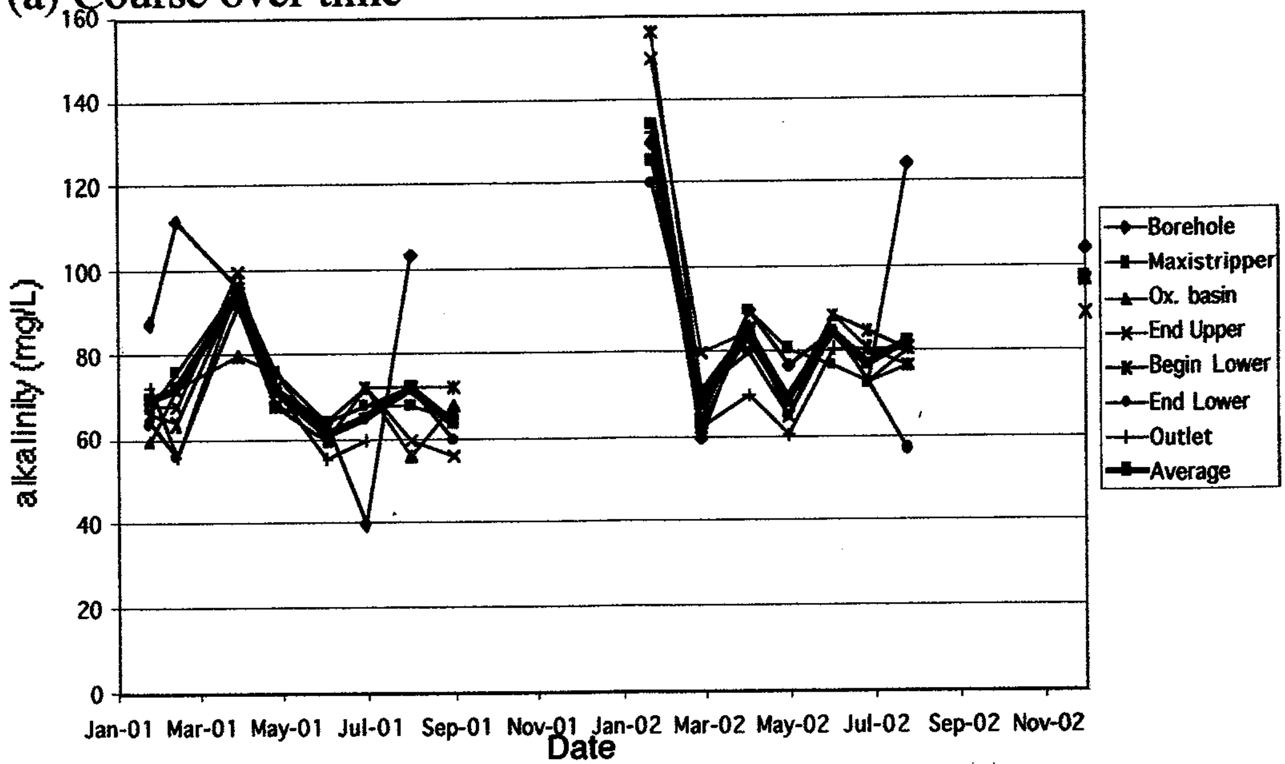


Figure 12 - Course of Alkalinity

Dundee Road Wetland, Hanover Twp., PA

Data from Wilkes University Wetland Team. 2001 - 2002

(a) Course over time



(b) Course from borehole to outlet - 2001

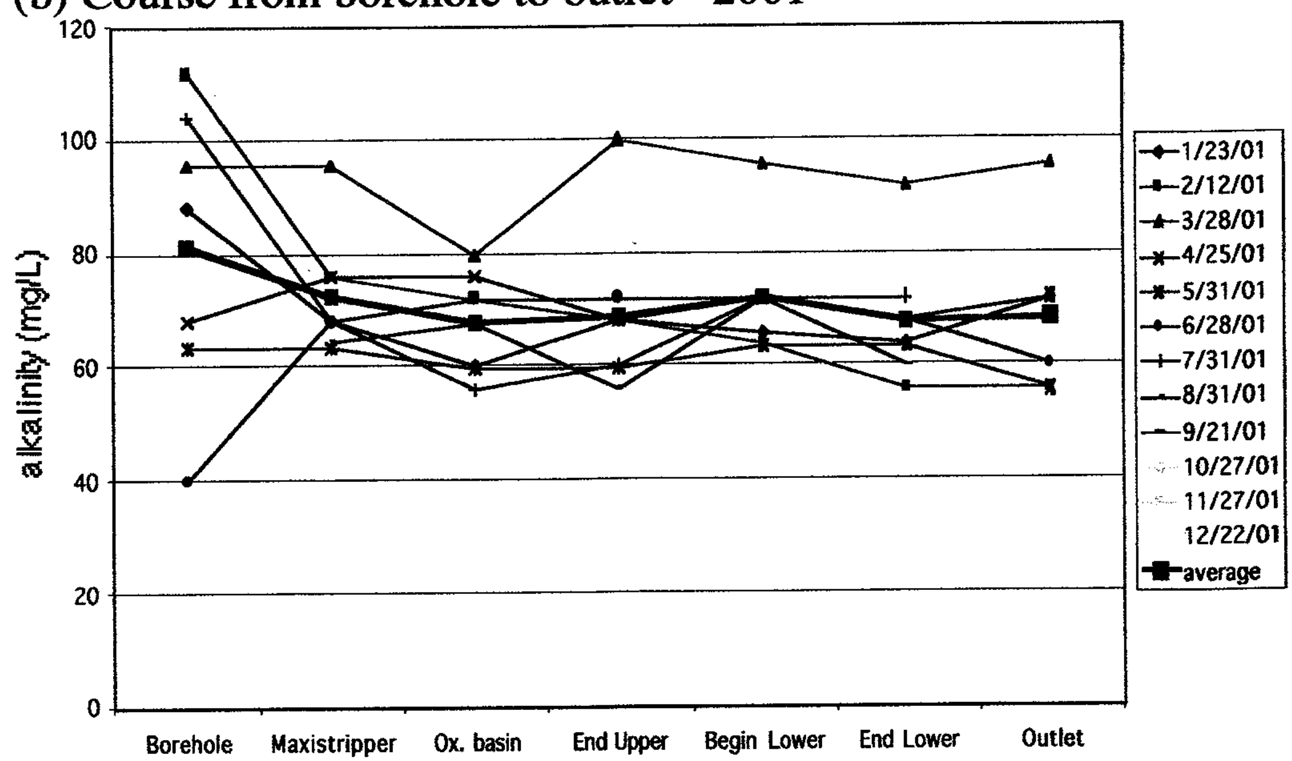
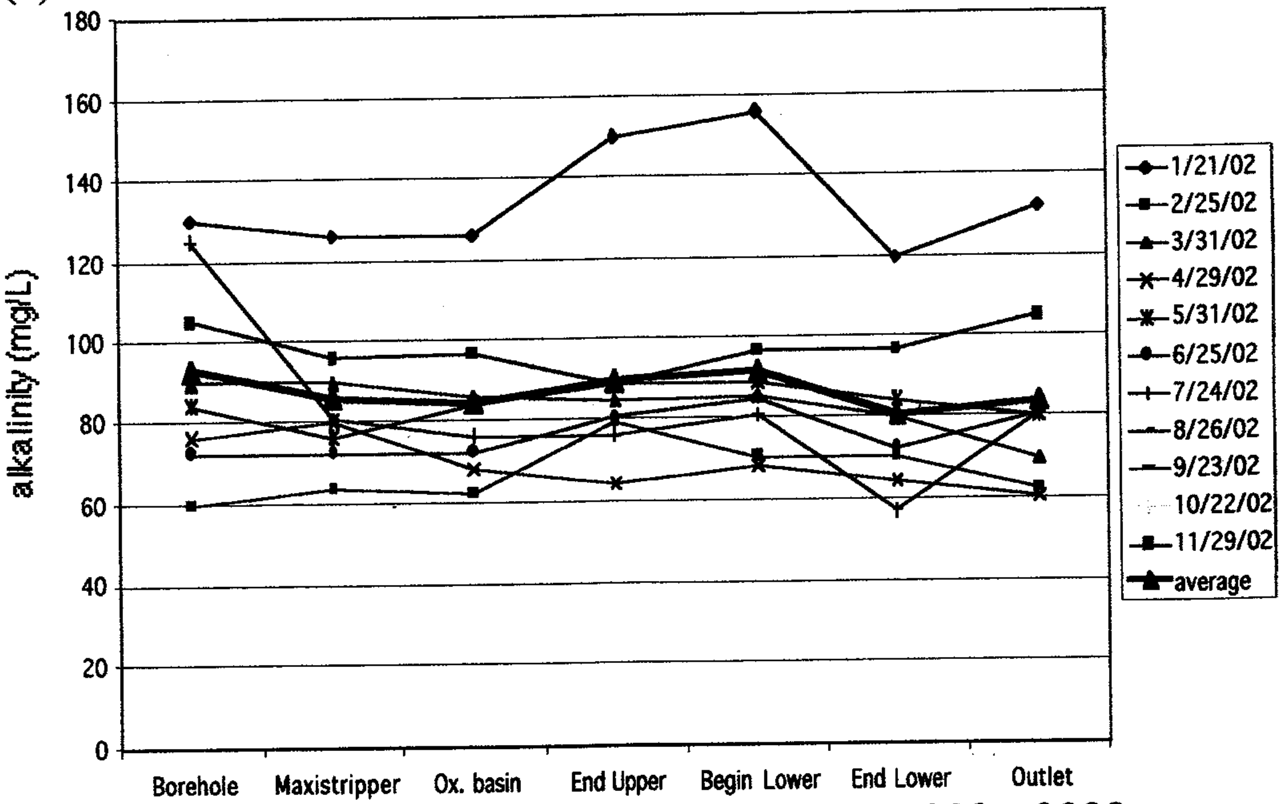


Figure 12 - Course of Alkalinity

Dundee Road Wetland, Hanover Twp., PA

Data from Wilkes University Wetland Team. 2001 - 2002

(c) Course from borehole to outlet - 2002



(d) Course from borehole to outlet - averages 1999 - 2002

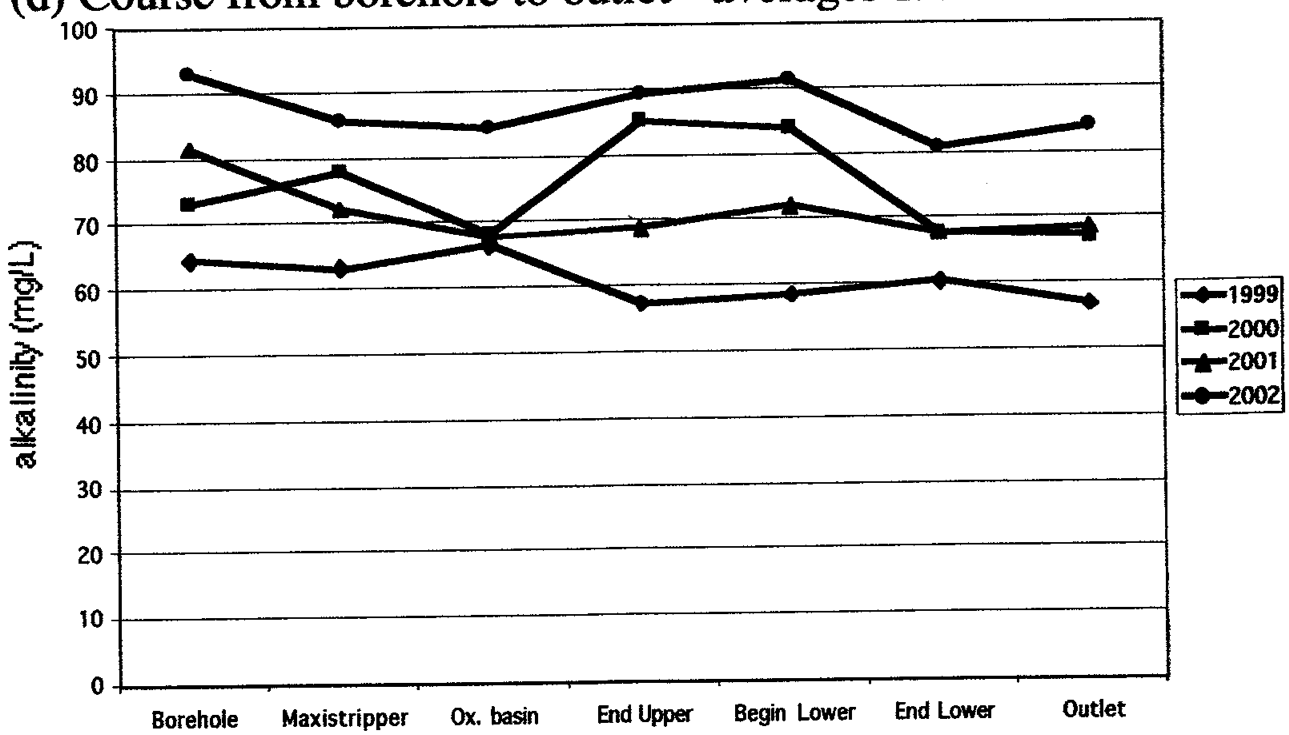
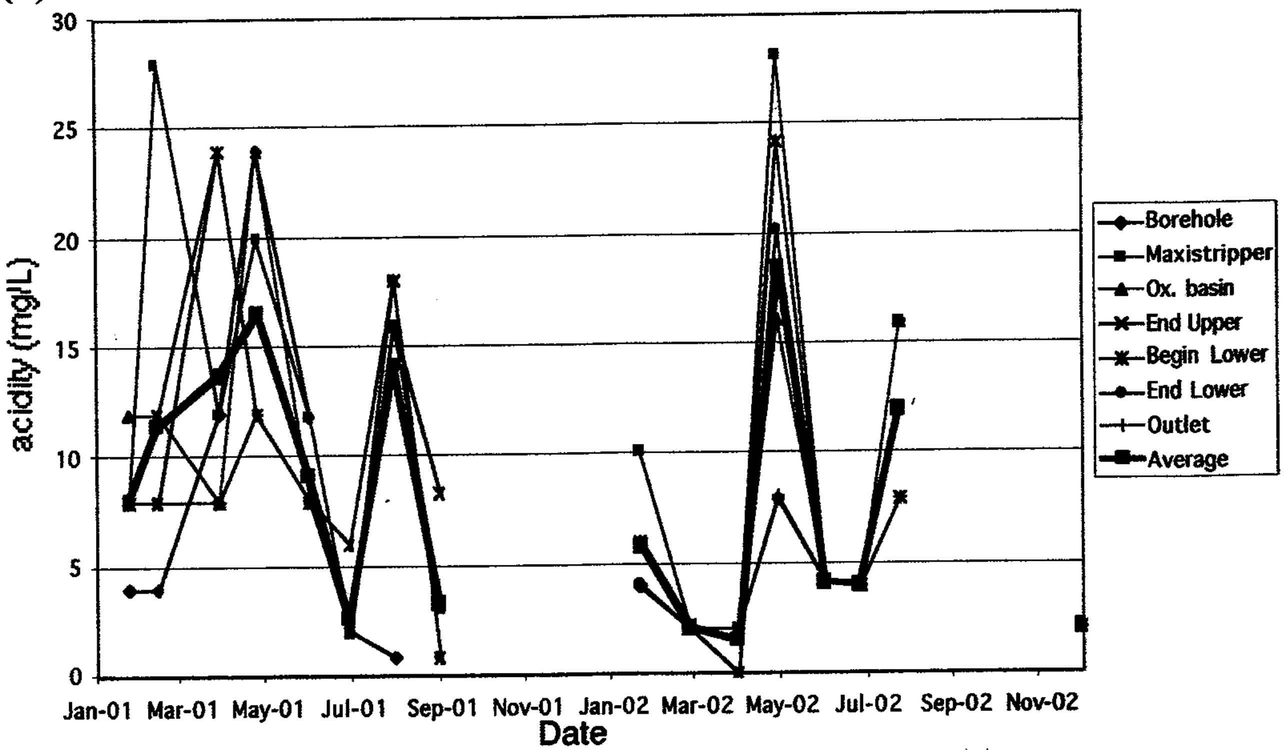


Figure 13 - Course of Acidity

Dundee Road Wetland, Hanover Twp., PA

Data from Wilkes University Wetland Team. 2001 - 2002

(a) Course over time



(b) Course from borehole to outlet - 2001

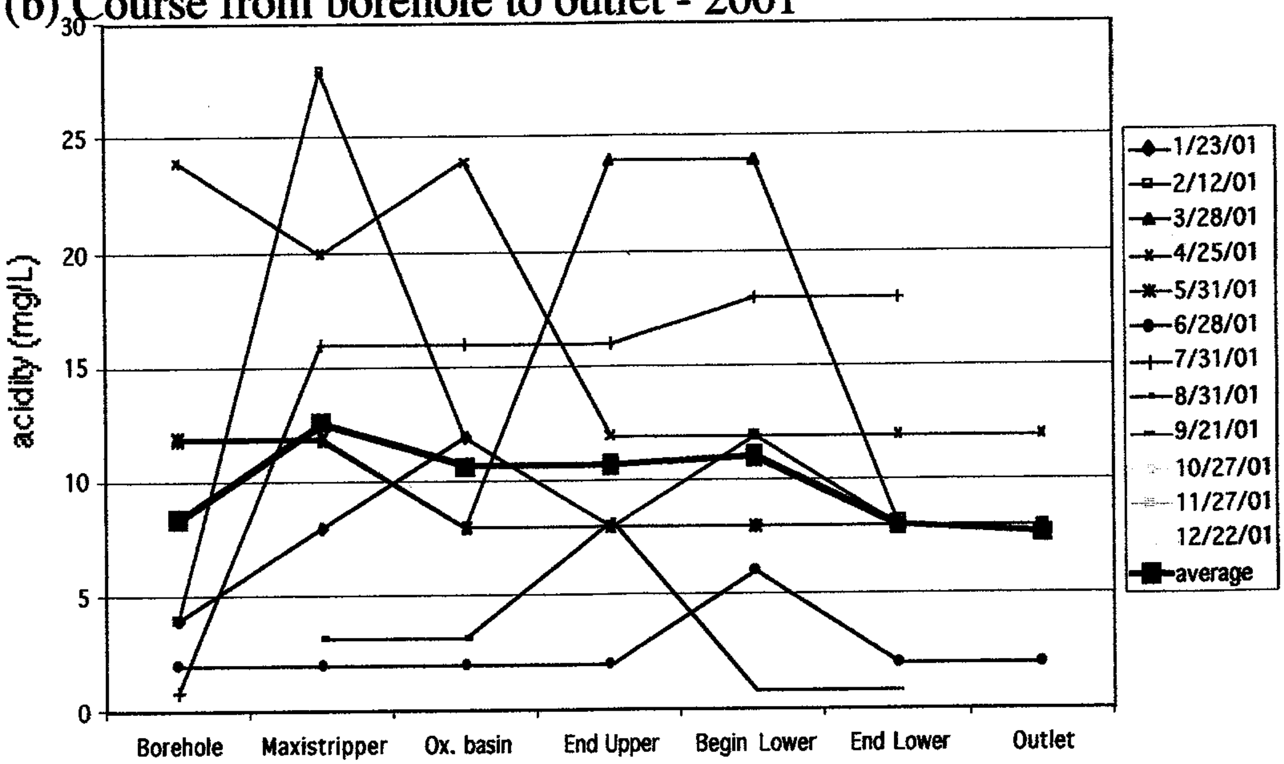
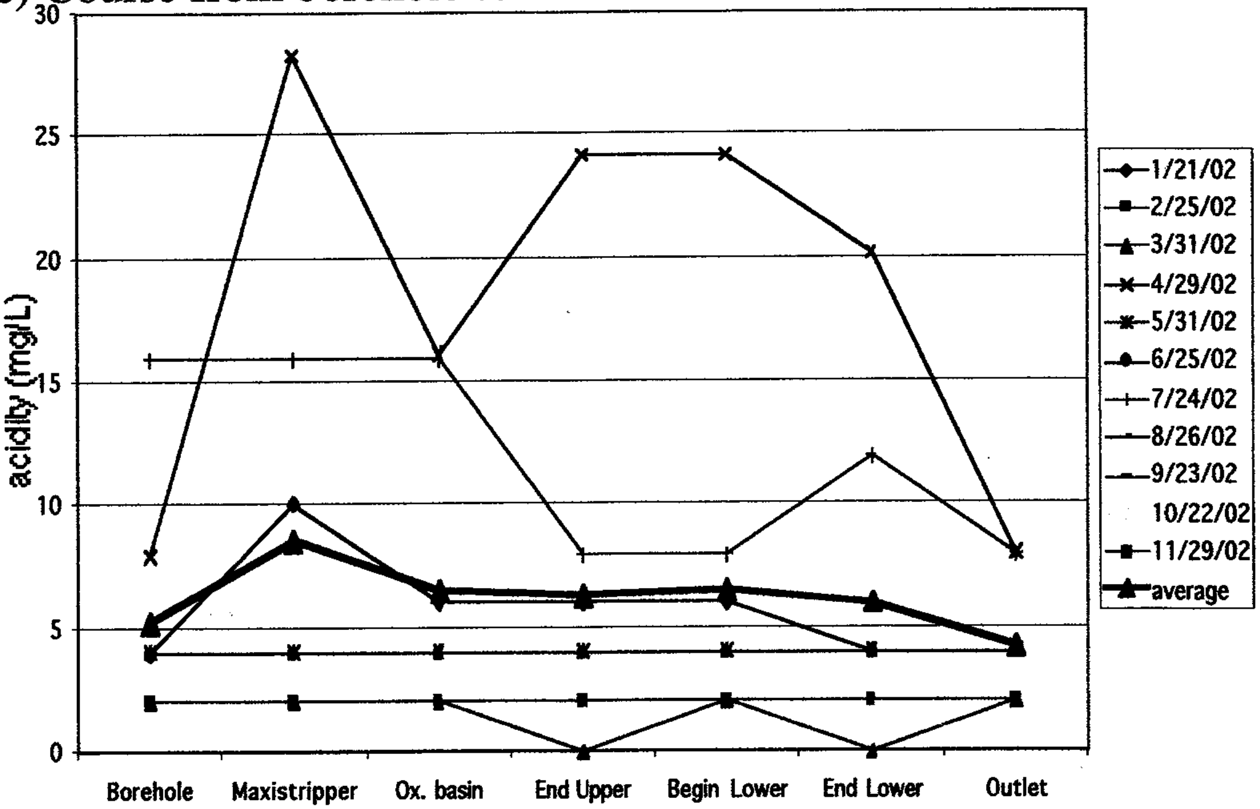


Figure 13 - Course of Acidity

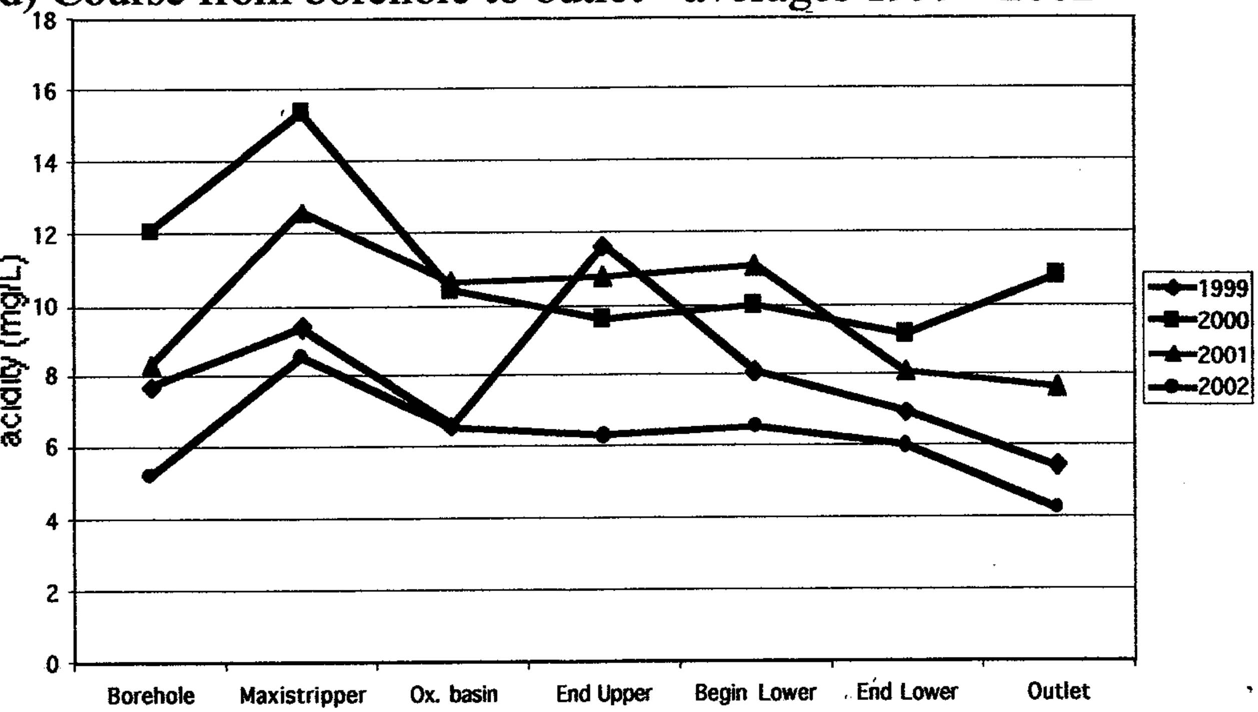
Dundee Road Wetland, Hanover Twp., PA

Data from Wilkes University Wetland Team. 2001 - 2002

(c) Course from borehole to outlet - 2002

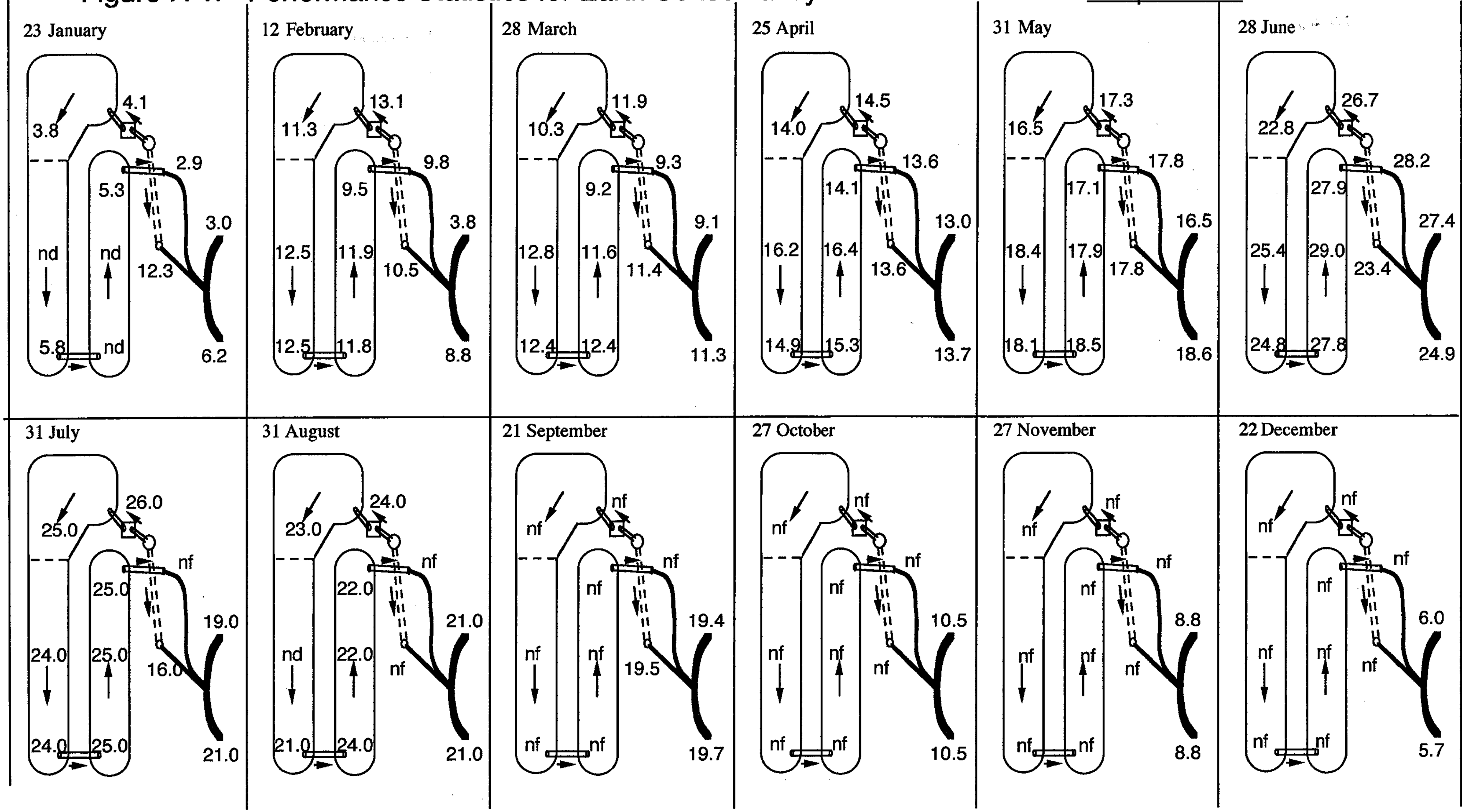


(d) Course from borehole to outlet - averages 1999 - 2002



Individual Monthly Readings

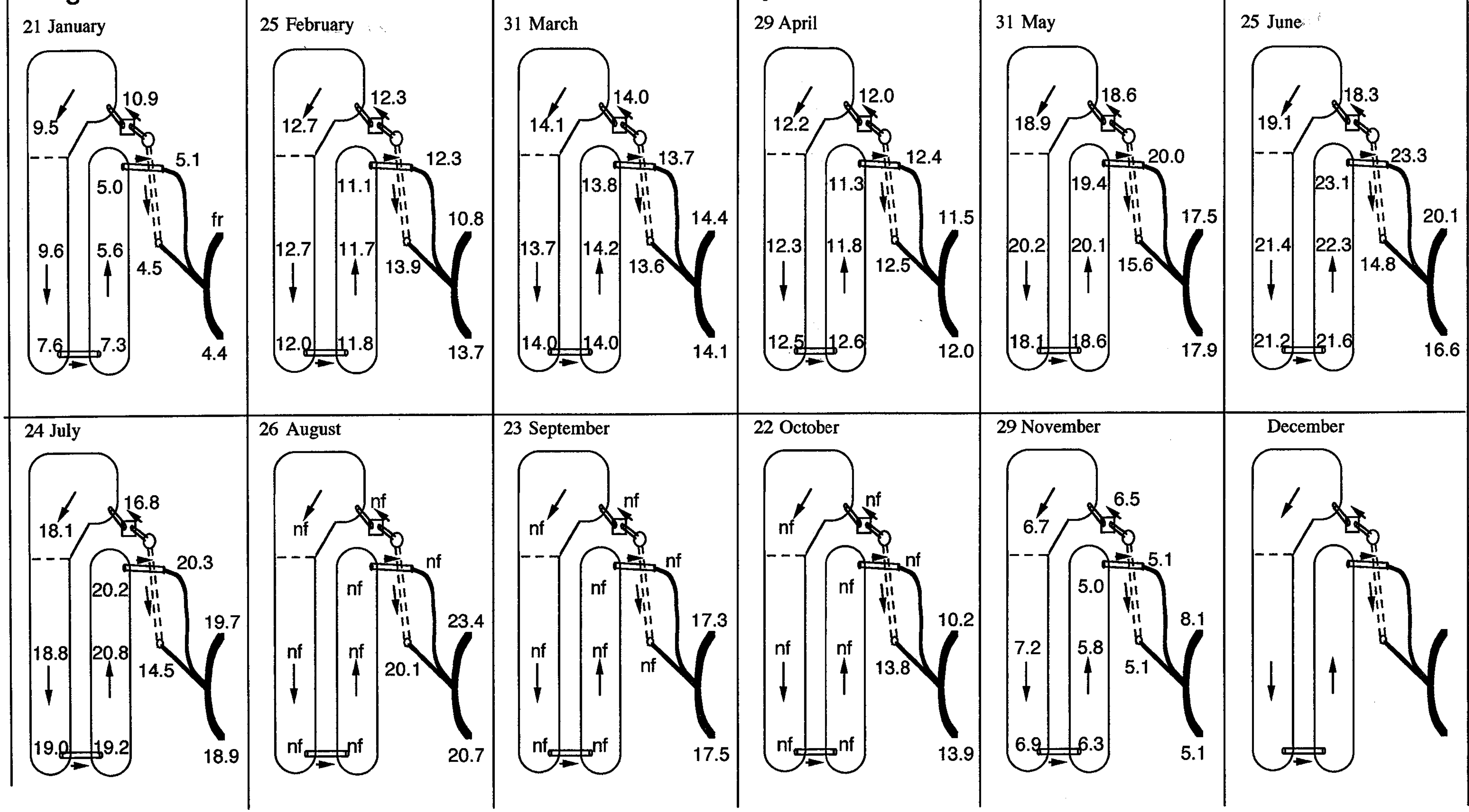
Figure A-1. Performance Statistics for Earth Conservancy Phase II Wetland for temperature in 2001



Data provided by Wilkes University Wetland Team

Kenneth M. Klemow, Ph.D. - Project PI, Brian Oram - WQ Lab Supervisor, Chris Watkins, John Pagoda - Technical Associates

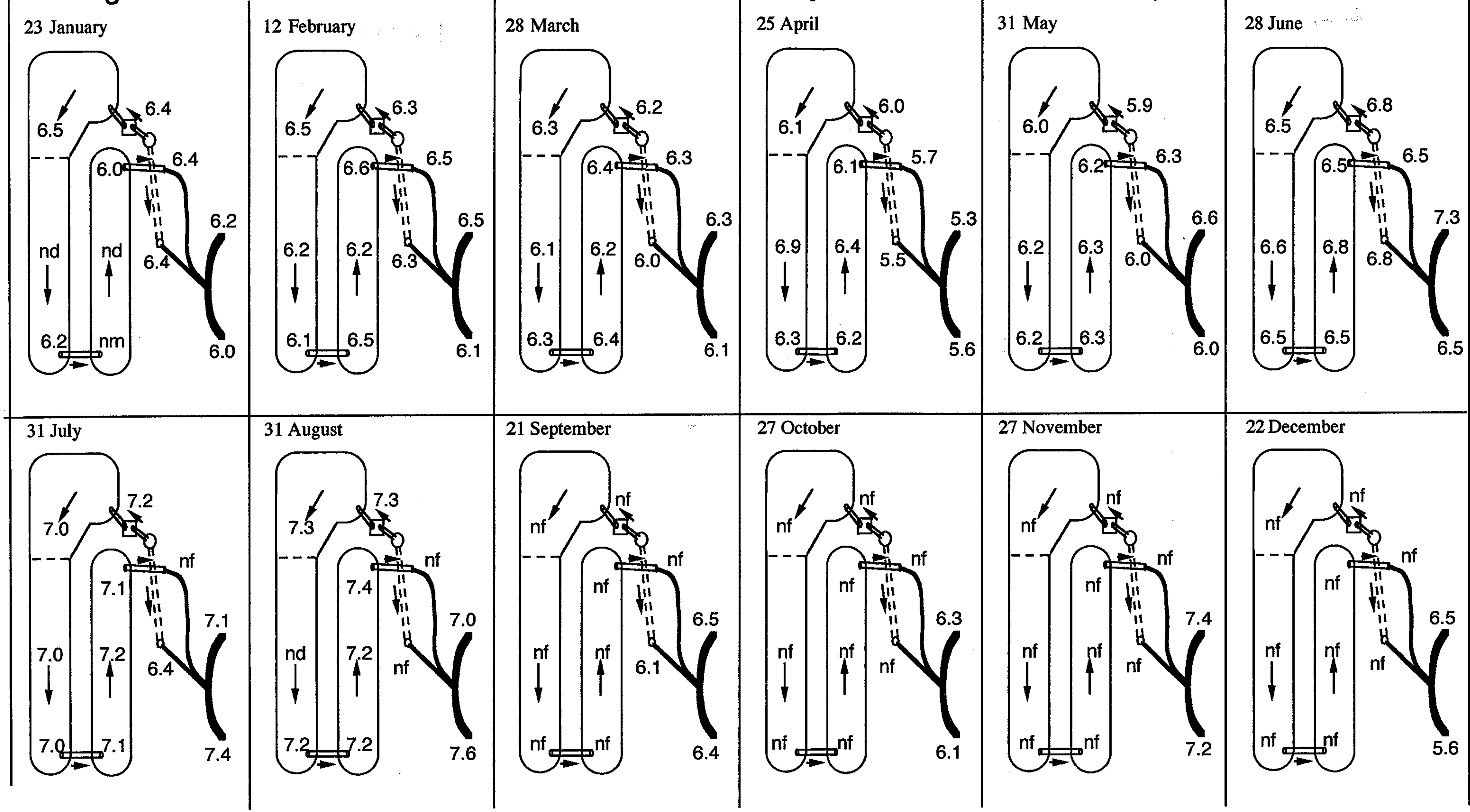
Figure A-2. Performance Statistics for Earth Conservancy Phase II Wetland for temperature in 2002.



Data provided by Wilkes University Wetland Team

Kenneth M. Klemow, Ph.D. - Project PI, Brian Oram - WQ Lab Supervisor, John Pagoda - Technical Associate

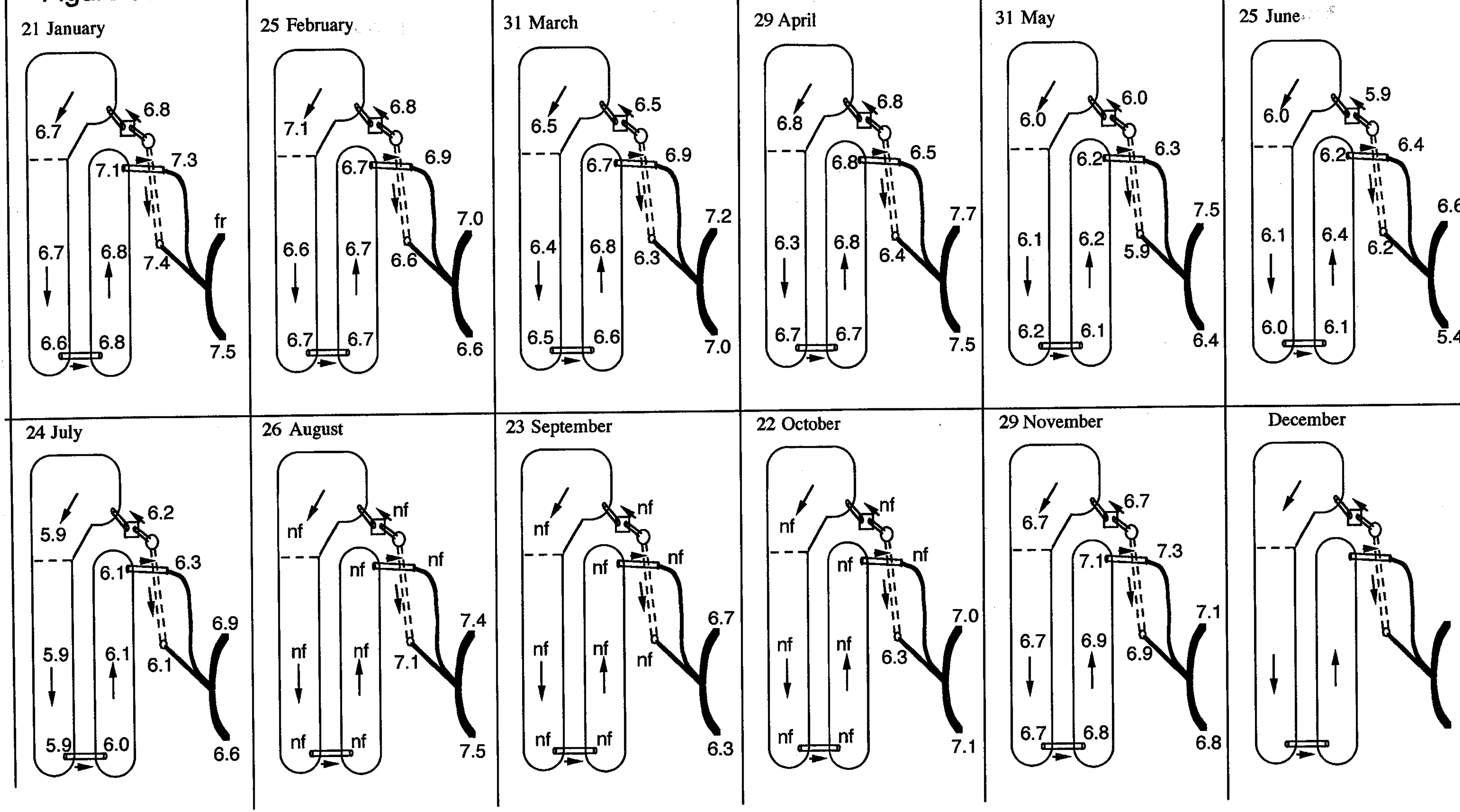
Figure A-3. Performance Statistics for Earth Conservancy Phase II Wetland for pH in 2001



Data provided by Wilkes University Wetland Team

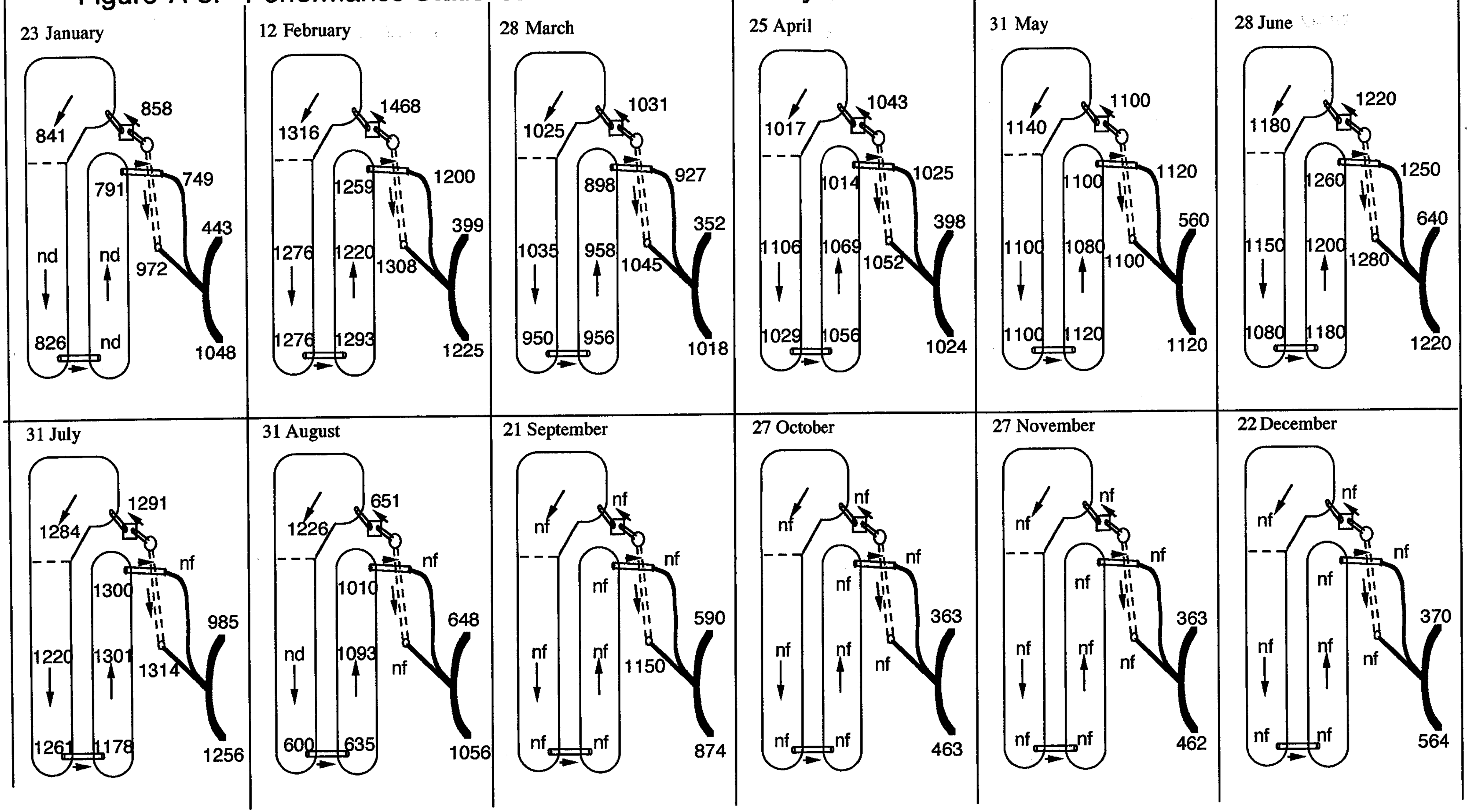
Kenneth M. Klemow, Ph.D. - Project PI, Brian Oram - WQ Lab Supervisor, Chris Watkins, John Pagoda - Technical Associates

Figure A-4. Performance Statistics for Earth Conservancy Phase II Wetland for pH in 2002.



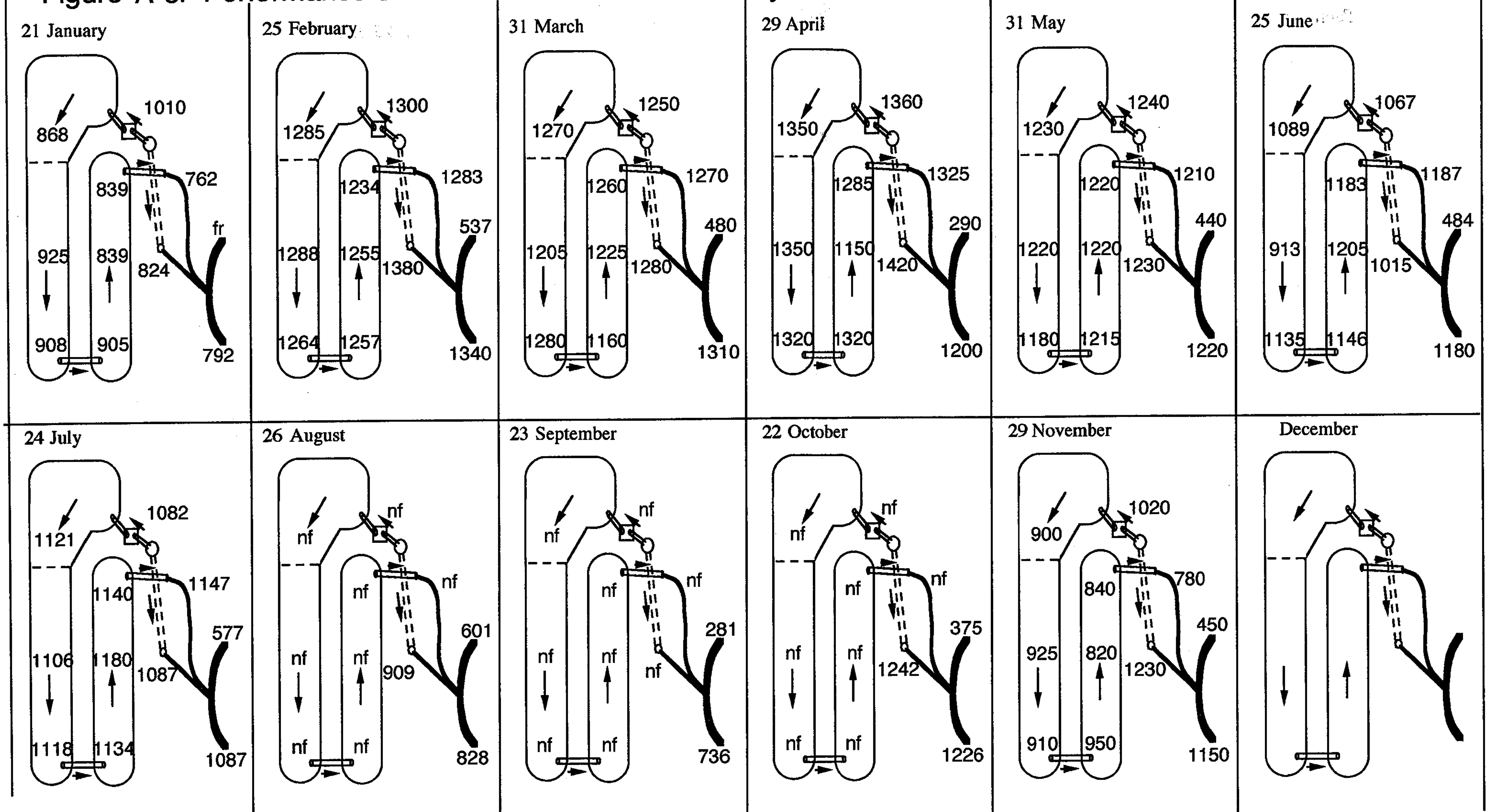
Data provided by Wilkes University Wetland Team
Kenneth M. Klemow, Ph.D. - Project PI, Brian Oram - WQ Lab Supervisor, John Pagoda - Technical Associate

Figure A-5. Performance Statistics for Earth Conservancy Phase II Wetland for conductance in 2001



Data provided by Wilkes University Wetland Team
Kenneth M. Klemow, Ph.D. - Project PI, Brian Oram - WQ Lab Supervisor, Chris Watkins, John Pagoda - Technical Associates

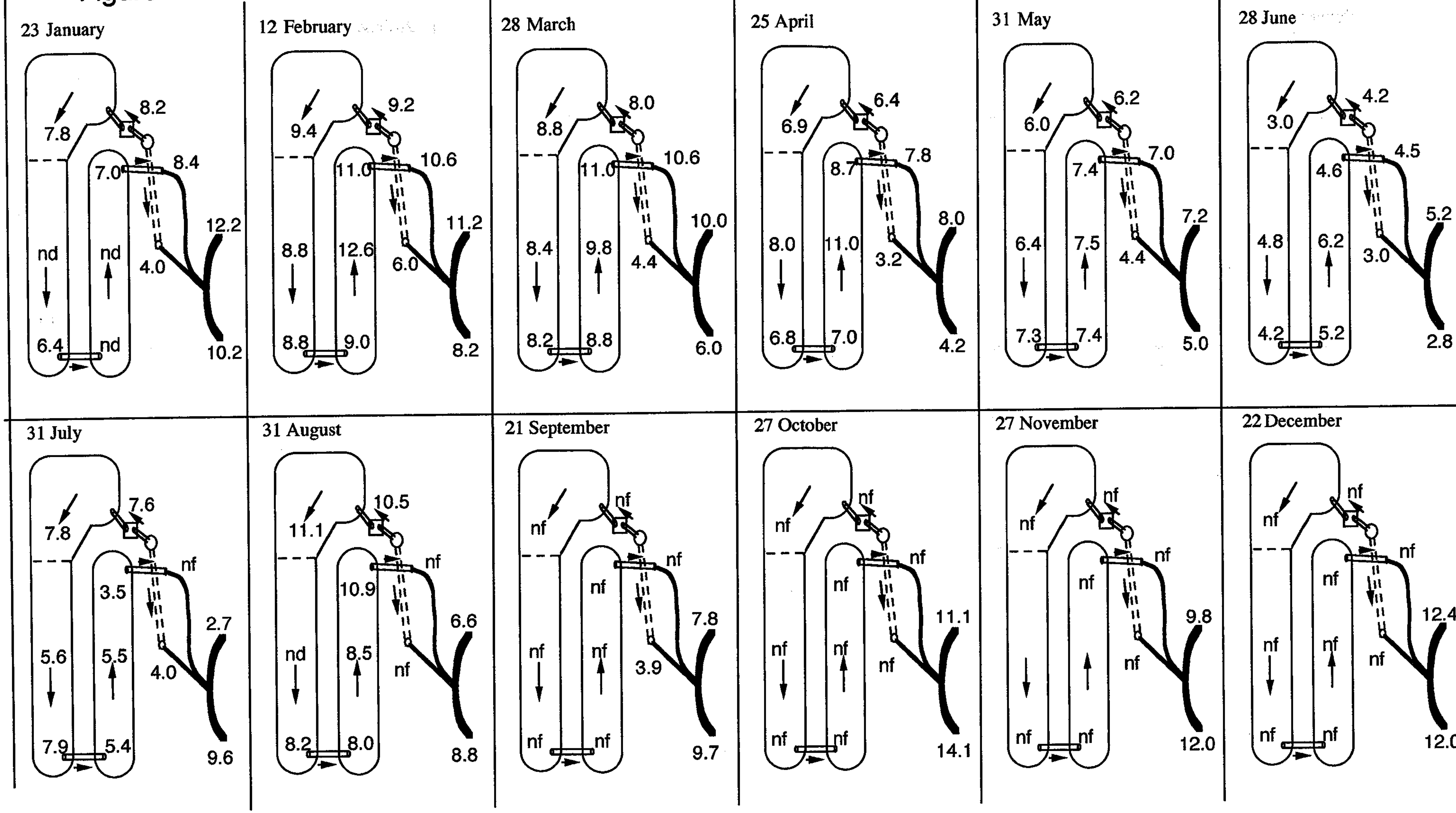
Figure A-6. Performance Statistics for Earth Conservancy Phase II Wetland for conductance in 2002.



Data provided by Wilkes University Wetland Team

Kenneth M. Klemow, Ph.D. - Project PI, Brian Oram - WQ Lab Supervisor, John Pagoda - Technical Associate

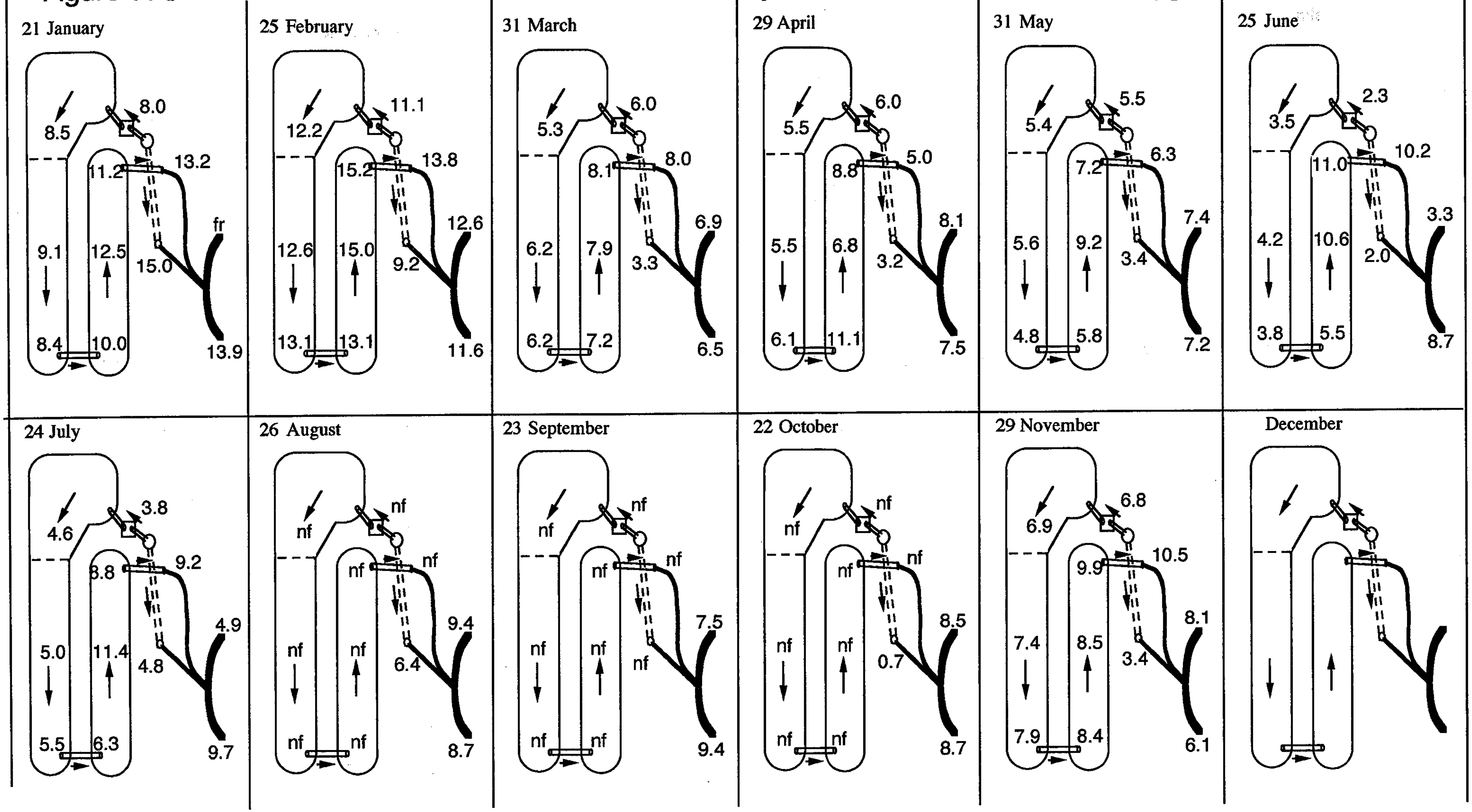
Figure A-7. Performance Statistics for Earth Conservancy Phase II Wetland for diss. oxygen in 2001



Data provided by Wilkes University Wetland Team

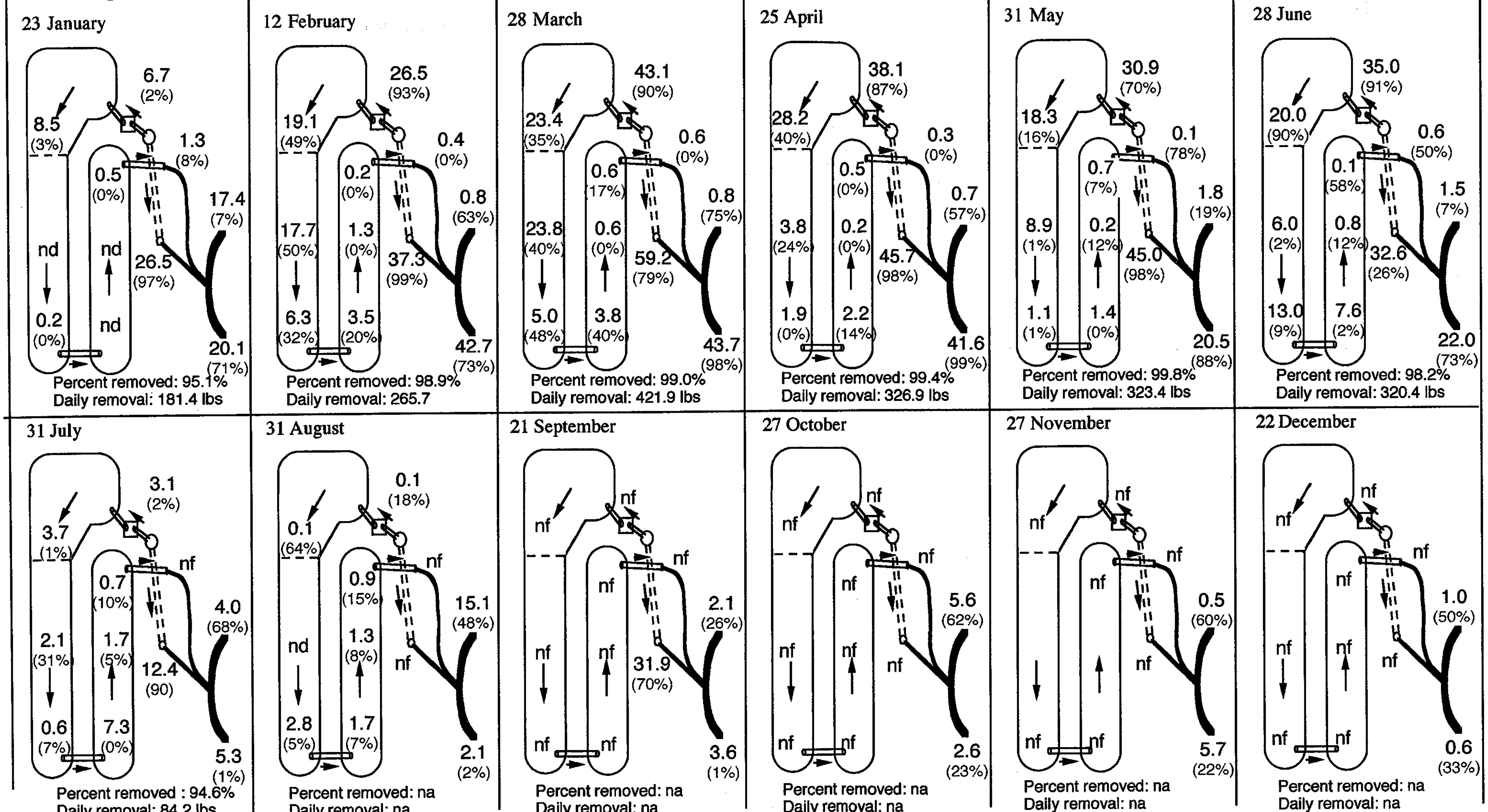
Kenneth M. Klemow, Ph.D. - Project PI, Brian Oram - WQ Lab Supervisor, Chris Watkins, John Pagoda - Technical Associates

Figure A-8. Performance Statistics for Earth Conservancy Phase II Wetland for diss. oxygen in 2002.



Data provided by Wilkes University Wetland Team
Kenneth M. Klemow, Ph.D. - Project PI, Brian Oram - WQ Lab Supervisor, John Pagoda - Technical Associate

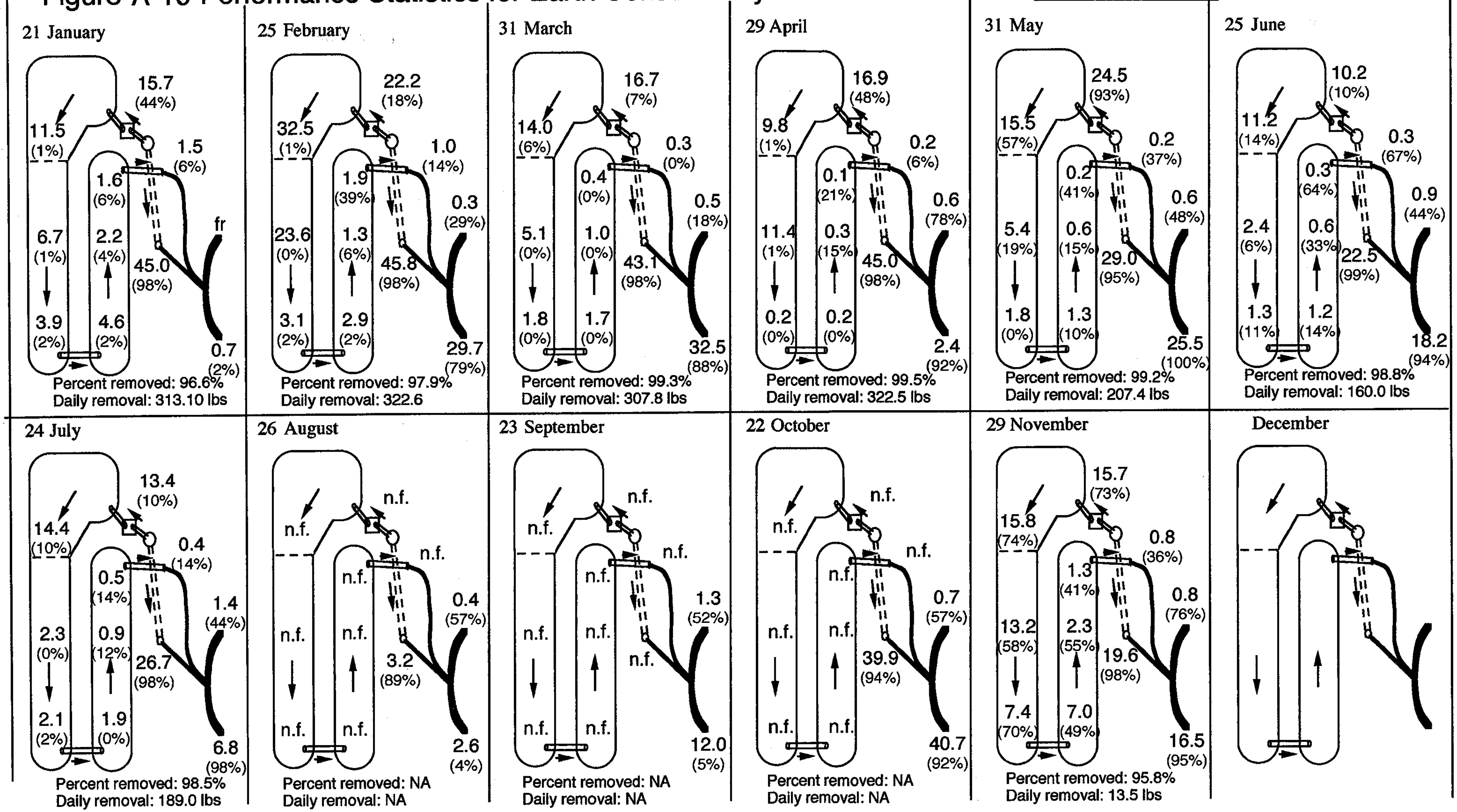
Figure A-9. Performance Statistics for Earth Conservancy Phase II Wetland for iron in 2001



Data provided by Wilkes University Wetland Team

Kenneth M. Klemow, Ph.D. - Project PI, Brian Oram - WQ Lab Supervisor, Chris Watkins, John Pagoda - Technical Associates

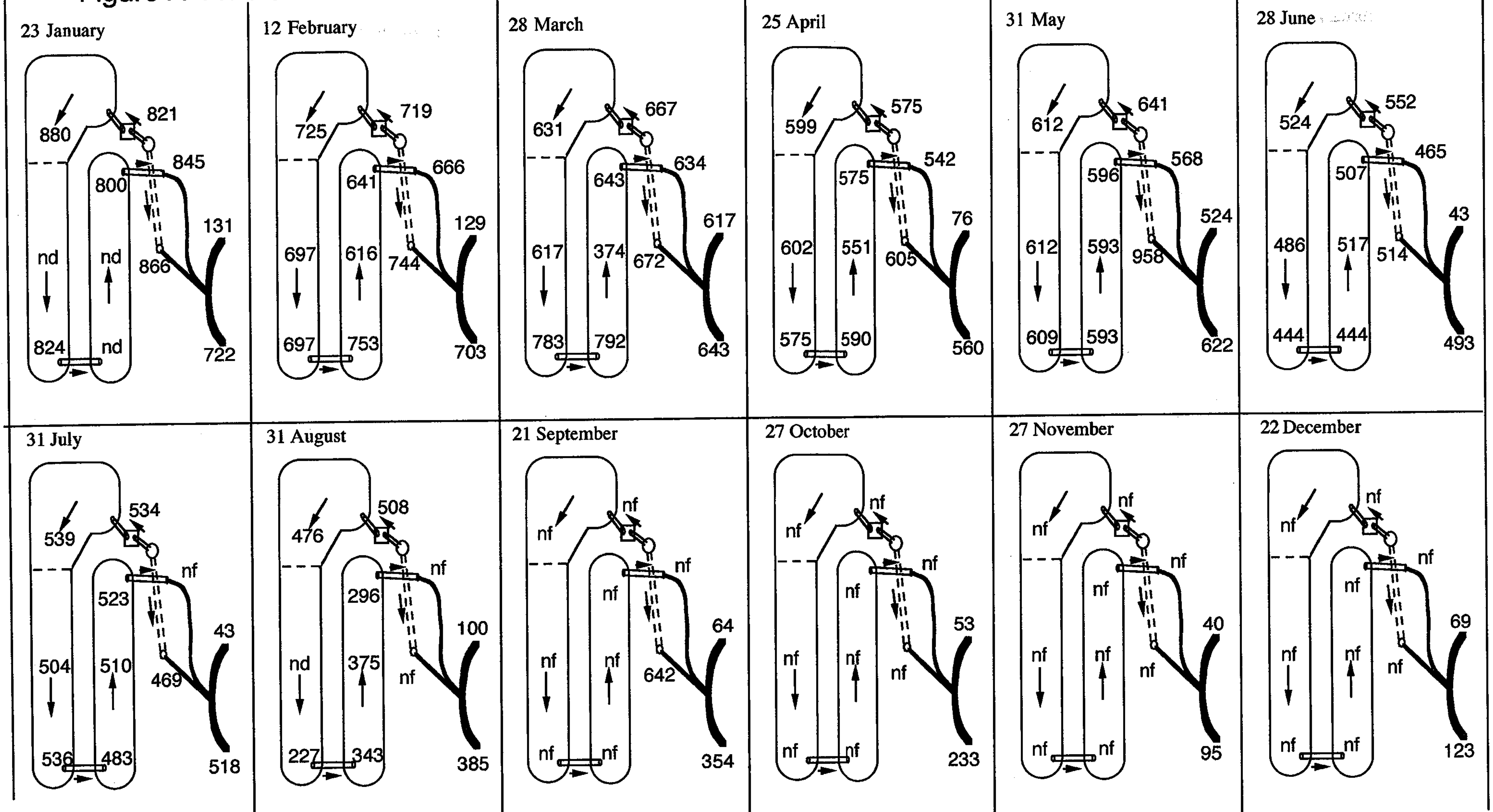
Figure A-10 Performance Statistics for Earth Conservancy Phase II Wetland for iron in 2002.



Data provided by Wilkes University Wetland Team

Kenneth M. Klemow, Ph.D. - Project PI, Brian Oram - WQ Lab Supervisor, John Pagoda - Technical Associate

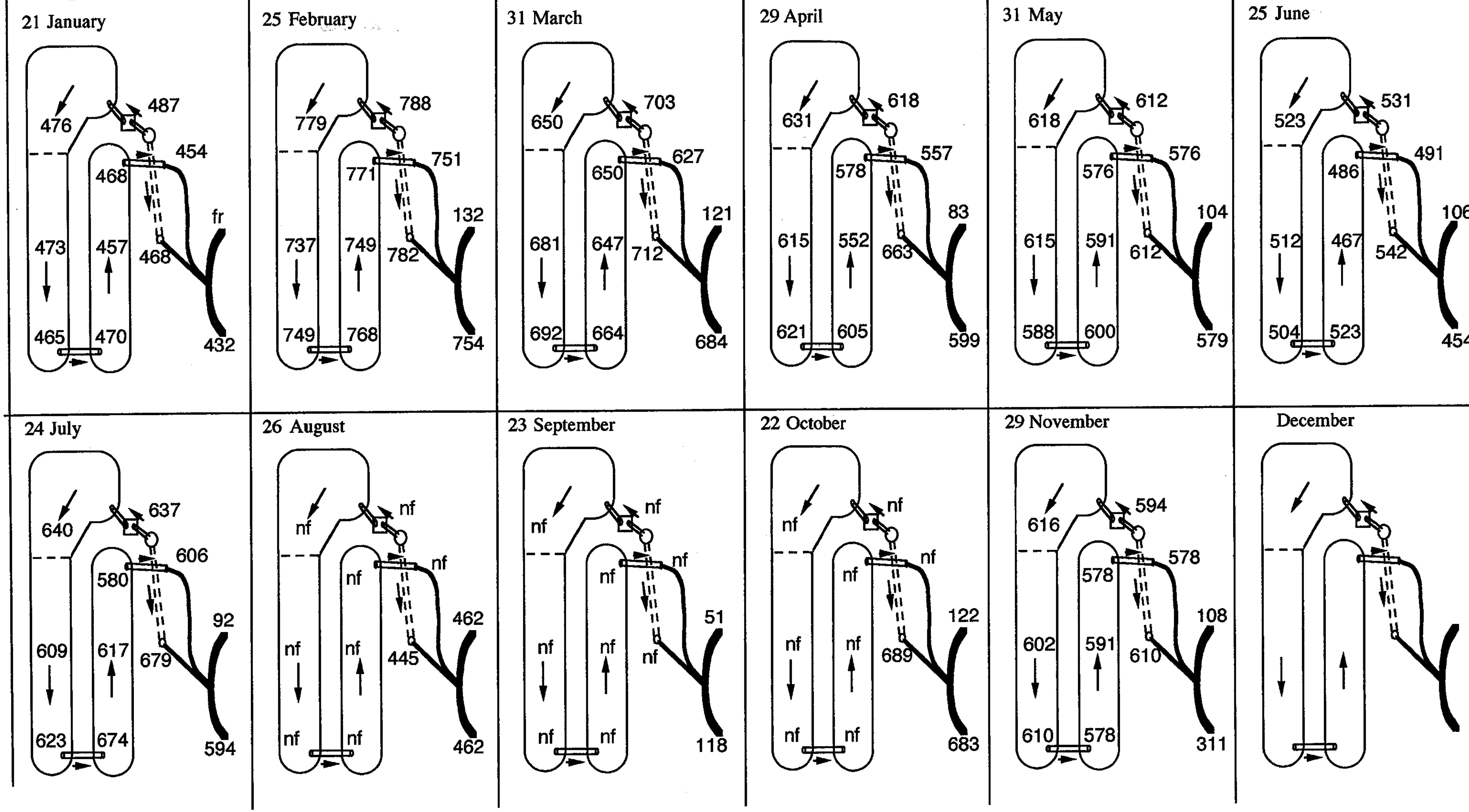
Figure A-11. Performance Statistics for Earth Conservancy Phase II Wetland for sulfate in 2001



Data provided by Wilkes University Wetland Team

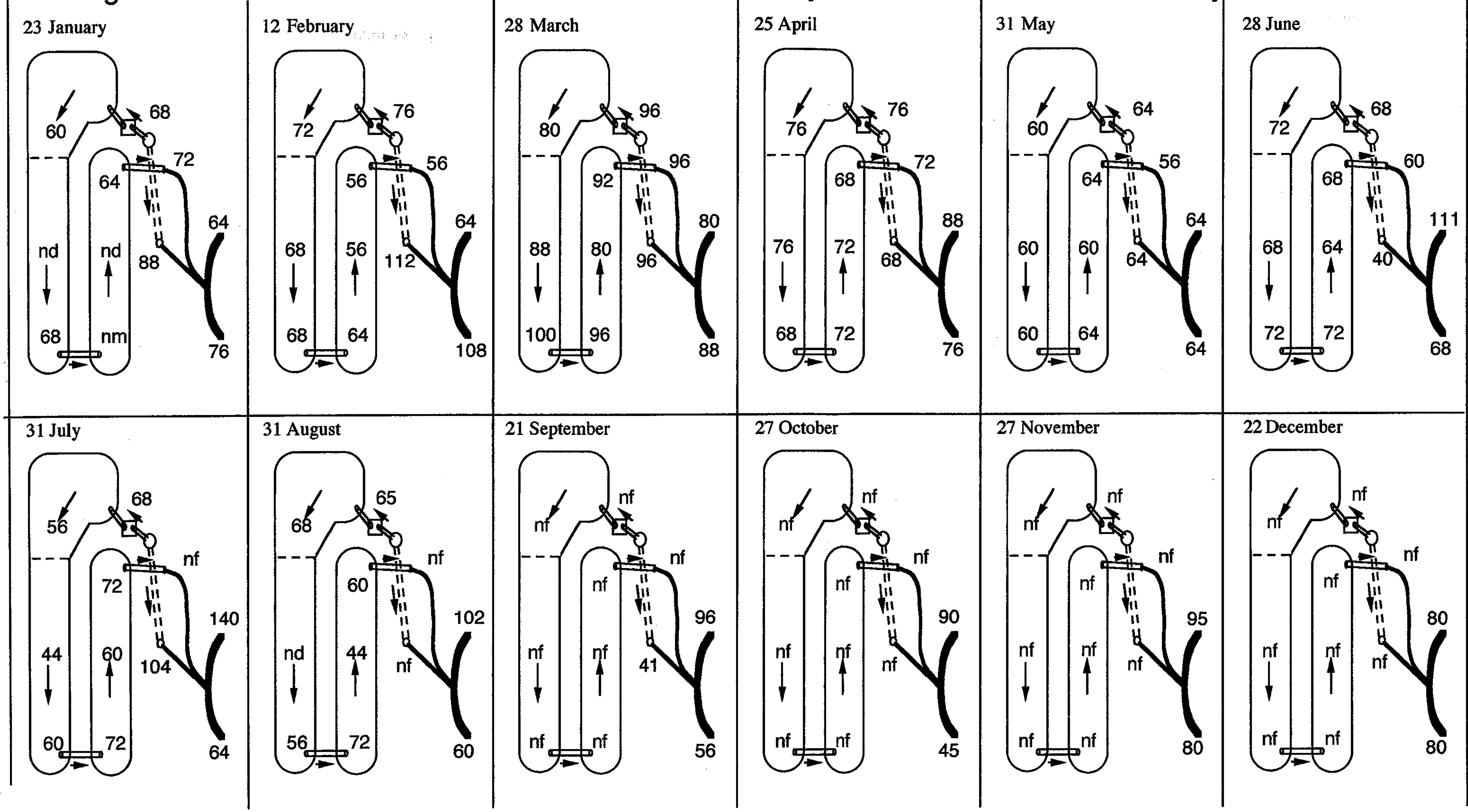
Kenneth M. Klemow, Ph.D. - Project PI, Brian Oram - WQ Lab Supervisor, Chris Watkins, John Pagoda - Technical Associates

Figure A-12 Performance Statistics for Earth Conservancy Phase II Wetland for sulfate in 2002.



Data provided by Wilkes University Wetland Team
Kenneth M. Klemow, Ph.D. - Project PI, Brian Oram - WQ Lab Supervisor, John Pagoda - Technical Associate

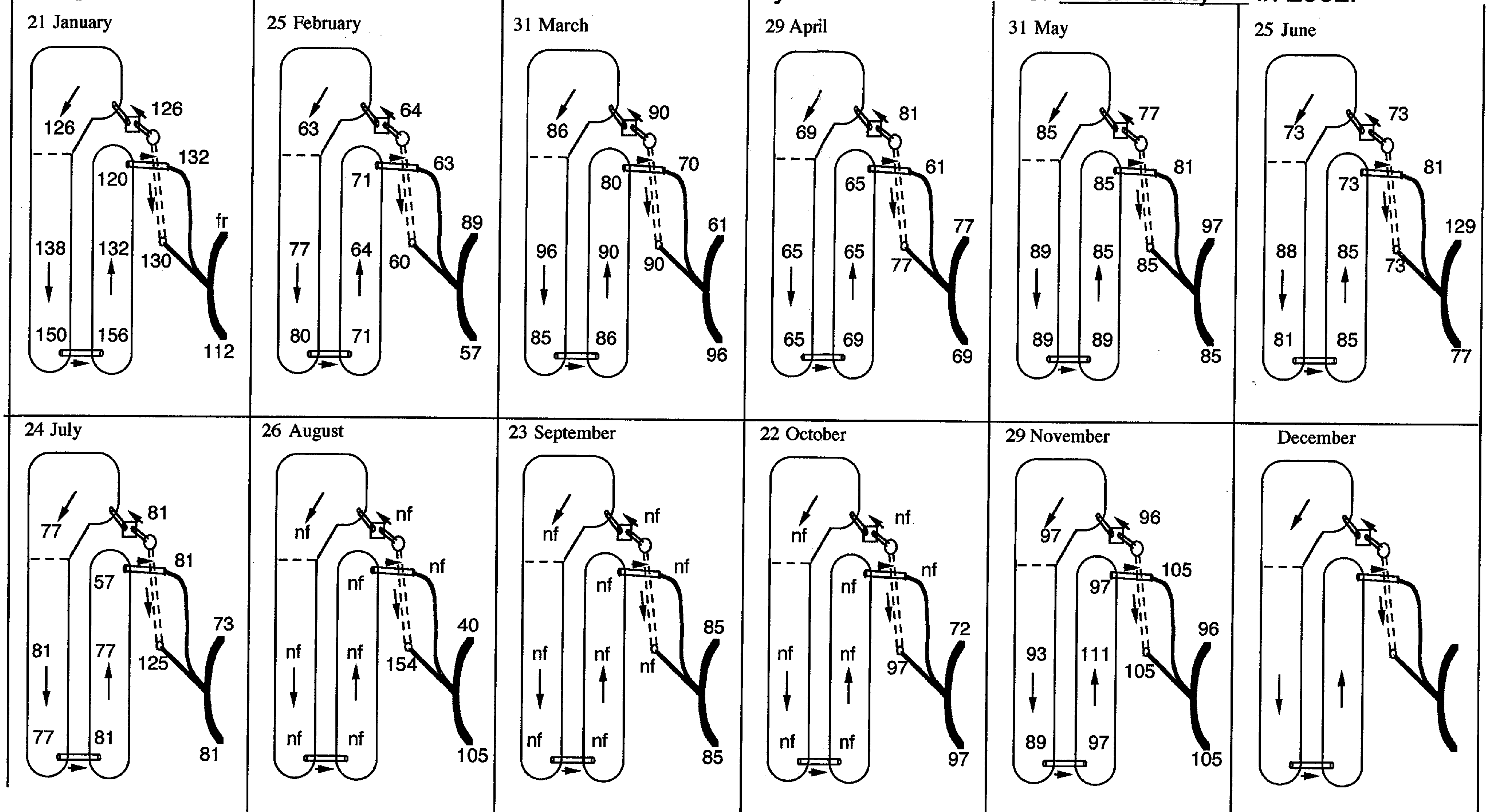
Figure A-13. Performance Statistics for Earth Conservancy Phase II Wetland for alkalinity in 2001



Data provided by Wilkes University Wetland Team

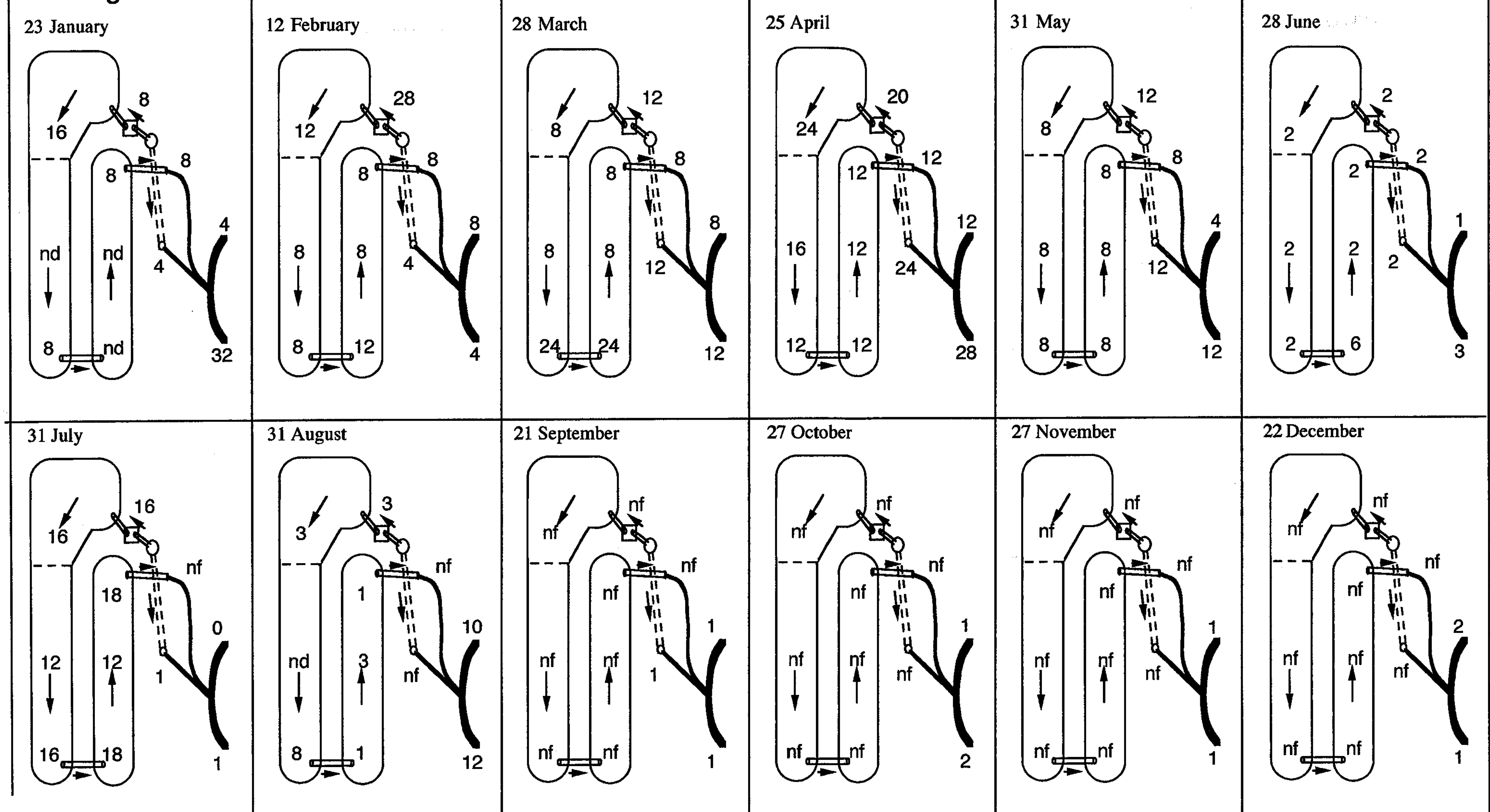
Kenneth M. Klemow, Ph.D. - Project PI, Brian Oram - WQ Lab Supervisor, Chris Watkins, John Pagoda - Technical Associates

Figure A-14. Performance Statistics for Earth Conservancy Phase II Wetland for alkalinity in 2002.



Data provided by Wilkes University Wetland Team
Kenneth M. Klemow, Ph.D. - Project PI, Brian Oram - WQ Lab Supervisor, John Pagoda - Technical Associate

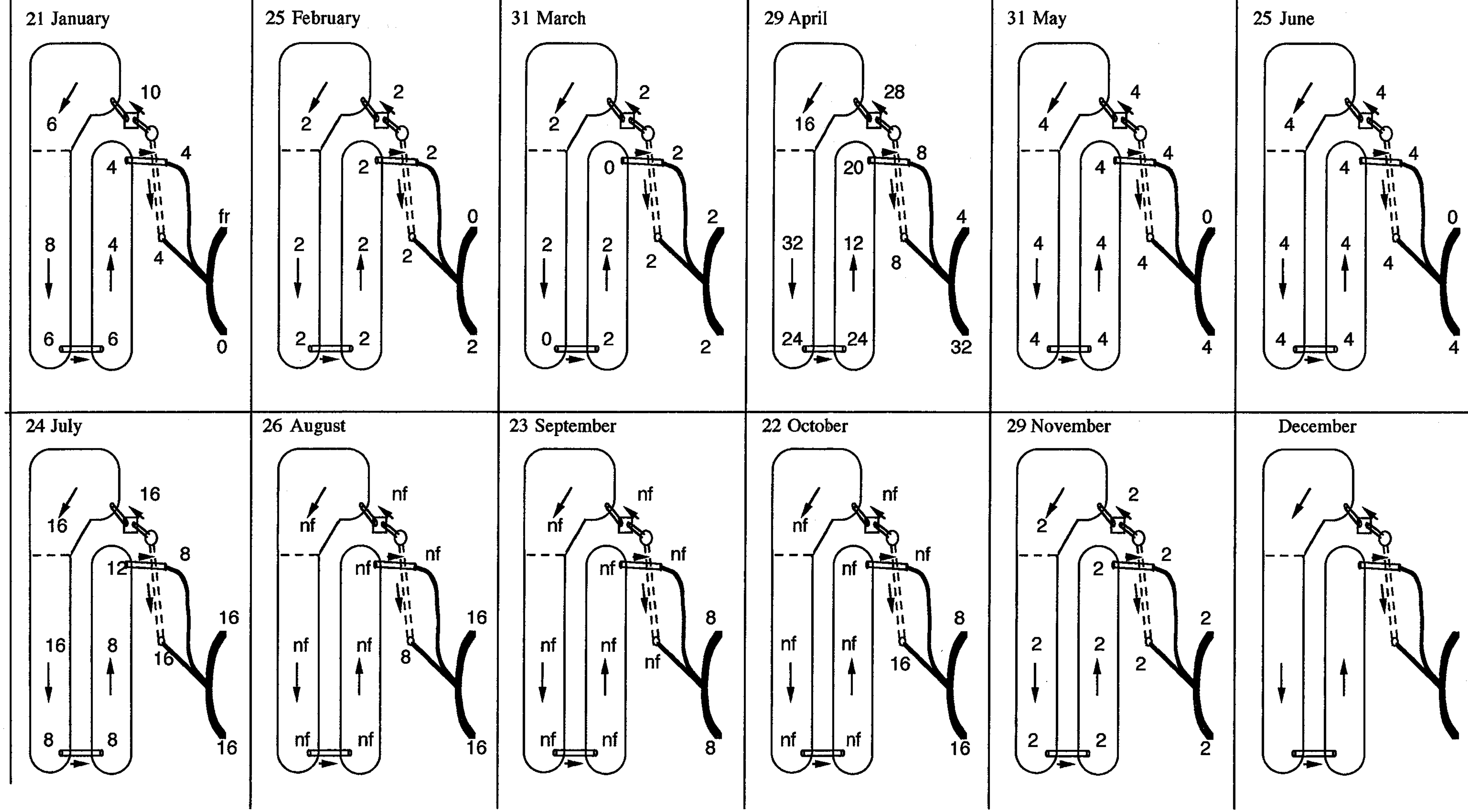
Figure A-15. Performance Statistics for Earth Conservancy Phase II Wetland for acidity in 2001



Data provided by Wilkes University Wetland Team

Kenneth M. Klemow, Ph.D. - Project PI, Brian Oram - WQ Lab Supervisor, Chris Watkins, John Pagoda - Technical Associates

Figure A-16 Performance Statistics for Earth Conservancy Phase II Wetland for acidity in 2002.



Data provided by Wilkes University Wetland Team

Kenneth M. Klemow, Ph.D. - Project PI, Brian Oram - WQ Lab Supervisor, John Pagoda - Technical Associate