Water Quality Assessment for the Earth Conservancy Phase I Wetland

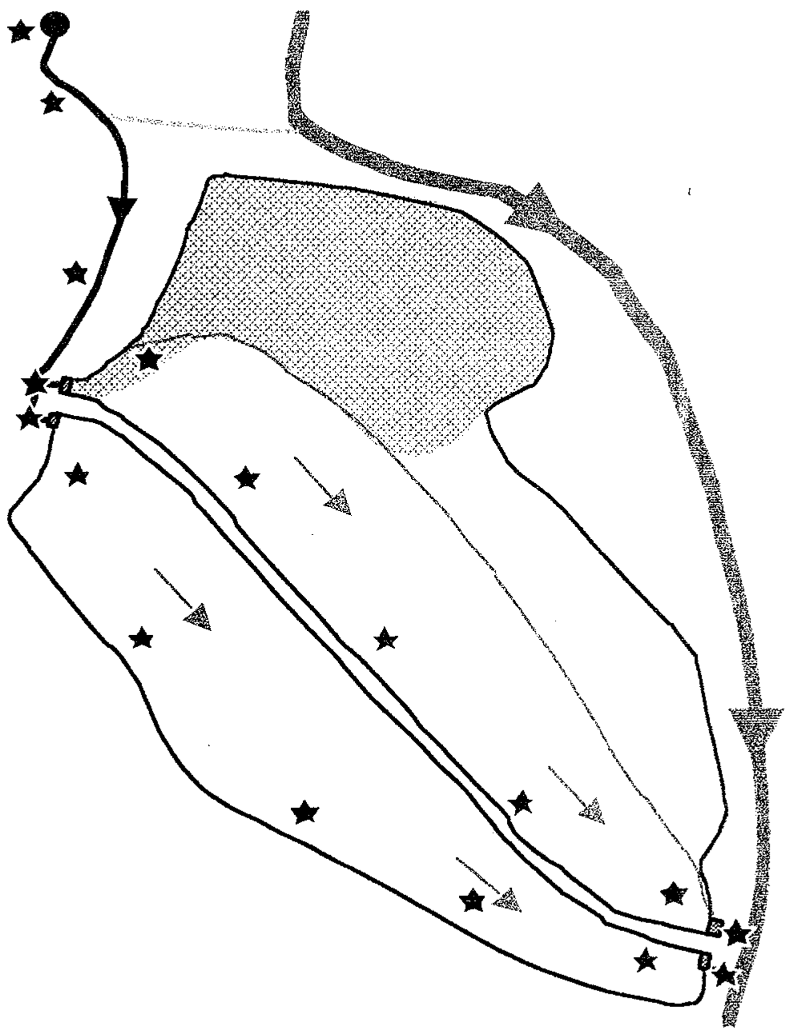
November 2000 - November 2002

FINAL REPORT

27 December 2002

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

Kenneth M. Klemow, Ph.D., Principal Investigator
Department of Biology, Wilkes University, Wilkes-Barre, PA 18766
kklemow@wilkes.edu



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I. SUMMARY

Key water quality parameters were assessed within the Earth Conservancy's Phase I mine drainage treatment wetland system along Espy Run in Hanover Township, Luzerne County, PA between November 2000 and November 2002. The assessment period overlapped an enlargement of a portion of the Phase I system conducted in late summer / early fall 2001. This analysis was conducted by the Wilkes University Wetland Technical Team, supported by funding provided by the Earth Conservancy. That funding originated as a grant from the US Office of Surface Mining to the Earth Conservancy.

Water quality parameters were investigated at seventeen locations throughout the wetland complex, as well as above and below the wetland's discharge into Espy Run.

The analysis revealed that the wetland received an average of 108 GPM, though monthly readings varied from 75 to 145 GPM. The water entering the wetland had relatively high levels (average = 283 mg/L) of alkalinity, leading to pH levels that averaged a nearly neutral 6.7-6.8. The water had moderately high levels of sulfate (300 mg/L), specific conductance (1025 μmho/cm), and iron (20 mg/L). Daily iron load was estimated to average 25.2 lbs/day

Differential positioning of the inlet weirs caused flow to be much less in the east cell (20 GPM) than in the west cell (85 GPM). Detention time averaged 21 hours in the east cell. In contrast, the creation of a detention basin and enlarged wetland cell caused detention time in the high flow west cell to increase tenfold, from 3 to 30 hours.

The reconstruction of the wetland was conducted to improve iron removal. The inlet weirs to both cells received an average of 19 mg/L of iron. Water leaving the low-flow east cell had iron concentrations that averaged 1.7 mg/L, representing a removal efficiency of 90%. Removal was particularly good (>97%) in the east cell during the summer months. Before reconstruction, the high-flow west cell removed only 15% of its iron, discharging an average of 17 mg Fe/L. That yield declined to 6 mg/L following enlargement, representing a 63% removal rate. Expressed in terms of loading, the wetland system removed an average of 18.5 lbs Fe/day following reconstruction, compared to 7.2 lbs/day before reconstruction. Enhanced iron removal in the west cell resulted from longer detention time (increasing from 3.5 to 20 hours) following reconstruction. That greater detention time allowed iron to more fully undergo the oxidation, hydrolysis, and flocculation reactions needed for its removal.

Though flow from the reconstructed wetland continues to load iron into Espy Run, downstream concentrations following reconstruction were significantly lower (5.6 vs 9.4 mg/L) following construction than before.

The wetland enlargement was carried out as designed, thereby maximizing the land available for wetland construction between Espy Run and the embankment east of the wetland. Rates of iron removal should continue to improve as the vegetation matures in the west cell. However, the EC may wish to take more aggressive measures, including the installation of an aeration device at the inlet weirs, and/or creation of additional wetland in the low area west of the west cell to fully address the AMD problem at the site.

II. INTRODUCTION

Streams within the Wyoming Valley of northeastern Pennsylvania have been degraded by discharge from abandoned anthracite mines located throughout the valley. Numerous studies have found the mine effluent to be rich in pollutants like iron and sulfate (Ash & Whaite 1953; Skelly and Loy 1974; Geo-Technical Services 1975; Ladwig 1984; Klemow, et al. 1995, Klemow 2002). The iron is especially troublesome because it undergoes a series of oxidation and hydrolysis reactions, producing insoluble iron hydroxide. Stream channels downstream of mine discharges are coated by deposits of iron hydroxide, resulting in watercourses that are biologically degraded and aesthetically unappealing (Klemow 2002).

In 1993, Congressman Paul Kanjorski (11th District) outlined an initiative to treat abandoned mine drainage (AMD) by use of constructed wetlands. Funding to construct a demonstration treatment wetland was made available through the Environmental Protection Agency. A group of scientists from Wilkes University, working under the auspices of the Earth Conservancy (EC) of Ashley, PA, developed a plan to locate, design, and oversee construction of a demonstration treatment system.

After a comprehensive multi-watershed assessment and alternative analysis, the Wilkes Technical Team (WTT) and EC identified a site along Espy Run in northwestern Hanover Township, Luzerne County, PA as optimal for wetland construction (Figure 1). At that location, Espy Run received discharge from a seep originating in an old spoil bank flanking its eastern edge. Above that location, Espy Run showed little impact from mine drainage. Downstream of that point, however, water in the creek had high levels of turbidity, and its bed was visibly coated by deposits of iron hydroxide.

Water quality assessments made between July 1994 and January 1995 showed iron concentrations in the seep discharge to be 11-18 mg/L. Flow rates were estimated to be 100 gallons per minute.

Taking site features (especially topography and surrounding natural wetlands) and published loading criteria into account, the WTT designed a wetland sized at 0.26 acres that would treat the entire flow from the seep diverted via a channel. To facilitate experimentation, the design called for a system consisting of two parallel cells, each sized at 0.13 cells. Flow rate into each cell would be regulated by an adjustable inlet weir. Depth of ponding in each cell would be regulated by an adjustable outlet weir.

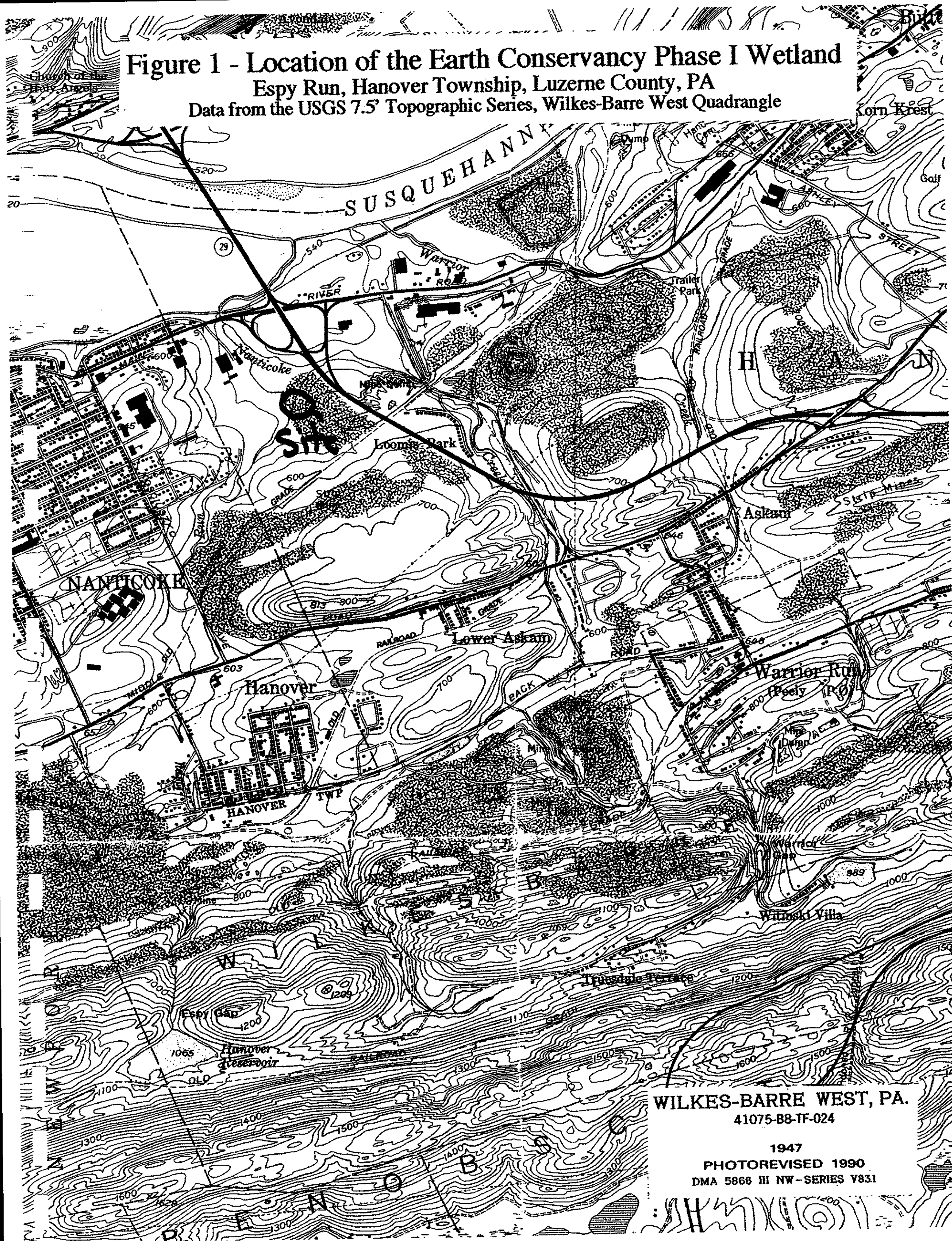
Construction of the wetland complex was started in the fall of 1995 and was completed in summer 1996. Assessment of wetland performance was carried out on an occasional basis between December 1996 and September 1997. A biweekly assessment was carried out by the WTT between September 1997 and December 1998. Key water quality parameters including temperature, pH, conductivity, and iron were analyzed in the field and at the Wilkes University Water Quality Laboratory (WWQL). No assessment was done between January and September 1999, after which sampling resumed on a monthly basis until July 2000. The original parameters, along with dissolved oxygen, sulfate, alkalinity, and acidity were measured during those twelve sampling dates. The water quality assessment was again suspended between July and November 2000.

During the wetland's first year of operation, assessments and visual inspection found water leaving the system still had high concentrations of iron. In 1997, flow rates were restricted into the east cell to determine whether the wetland could remove iron from a trickle of water - which it did. Throughout 1997 and 1998, flow into the east cell was increased to 20-30 GPM, and iron removal remained high (>95%), especially during the summer. Rusting of the inlet weirs prevented any further adjustments of flow rates after the fall of 1998. In contrast, the west cell received the remaining flow (70-170 GPM) and typically removed <30% of entering iron. Iron removal rates by the entire wetland complex were generally 30-45%, which was lower than anticipated. Since the low-flow east cell was effectively able to remove iron, the relatively small size and limited detention time of the existing system evidently limited its effectiveness when viewed on whole.

Figure 1 - Location of the Earth Conservancy Phase I Wetland

Espy Run, Hanover Township, Luzerne County, PA

Data from the USGS 7.5' Topographic Series, Wilkes-Barre West Quadrangle



To improve the performance of the Phase I wetland, the WTT and EC proposed to design and implement an enlargement of the system's west cell. Specifically, the enlargement project involved the creation of a detention basin and wetland expansion to total 0.39 acres (see Figure 2).

The EC received a grant from the US Office of Surface Mining (OSM) in the fall 2000 to implement the plan. That enlargement was carried out in the late summer and early fall of 2001. The OSM grant also provided funds to underwrite the analysis of water quality at Phase I. In November 2000, the EC and Wilkes University agreed to resume a water quality assessment for a two-year period, though the beginning and end dates for that agreement was two months behind that of the EC-OSM agreement.

This document reports on the findings of the water quality analysis of the EC's Phase I wetland for November 2000 through November 2002. Included herein is a summary of the methods, monthly and summary data for each of the eight parameters examined, and a narrative that describes and interprets the findings.

III. METHODS

This assessment involved several components. A monthly water quality assessment was conducted at established locations throughout the wetland, as well as locations along Espy Run 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.

Iron loading and removal rates were determined by combining iron concentration data with flow rate data. Detention times were estimated before and after construction through an as-built analysis of wetland size, depth of ponding, and flow rate. Combining iron removal and detention time allowed an estimation of iron removal kinetics to provide additional insight into the effectiveness of the reconstruction effort.

A. Field Work for Water Quality Assessment

Water samples were collected at seventeen different locations as depicted in Figure 2. Three of the sites were located above the inlet weirs of the wetland: in the seep, riffle, and diversion channel. Six samples were collected in each of the two parallel wetland cells. The final two sites were located within the main stem of Espy Run: one upstream of the wetland discharge into the creek, and the second ca. 50' downstream of the wetland discharge.

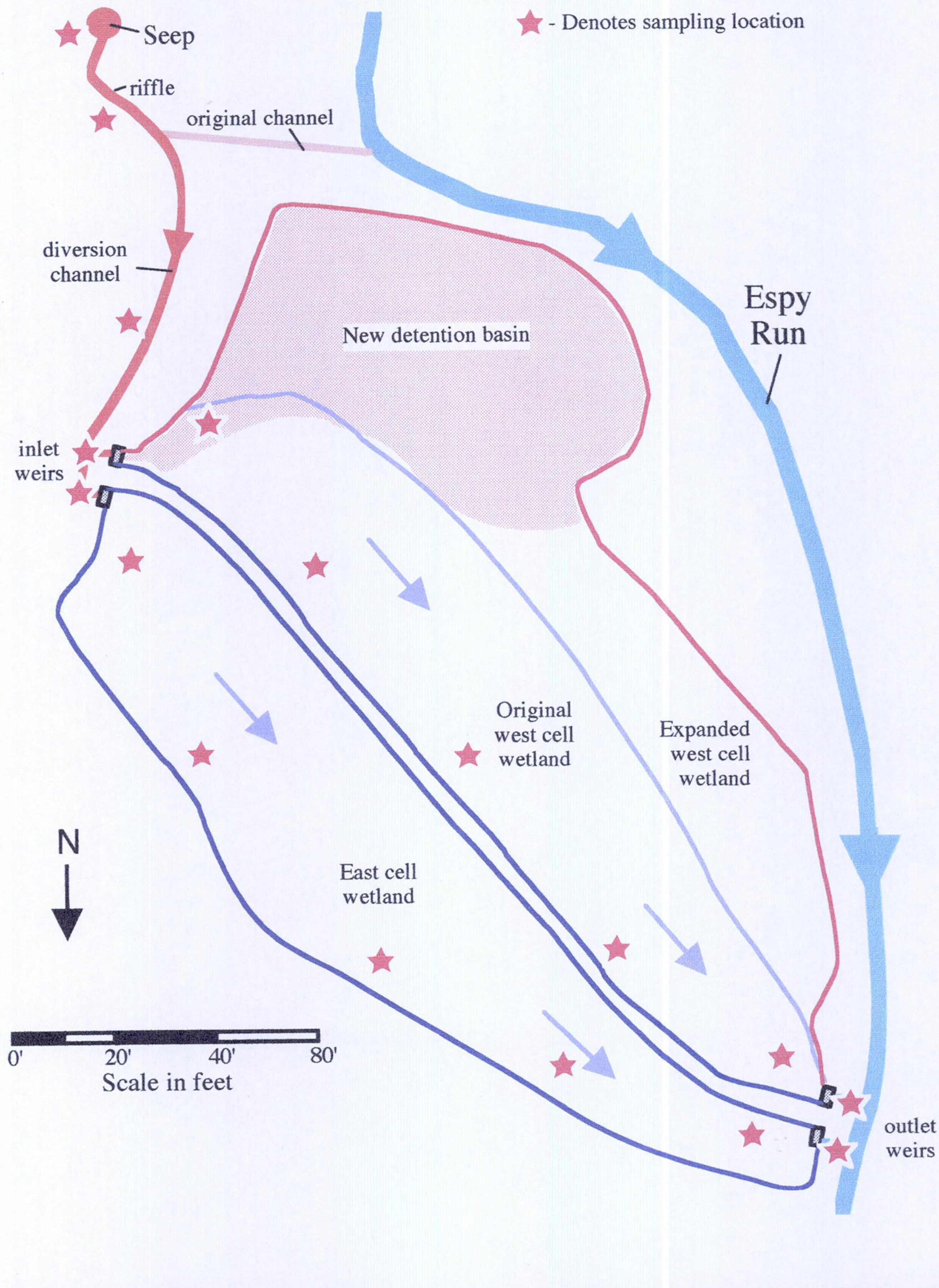
Samples were taken whenever free water was present in the wetland or stream, beginning in late November 2000. Samples were not taken within the wetland when it was shut down between mid-July and mid-November 2001. Sampling resumed in late December 2001 and continued through late November 2002.

1. Estimation of flow rates

At each sampling date, the water level was measured in inches from the bottom of each of the four V-notch weirs (two inlet and two outlet) to the top of the water surface. The measured value was divided by 12 to give the height in feet (H).

Figure 2 - Schematic Diagram of the Earth Conservancy 's Phase I Mine Drainage Treatment Wetland at Espy Run, Hanover Township, Luzerne Conty, PA

Dimensions based on compass and tape measure surveys by Dr. K. M. Klemow, 1997 and 2002



Flow rate in GPM was estimated using the formula:

$$Q\ (GPM) = H^{2.5} \times 461.48$$

Flow rates for the inlet and outlet weirs in each cell were compared to assess the degree of loss in flow within the wetland.

2. 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 AP10 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 from 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 from the meter.

3. 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.

4. 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 WWQL, 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 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. Data were transcribed into a dataform that was prepared by the project PI. That form contained the expected range for each parameter at each site. Data values that exceeded the expected range were checked as an initial quality-assurance step.

C. Data Management, Analysis, 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 twelve 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 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.

The raw data for each parameter at each site were then transcribed onto a series of schematic diagrams of the Phase I system to enable the visualization of spatial and temporal trends, especially as they relate to the impact of the seep / wetland complex on Espy Run (Figures A-1 - A-16).

Concentration data for total and dissolved iron were subject to further analyses to determine loading rates and removal trends at the inlet and outlet of each cell. The percentage of particulate iron was calculated in two ways. The first was calculated based on the total iron in the water sample taken at each weir. That value gave a snapshot of the degree to which the suspended iron in that sample was in the particulate vs dissolved form. The second was based on the amount of total iron entering each cell, and thus included the amount of iron precipitated within the wetland cell.

The amount of iron entering or leaving each cell was calculated by the formula:

$$\text{Fe (lbs/day)} = [\text{Fe}_{\text{total}}\ (\text{mg/L})] \times \text{Q (GPM)} \times 0.01221$$

The daily iron removal rate was calculated as the arithmetic difference between the amount of iron entering and the amount leaving.

The per-acre iron loading rate (lbs Fe / acre / day) was calculated for the east cell by dividing the daily iron removal rate by 0.13 acres. For the west cell, the rate was calculated using 0.13 as the denominator for samples taken before July 2001, and 0.258 (see below) as the denominator for the samples taken beginning December 2001.

The iron removal coefficient (k) was calculated using the formula:

$$k = -(1/T_d) \times \log_e ([\text{inlet Fe}_{\text{total}}\ (\text{mg/L})] / [\text{outlet Fe}_{\text{total}}\ (\text{mg/L})])$$

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 3-30.

To facilitate an understanding of the impact of the wetlands, and especially the reconstruction effort on water quality improvement, monthly data values were averaged and standard deviations were calculated. Data subjected to such analysis included those from the Espy Run seep, the inlet weirs for each cell, the outlet weirs for each cell, Espy Run above the wetland discharge, and Espy Run below the discharge. Temporally, data were grouped, split according to readings collected before vs after the November 2000 start of the study, and split according to readings collected before and after the west cell was enlarged (October 2001). The statistical significance of differences found comparing sites (east vs west cells, inlets vs outlets, upstream vs downstream positions in Espy Run), or different time periods (e.g., before vs after construction) were analyzed by subjecting the raw population data to repeated Student t-tests using the algorithm present in MS Excel. No attempt to transform the data, or subject it to an Analysis of Variance was made in this analysis. 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. The summaries of the means, standard deviations, and t-test results are given in Tables 1-10.

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 it was received from the WWQL, the Project PI opened the datafile and he 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. In instances where samples could not be reanalyzed, values were inserted based on those of adjoining sites in the wetland complex.

E. Determination of Wetland Size for Detention Time Analysis

The size of each wetland cell was determined in fall of 1997 for estimation of detention time by use of a compass and tape measure. Using the distance and bearing information from that survey, a map showing the outline of each cell was generated using MacDraw Pro software on the Principal Investigator's PC. The area of each cell was then estimated using a point-grid method based on points arrayed on 5' centers.

The volume of each cell was estimated by the following formula:

$$V\ (ft^3) = 5600 \text{ sq. ft.} \times 0.5' \text{ average depth}$$

$$\text{yielding } V = 2800\ ft^3$$

Detention time in hours was calculated for each sampling date according to the formula:

$$T_d = 2800\ ft^3 \times 7.47\ gal.\ per\ ft^3 / Q\ (GPM) / 60\ min\ per\ hour$$

The as-built size of the reconstructed west cell was estimated in mid-June 2002 using the same compass and tape measure approach employed in 1997. However, the area covered by the sedimentation basin and pool were estimated separately.

The volume of the newly reconstructed west cell was estimated as follows:

$$V\ (ft^3) = [3875\ ft^2\ (\text{area of detention basin}) \times 3'\ (\text{average depth of detention basin})] + [7400\ ft^2\ (\text{area of wetland}) \times 0.33'\ (\text{average depth of wetland})]$$

yielding $V = 14{,}092\ ft^3$

The detention time of the reconstructed west cell was calculated for each sampling date using the formula:

$$T_d = 14{,}092\ ft^3 \times 7.47\ gal.\ per\ ft^3 / Q\ (GPM) / 60\ min\ per\ hour$$

IV. RESULTS

A. Integrity of Wetland System

The original construction of the Phase I system in 1996 required considerable earth moving to create the two wetland cells with well-defined 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.

Some slumping of the eastern bank of the eastern wetland cell was noted in 1996 and 1997, and was addressed by the Earth Conservancy. No slumping of that side was noted throughout the duration of this investigation, though it was frequently wet due to seepage from the higher ground to the east. That bank became colonized by a variety of grasses and hydrophytic rushes and sedges.

The bed and banks of the wetland cells generally maintained the same grade as recontoured in 1997. However, the berm separating the two wetland cells began to develop some slumping near the inlet pools in the early summer of 2002. The Earth Conservancy added some sand bags as a remedy, though they too appeared to begin to fail by early fall. Those berms were colonized by a dense growth of early successional herbaceous species.

The masonry and metal plates associated with the inlet and outlet weirs continued to look and function as designed. The weir positions were maintained as established in spring 1998, allowing limited flow to the east cell and the remaining flow to the west cell. Before reconstruction, flow in the west wetland cell showed normal patterns whereas flow in the east cell disappeared by June. No water left the outlet weir throughout that month. Flow was diverted away from the system as the wetland was reconstructed, beginning in July. Flow was reestablished in mid November 2001. Water flowed through both wetland cells throughout 2002.

During the first two years of operation, a plant community of soft rush (*Juncus effusus*) and bulrush (*Scirpus atrovirens*) was introduced by a troop of Cub Scouts and teams of Wilkes University students. The transplants showed excellent survival, and were joined by additional species including cattail (*Typha latifolia*), bur-reed (*Sparganium* sp.), and water star-wort (*Callitriche verna*).

The plant community that developed in the east cell became especially dense and diverse.

In addition to supporting a vigorous hydrophytic plant community, the wetland continued 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 summer. Thus, the system inarguably continued to function as a wetland ecosystem.

B. Impact of Reconstruction

As a result of reconstruction, the west cell was considerably reworked. One noteworthy change involved the creation of an oxidation basin that covers 3875 ft^2, (0.089 acres) and holds an estimated 11,625 ft^3 (ca. 87,000 gallons) of water. The second involved a 14-19' wide expansion of the existing wetland cell (Figure 2). A smaller outlet basin was also created above the outlet weir.

The reconstruction involved the creation of a small roadway that crossed the diversion channel, necessitating its enclosure within a culvert. That roadway continued onto the redefined berm that was constructed along the western edge of the west cell, especially around the new oxidation basin. The top of that berm was flat, and it had steep edges. In the first winter, some erosion was noted along the western edge of that bank leading down to the silt fence placed along the bank of Espy Run. That erosion ceased by mid spring 2002, and the banks remained intact throughout the rest of the investigation. Ryegrass planted on the berm for stabilization in the fall sprouted in the spring, and formed a plant community that became increasingly well developed throughout the year.

The construction left the original wetland community in the west cell intact. Plugs of soft rush and other hydrophytic species were transplanted into the west cell by a team of Wilkes University students in mid-November 2001. Those plants showed excellent survival throughout the subsequent winter and growing season. In addition, some colonization by water starwort was noted during mid and late summer. By the end of the summer, total plant cover within the wetland cell was 40-50%, in contrast to the 70-100% cover attained in the previously constructed cells that were left intact by the reconstruction effort. The combination of the planted individuals and the colonizers is critically important to effecting iron removal.

C. Seasonal Flow Patterns

Despite the fact that the summers of 2001 and 2002 were unusually dry, Espy Run seep flowed throughout the entire period of investigation, and thus followed its pattern of being a perennial seep.

Before reconstruction, flow rates entering the wetland averaged 126.5 GPM, fluctuating between 75 and 140 GPM (Table 1a, Figure 3A). No flow entered the wetland cells between July and mid-November 2001 because it was diverted into its original channel as a result of the reconstruction project. After flow resumed in November 2001, rates rose from 95 to 135 GPM by February. They maintained that level until May 2002, where they declined to 75 GPM by September. Flow rates rebounded to 110 -115 GPM by November 2002. Overall, flow averaged 114.8 GPM, which was not significantly different from that in the first six months of 2001. The prevailing flow regime observed in this assessment was similar to that noted in the assessment conducted between August 1999 and June 2000, though rates were less than that noted in 1996 (Figure 4A).

The differential in flow between the two cells that was created soon after the wetland was constructed was maintained throughout the duration of this study. As a result, flow in the east cell was limited to an average of 21.8 GPM, with most monthly readings varying between 8-35 GPM throughout the study (Table 1a, Figure 3A). In contrast, the west cell received the remaining flow, averaging 86.2 GPM, and monthly readings varying between 65 and 110 GPM. Differences in flow rates, including those taken before construction and after construction, were statistically significant (Table 1a).

Except when the wetland was being reconstructed, water typically flowed normally through the cells. However, during the summer of 2001, the amount of flow leaving the outlet weir in the low-flow east cell was far less than that entering. It was not clear whether the cell was leaking, or whether all the water entering was evaporating. Flow in both cells seemed normal following reconstruction, and no short circuiting was noted.

Patterns of detention times differed greatly between the two years of this assessment. Reconstruction enabled detention times in the high-flow west cell to increase from 3-5 hours (avg. = 3.5) to 17-22 hours (avg. = 20.3 hours) (Table 1b, Figure 3B). That increase was strongly significant, statistically ($P < 0.0001$). Indeed, post-construction detention times in the west cell were higher than those observed in any of the years before reconstruction (Figure 4B)

Before reconstruction, detention times in the low-flow east cell averaged 31.1 hours, varying greatly from 10 to 43 hours (Table 1b, Figure 3B). Detention time were especially high in late fall 2000 and spring 2001. Times were lower in mid winter, due to higher flow rates observed then. Following reconstruction, detention times in the east cell averaged 13.8 hours (Figure 3B), which was significantly lower than that pre-construction ($P<0.0001$). Before construction detention times were significantly higher in the east cell ($P<0.0001$), whereas after construction, they were significantly higher in the west cell ($P<0.0001$) (Table 1b).

Considering the two cells together, the reconstruction effort, raised detention times from an average of 6.0 hours (range 3-10 hours) to an average of 18.7 hours (range 15-20 hours) (Table 1b, Figure 3B). That increase was statistically significant ($P<0.0001$).

Water was present in Espy Run throughout both years of this assessment allowing samples to be collected at both creekside locations during most sampling sessions.

D. Measured Parameters

1. Temperature

As expected, water temperature varied on a seasonal basis (Figures 5, A-1). Temperatures at the seep were generally between 10.0 and 13.0 °C, with the exception of a few samples in mid-summer 2001 that ranged up to 29 °C (Figures A-1, A-2). In the fall and winter of 2000 / 2001 temperatures in the wetland cells were mostly between 7 and 11 °C. They rose noticeably between April and June reaching 21.5 to 25.0 °C. In the year following reconstruction temperatures showed a clear seasonal progression, cycling between 5 and 20 °C. Summertime temperatures were observed to be somewhat lower in 2002 than in the previous summer. During the winter, temperatures tended to be lower at the outlets than the inlets, which would be expected for groundwater exposed to cold ambient temperatures (Figures 5A, B). Likewise, water temperature tended to increase by 3-7 °C as it passed through the wetland in the warmer months. In the summer, water temperatures in the east cell tended to be a bit warmer than those in the west cell, possibly due to the comparatively low volume of flow in that cell (Figure A-1). Temperature patterns observed throughout the study were generally similar to trends noted in previous years (Figure 6).

Water temperatures within the two sites along Espy Run went through the expected seasonal progression in both years, with temperatures in the coldest months being 2-7°C and those in the warmer months being mostly 18-20 °C (Figures A-1, A-2). Typically, flow from the wetland complex caused an increase in creek water temperatures between November and February. During other months, flow downstream of the wetland discharge was similar to that upstream (Figures A-1, A-2).

2. pH

Water discharging from the Espy Run seep was alkaline, distinguishing it from acidic discharges found in other abandoned mine discharges. Throughout the study, pH levels at the seep were typically between 6.2 and 7.4, averaging 6.8 (Table 2a, Figures A-3, A-4). No clear seasonal patterns were noted, nor were any differences before or after construction observed (P=0.703).

Water pH at both inlets averaged 6.7, varying between 6.2 and 7.0 throughout the study (Table 2b, Figures 7A, 7B). In previous years, pH at the inlets was slightly but significantly (P=0.03) higher, averaging 7.0 (Figure 8).

Water pH increased to an average of 7.0 as it passed through each of the two cells (Table 2b, Figures 7A, 7B), an increase that was significant in both cells (P<0.001). Reconstruction did not enhance the increase of pH in the west cell.

On average, pH levels in Espy Run above the wetland discharge was 7.1 (Table 2c, Figures A-3, A-4), again due to the high net alkalinity patterns throughout most of the watershed (Klemow 2002). Downstream pH readings averaged 7.0 before and after the reconstruction effort (Table 2, Figures A-3, A-4). Thus, the wetland complex did not have any consistent impact on increasing or decreasing pH levels within the creek during the study.

3. Specific conductance

Water discharging from the Espy Run seep had a relatively high specific conductance during the study, thanks to high levels of dissolved ions like sulfate and iron. Conductance levels averaged 1025 μmho/cm, varying in most months between 850 and 1150 μmho/cm (Table 3a, Figures A-5, A-6). The lowest reading, 624 μmho/cm, was found in September 2001 (Figure A-5).

Conductance levels at both inlet weirs averaged 1020 μmho/cm (Table 3b). Patterns within the wetlands each month are shown in Figures A-5 and A-6. Average conductance did decline somewhat to 961 and 977 μmho/cm in the east and west cells, respectively. While those decreases were statistically significant (east cell P=0.017, west cell P=0.039), the decline averaged only 5.7% in the east cell and 4.3% in the west cell (Table 3c, Figures 9 and 10).

Conductance readings taken during the study were somewhat lower than those taken between 1997 and 2000 (Table 3b, Figure 10). The reconstruction effort did not have a clear impact on causing an improvement in the levels of conductance in the west cell (Table 3c).

Conductance readings at the Espy Run site upstream of the wetland discharge remained lower than those in the seep and wetland, averaging = 500 μmho/cm) (Table 3d). That value was significantly (P=0.005) lower than observed between February 1997 and June 2001 where the mean was 646 μmho/cm. Readings downstream averaged = 761 μmho/cm (range = 500 - 1000 μmho/cm). A paired t-test showed that the increase in conductivity caused by the wetland's discharge was statistically significant (P<0.0001). While downstream conductance was statistically lower following reconstruction than before, that reduction may be attributable to the fact that upstream conductance was also lower (Table 3d).

4. Dissolved oxygen (DO)

Water discharging from the Espy Run seep had DO levels that averaged 3.5 mg/L, with a range of 0.8 - 8.3 (Table 4a, Figures A-7, A-8). Those readings were consistent with measurements taken before this study. Low DO levels at the seep were expected because the water was freshly emerging from the ground at that point.

DO readings increased to an average of 5.0 mg/L at the inlet weirs, though in some months little increase was noted (Table 4b, Figures A-7, A-8). For the entire study, DO levels increased to an average of 7.5 and 7.2 mg/L in the east and west cells, (Table 4b, Figures 11, 12, A-7, A-8). Both increases were significant at the P<0.0001 level. DO levels before reconstruction increased from 4.5 mg/L in the inlet weirs to 6.6 in the east cell outlet weirs and 6.7 in the west outlet weirs. Interestingly, no difference in DO levels were noted between the two outlet weirs despite the large difference in detention times. Enlargement of the west cell similarly did not cause an increase in DO levels there.

Water within Espy Run upstream of the AMD discharge averaged DO concentrations of 9.2 mg/L (Table 4c, Figure A-7, A-8), which was significantly (P=-0.002) higher than the 6.9 mg/L observed in the previous two years. Readings taken in warmer months were typically lower than those in cooler months, which would be expected because oxygen declines in solubility with increase in temperature. Discharge from the wetland had no discernible impact on DO concentrations in the stream channel.

5. Iron

As noted above, the Espy Run treatment wetland was designed primarily to remove iron from the minewater that it receives. Reconstruction of the west cell was conducted to enhance iron removal, which had been generally in the 8-30% range. To that end, iron dynamics were studied intensively and data are expressed in terms of measured concentrations for total and dissolved iron at the inlet and outlet weirs for each cell, the rate at which particulate iron was being formed, iron loading and removal (both in terms of total iron removed and percent removed as a function of starting load), and iron removal kinetics. The information presented herein provide an assessment of the success of the reconstruction effort in the first year following its completion.

a. Total iron concentrations

Water entering the system from the Espy Run seep averaged 20.0 mg Fe/L during this assessment, with individual monthly measurements varying between 11.7 and 29.9 mg/L (Table 5a, Figures A-9, A-10). That level of iron contamination was nearly the same as noted in samples taken between 1994 and 2000 (average=20.4 mg/L, P=0.71). However, the average for samples taken in 1994 alone were 15.2 mg/L suggesting that over the longer term, iron pollution at the Espy seep may be getting worse.

Total iron concentrations entering the two wetland cells paralleled those at the outfall, ranging between 15 and 25 mg/L (Figures 13, A-9, A-10), and averaging 19.0 mg/L (Table 5b). Those values generally coincided with the longer-term trends noted between 1994 and 2000 (Table 5b, Figure 14).

Between November 2000 and May 2002, total iron concentrations averaged 3.4 and 15.9 mg/L at the east and west outlet weirs, respectively. Those averages differed significantly from each other (P=0.001), but were not significantly different from the historic readings of 3.6 and 16.6 mg/L (Figure 14). Iron concentrations taken after the west cell was reconstructed declined to an average of 0.7 and 6.0 mg/L at the east and west outlet weirs, respectively (Table 5b, Figure 13). The difference between pre- and post-construction values was significantly different at the P=0.0001 level. Iron concentrations were particularly low (<3 mg/L) in the west cell between August and October 2002.

In terms of percent iron removal, pre-construction rates averaged 81.5% and 15.7% on the east and west cells, respectively (Table 5c, Figures 13, 14). The corresponding post-construction averages rose to 95.9% and 63.2%, which was especially significant in the west cell. All of those values were significantly different from each other at the P=0.0001 level. For the east cell, removal percentages post-construction consistently exceeded 92%, and occasionally exceeded 98% (Figure 13C). In contrast, many monthly values pre-enlargement were in the 40-80% range (Figure 14C). Since the west cell was not impacted by the construction effort, its enhanced iron removal was unexpected, yet still welcome. For the west cell, removal percentages post-enlargement also fluctuated markedly from month to month (Figure 13C). Still, even the worst months had higher removal percentages than before the west cell was enlarged, where rates in the 8-25% range were common (Figure 14C).

Inspection of the monthly concentrations at each point in each wetland cell revealed that all parts of the wetland were important in removing iron (Figures A-9, A-10). During some months, most of the removal occurred between the inlet pool and the halfway point, whereas in other months removal was downstream of the halfway point. Due to the shallow ponding and heavy iron accumulation in the cells (especially the east cell), obtaining a whole water sample free of sediment was occasionally difficult. Therefore, interpreting iron removal within each cell should be done with caution.

b. Dissolved / particulate iron

A determination of the proportion of dissolved iron as a function of the total provides insight into the iron removal process since iron must undergo a process of oxidation and flocculation before being filtered from the system. Higher proportions of dissolved iron denotes a situation in which the iron is not "ready" to be removed. To that end, both total and dissolved iron were assessed in this analysis.

As would be expected for fresh mine water, nearly all of the iron in the water emerging from the Espy Run seep was in a dissolved form (Figures A-9, A-10). When the water reached the inlet weirs, the percentage of dissolved iron in the water were still high ≥95%, though exceptions were noted.

Though considerable variability was noted from month-to-month and site-to-site, the proportion of dissolved iron did drop noticeably as water passed through the wetland system (Table 6a, Figures A-9, A-10). By the system's midpoint in each cell, values were mostly <60%, and occasionally far less. By the 3/4 point, most values were <35%.

As expected, concentrations of dissolved iron were lower at both outlet weirs than concentrations of total iron (Figure 15). In 2002, virtually no dissolved iron left the east cell (Figure 14A), whereas the amount leaving the west cell was mostly <5 mg/L (Figure 15B). Compared to pre-construction levels, the amount of dissolved iron was substantially lower at both outlet weirs; a difference that is both noteworthy and encouraging (Table 6a, Figure 16).

Additional insight can be gained by examining the dynamics of particulate iron, which can be calculated as [total Fe] - [dissolved Fe]. The amount of particulate iron in the water was expressed in two ways. The first expressed particulate iron as a function of the amount of iron in the whole water sample (suspended iron), and thus provided a snapshot of the oxidation - coagulation process at that point. The second was calculated as a function of the total amount of iron entering the system, and thus included all of the iron that precipitated out within the wetland cell.

When expressed as a fraction of the suspended iron (Figure 17), the percentage of particulate iron in the water rose from 8% to 59% in the east cell, and from 9% to 43% on the west cell (Table 6b). Such an increase would be expected since iron would have the time to go through the oxidation - hydrolysis - flocculation reactions needed to enter the particulate form. Substantial month-month variability was noted in both cells. In the low-flow east cell, the variability was attributable to the extremely low concentrations of iron leaving that cell (Figure 17A). The proportion of particulate iron was at the level of detection of the methodology, and therefore subject to chance variability. In contrast, the west cell showed very high levels (>85%) of particulate iron between December 2001 and February 2002 (Figure 17B). However, levels declined throughout the spring, reaching 20-45% between April and September 2002. That decline was contrary to expectation since the enlarged wetland should have promoted the formation of particulate iron. Regardless, the levels of particulate iron were certainly higher in the west cell post construction (57.6%) than before construction (26.2%), a difference that was significant at P=0.001 (Table 6b, Figure 18). The implication is that the enlarged wetland did indeed promote the processes needed for iron removal.

When the calculation of particulate iron included that removed within the wetland itself, the effect of reconstruction became particularly apparent. After construction, nearly all (97.8%) of the iron entering the east cell became converted into the particulate form by the outlet weir (Table 6c, Figure 19A). In the west cell, the average was 85.1% (Table 6c, Figure 19B). In contrast, the pre-construction percentages were 88.9% and 38.0% (Table 6c). Both increases were statistically significant (P=0.0002 and P<0.00001). While the reconstruction can explain the improvement for the west cell, the excellent performance of the east cell cannot be explained by any reason other than the maturation of the vegetation within the cell.

c. Iron loading rates and removal kinetics

Iron loading into the system and iron removal from the system are both possible by combining concentration and flow data. As a result, an iron budget can be calculated. The total amount of iron entering the system averaged 25.2 lbs/day (Table 7a), with individual monthly estimates varying between 10 and 41 lbs/day (Figure 21A). Estimated iron loading between 1997 and 2001 averaged 30.9 lbs/day, which was not significantly different (P=0.19) from that noted during the two year duration of this study (Table 7a, Figure 22A).

As expected, the greater flow in the west cell brought in more iron (20.2 lbs/day) than in the east cell (5.0 lbs/day) (Table 7a, Figure 21A). Those loading rates paralleled those observed in the previous years (Figure 22A).

Iron removal by the wetland complex varied greatly from month to month, especially after the west cell was enlarged, averaging 14.2 lbs/day (Table 7b, Figure 21B). Following enlargement, the west cell removed an average of 12.8 lbs / day, compared to 3.9 lbs / day before enlargement (P=0.0006). Corresponding values for the east cell were 5.6 and 3.3 lbs/day (P<0.0001). In total, the reconstructed wetland removed 18.5 lbs Fe /day compared to 7.2 lbs/day before (Table 7b, Figure 22B). That increase was significant (P=0.0002), and was due to the west cell's ability to remove more iron.

Rates of iron removal were expressed on a per acre basis to determine the degree to which the system approached the 180 lbs Fe/acre/day loading rate established for AMD-treatment wetlands. Rates for the two cells together averaged 39.7 lbs Fe/acre/day (Table 7c), though monthly readings varied greatly from date to date, with a low of 11 lbs/acre in May 2001 to a high of 72 lbs / acre in December 2001 (Figure 21C). Rates for the east and west cells averaged 35.0 and 43.5 lbs Fe/acre/day (Table 7c). However, large monthly variability obscured any differences between sites (P=0.10). Before enlargement, rates were 25.1 and 30.4 lbs Fe/acre/day on the east and west cells, (Figure 22C). After enlargement, rates increased to 43.4 and 49.7 on the east and west cells. Both of those increases were significant at the P=0.05 level (Table 7c). Thus, while some improvement was noted, area-based removal rates remained far below the 180 lbs Fe/acre/day benchmark.

Iron removal kinetics were calculated, based on flow rates and concentration information, following the formula given in the Methods section. During the two years of this study, removal rate constants averaged -0.213 in the east cell and -0.065 in the west cell (Table 7d, Figure 23). Interestingly, the reconstruction project had its most pronounced impact on removal constants in the east cell, which decreased from -0.124 before reconstruction to -0.300 after (Figure 24). In contrast, rate constants in the west cell showed a non-significant decline from -0.052 to -0.068 (Table 7d). The highly negative removal constants on the east cell are likely due to the fact that the limited flow allows iron to be efficiently removed within the dense vegetation. In contrast, one explanation for the lower removal rate constant in the west cell is because the vegetation is not yet well developed enough to efficiently clarify the water. Additional examination into 2003 would be needed to determine whether the west cell's removal constant can be improved by the further maturation of the wetland vegetation in there.

d. Impacts on Espy Run

The impact of the wetland on iron loading with Espy Run was examined throughout the two years of the study. Iron levels upstream of the wetland discharge averaged 3.2 mg/L. In comparison, concentrations between 1994 and 2000 averaged 2.6 mg/L, which was not significantly different (P=0.62). Some iron contamination of Espy Run occurs due to the presence of several seeps located <200' upstream of the wetland discharge.

Iron levels downstream of the discharge averaged 6.0 mg/L for the two years of this study (Table 5d). Significantly, samples taken after reconstruction averaged 5.6 mg/L, which was significantly (P=0.003) less than the 9.4 mg/L observed before the wetland was reconstructed (Table 5d). Thus, while the full impacts of the reconstruction project are probably still yet to be realized, the analysis thus far reveals that the project has had a demonstrated benefit of improving water quality in Espy Run.

6. Sulfate

Water samples collected from the Espy Run seep were analyzed for sulfate between July and December 1994, and again between August 1999 and June 2001. In total, concentrations then were 307 mg/L (Table 8a). Throughout this analysis, sulfate concentrations were not significantly different (P=0.61), averaging 296 mg/L, and ranging from 190-353 mg/L (Figures A-11, A-12).

Sulfate concentrations throughout the wetland complex were mostly similar to those noted at the seep, with values being mostly 250 - 350 mg/L (Figure 25, A-11, A-12). Average sulfate concentrations at the outlets were 287 in the east cell and 296 in the west cell, a difference that was not statistically significant (P=0.159) (Table 8c). The decline in sulfate concentrations between the inlet and outlet was significant in the east cell (P=0.005), but not in the west cell (P=0.612). Reconstruction did not improve the ability of the west cell to remove sulfate, even when data included back to 1999 were incorporated (Table 8c, Figure 26). The latter finding was not problematic because sulfate removal was not a key outcome of the Phase I wetland.

During this study, sulfate concentrations in Espy Run above the wetland discharge averaged 139 mg/L (Table 8d; Figure A-6), which was significantly (P=0.036) less than the 220 mg/L found between 1999 and 2000. Downstream concentrations of sulfate averaged 241 mg/L, which was significantly (P=0.018) less than the 317 measured between 1999 and 2000 (Table 8d). Sulfate concentrations increased by ca. 100 mg/L both before and after reconstruction, which was not surprising since the wetland did not retain more sulfate as a result of the reconstruction effort.

7. Alkalinity

Alkalinity levels from the Espy Run seep varied between 108 and 432 mg/L (Figure A-13, A-14), averaging 283 mg/L (Table 9a). Those values were not statistically different (P=0.211) from the 304 mg/L found between 1999 and 2000.

Alkalinity levels within the wetland complex itself were mostly 250 - 350 mg/L (Figures A-13, A-14. 26), averaging 300 mg/L at both inlet and outlet weirs (Table 9b). No trends were noted in alkalinity, either comparing sites, or between the inlet and outlet to the wetlands (Figure 27).

Alkalinity within the wetland during this study were similar to those measured during the previous two years (Figure 28), and no consistent removal or addition trends were noted (Figure 9c).

In Espy Run, alkalinity upstream of the wetland discharge was generally in the 40-170 mg/L range throughout the period of investigation (Figure A-13, A-14), averaging 131 mg/L (Table 9d). Values obtained in 2001 - 2002 were nearly identical to those obtained in 1999-2000 (P=0.743). Alkalinity increased to an average of 209 mg/L below the wetland discharge, a difference that was significant at the P=0.0001 level (Table 9d). The reconstruction effort did not impact alkalinity trends in Espy Run.

8. Acidity

Levels of acidity at the seep varied substantially from month to month throughout this study, though values each month were consistently lower than those of alkalinity (Figures A-15, A-16). The average acidity measured 10.2 mg $CaCO_3$ / L. That average was almost identical to the average of 10.4 mg / $CaCO_3$ / L observed in 1999-2000 (Table 10a).

Acidity levels within the wetland tended to track those of the seep. Average levels at the east and west inlets were 7.7 and 8.0 mg $CaCO_3$ / L, respectively; a difference that was not statistically different (P=0.811) (Table 10b, Figure 29). Levels declined to 3.8 and 6.3 mg $CaCO_3$ / L at the east and west outlet weirs, respectively. The decline in acidity levels was statistically significant in the east cell (P=0.042), but not in the west cell (P=0.321) (Table 10b). Acidity reduction was greater after reconstruction than before, but in both cells. Therefore, reconstruction did not have any special impact on improving acidity levels within the west cell (Table 10c).

Acidity levels in Espy Run upstream of the discharge averaged 2.8 mg $CaCO_3$ / L during this study, compared to the average of 6.8 mg $CaCO_3$ / L found between 1999 and 2000 (a difference that was significant at P=0.018) (Table 10d). Below the wetland discharge, acidity levels averaged 2.5 mg $CaCO_3$ / L during the study. Before wetland enlargement, discharge from the wetland caused acidity levels to increase from 6.3 to 8.2 mg $CaCO_3$ / L, a difference that was significant at P=0.046. After wetland enlargement, discharge from the wetland caused acidity levels to decline from 1.8 to 0.9 mg $CaCO_3$ / L, though that decline was not statistically significant (P=0.20) (Table 10d).

V. CONCLUSIONS

Key water quality parameters were analyzed at the Earth Conservancy's Phase I mine drainage treatment wetland adjoining the Espy Run seep in Hanover Township, Luzerne County, PA between November 2000 and November 2002. This assessment represented a continuation of ongoing assessments made since the wetland was first constructed in 1996. This effort was particularly noteworthy because it included sampling both before and after the wetland's west cell was enlarged in the late summer / fall of 2001. That enlargement was carried out to improve the performance of the wetland complex to remove iron.

Water continued to flow into the two cells at a rate that averaged ca. 108 gallons per minute, varying between 75-145 GPM. That flow rate was consistent with readings made between 1999 and

2000, but lower than rates observed throughout much of 1998. The differential flow pattern into the two cells established in 1997 was maintained such that the east cell received an average of 21 GPM, while the west cell received the remainder (86 GPM).

Water quality parameters measured at the seep and entering the wetland complex were generally similar to those observed between 1994 and 2000. In particular, the water throughout the system had net alkalinity (average alkalinity = 283 mg/L vs average acidity = 10 mg $CaCO_3$/L), causing pH readings be a rather neutral 6.8-7.0. Specific conductance readings averaged 1025 μmho/cm, while sulfate concentrations averaged 296 mg/L. Iron concentrations, which were viewed as being the most important to the function of the wetland, averaged 20 mg/L. Expressed as loading, the Espy seep discharged an average of 25.2 lbs/day.

The low-flow east cell had a detention time that averaged 21 hours, which was actually less than times observed in previous years. In contrast, the creation of the detention basin and enlarged wetland cell caused detention time in the high flow west cell to increase tenfold, from 3 to 30 hours.

The wetland reconstruction effort was intended to improve iron removal, and thus an analysis of iron trends was central to this investigation. Thanks for its reduced flow, the east cell showed a reduction in total iron from 20 mg/L to 3.6 mg/L; a 81% loss before reconstruction. Even though the reconstruction effort did not affect the east cell, its ability to remove iron improved to 96% for the samples collected after flow resumed. Historically, removal was much poorer in the west cell (average 15%) because the large volumes of water prevented adequate detention in the wetland originally designed. The reconstruction of the west cell did have a significant impact, causing removal percentages to exceed 60%. Indeed, iron removal exceeded 90% in the west cell for three months during the summer of 2002. Expressed as iron loading, the wetland system removed an average of 18.5 lbs Fe/day following reconstruction, compared to 7.2 lbs/day before reconstruction.

The reconstruction project did lead to some evident improvement in water quality downstream of the wetland's discharge into Espy Run. Before reconstruction, discharge from the wetland caused iron concentrations to jump from 3.0 to 9.4 mg/L. After reconstruction, the rise was much more modest, from 2.4 upstream to 5.6 mg/L downstream.

While the reconstruction project did improve water quality both within the wetland and downstream, the ultimate goal of having iron-free water leaving the wetland was not achieved. Visits to the wetland site revealed that the water leaving the west cell continually had a disappointingly high level of turbidity, leading to discoloration in the stream channel downstream.

The Earth Conservancy has at least three courses of action that it may wish to pursue, if the ultimate objective is to have a system that discharges iron-free water. The first option would be to wait for the vegetation to mature in the west cell. Since the wetland community in the newly constructed part of the west cell was still rather sparse (25-35% cover) additional time may be all that is needed to allow for the development of a high density community that will effectively trap iron, as observed in the east cell. Clearly, that option has no cost associated with it, other than underwriting periodic water quality assessments to gauge the trends in iron removal.

A second option would be to install aeration devices, as done at the Phase II wetland site along Dundee Road. At present, the splash-aeration currently in place at the inlet weirs may not be enough to fully oxygenate the water. The fact that dissolved oxygen shows a significant increase between the inlet and outlet weirs indicates that the aeration process happens continually through the wetland. By installing an aeration device, the reactions leading to the production of iron hydroxide floc would be promoted. The possibility of introducing an aeration device is under consideration by the EC.

A third option would be to establish an additional treatment wetland in the area west of the west cell. At present, that area is a low woodlot through which Espy Run flows. Rerouting the creek 150-250' to the west would free up as much as 1.5 acres of land that could be converted into treatment wetland. Establishing a treatment wetland in that location would also capture the seepage from the bank south of the Phase I wetland that could not be addressed by the wetlands as designed. While the latter course of action might be the most effective in the long term, it may be the most costly, and may require extensive permitting through the US Army Corps of Engineers and the Pennsylvania Department of Environmental Protection. Officials from each agency are being invited to visit the site and provide their thoughts on the likelihood of securing a permit for that kind of project.

The Wilkes Technical Team intends to work closely with the Earth Conservancy to help decide on, and implement, a future course of action.

VI. ACKNOWLEDGMENTS

The original idea for enlarging the west cell was provided by Dr. Thomas Walski, Project Co-PI for the original Phase I construction project. He and Dr. William Tarutis provided insights into evaluating the kinetics of iron removal within each cell. Execution of this project was made possible by the diligent efforts of several colleagues and collaborators. Of particular importance were the excellent efforts of Christian Watkins and John Pagoda, Field Associates for the Wilkes University Water Quality Laboratory, who conducted field sampling and analysis. Brian Oram, Director, Wilkes University Water Quality Laboratory, provided crucial oversight and ensured that supplies and equipment were properly ordered and maintained. Most of Mr. Oram's time was donated to the project on an in-kind basis. Susan DiBonifazio, Accounting Assistant for Wilkes's Finance Office maintained the records of project charges and kept us aware of the project's financial status. Dr. John Harrison, Associate Dean, served as Project Manager and provided invaluable advice on finances and timetable. Original funding for this project was provided by a cooperative agreement (CA 070117) between the US Office of Surface Mining and the Earth Conservancy. This project was funded by a grant (Wilkes #CC-1024) from Earth Conservancy to Wilkes University.

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Tables

Table 1 - Summary of Hydrology Trends
Earth Conservancy Phase I Wetland

Espy Run, Hanover Township, Luzerne County, PA

Mean values are shown in bold type, ± 1 standard deviation. Data collection and analysis by the Wilkes University Wetland Technical Team

a. Rate of Water Influx (gallons/minute)

Study period	East Cell	West Cell	Combined	E vs W t-test
All samples (9/97-11/02)	**19.2** ± 10.1	**105.2** ± 32.0	**124.4** ± 36.6	P<0.0001
Prior studies (9/97-6/00)	**18.2** ± 10.1	**112.5** ± 33.9	**130.7** ± 39.1	P<0.0001
This study (11/00-11/02)	**21.8** ± 9.7	**86.2** ± 14.6	**108.0** ± 22.2	P<0.0001
t-test result	n.s.	P<0.0001	P=0.004	
Before enlargement (9/97-7/01)	**17.6** ± 10.1	**108.8** ± 33.7	**126.5** ± 39.3	P<0.0001
After enlargement (9/01-11/02)	**26.7** ± 5.7	**88.1** ± 11.8	**114.8** ± 16.4	P=0.0001
t-test result	P=0.0002	P=0.0005	n.s.	

b. Estimated Detention Time (hours)

Study period	East Cell	West Cell	Combined	E vs W t-test
All samples (9/97-11/02)	**28.1** ± 21.6	**6.4** ± 6.6	**8.2** ± 5.2	P<0.0001
Prior studies (9/97-6/00)	**30.8** ± 23.7	**3.3** ± 0.9	**5.8** ± 1.5	P<0.0001
This study (11/00-11/02)	**21.0** ± 12.5	**14.4** ± 8.3	**14.7** ± 6.1	n.s.
t-test result	P=0.032	P<0.0001	P=0.004	
Before enlargement (9/97-7/01)	**31.1** ± 22.6	**3.5** ± 0.9	**6.0** ± 1.7	P<0.0001
After enlargement (9/01-11/02)	**13.8** ± 3.9	**20.3** ± 3.3	**18.7** ± 3.2	P<0.0001
t-test result	P<0.0001	P<0.0001	P<0.0001	

Table 2 - Summary of pH Trends in the Earth Conservancy Phase I Wetland

Espy Run, 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 at the Espy Run Seep

Study period	Mean ±1 SD
All samples (7/94-11/02)	**6.8±** 0.3
Prior studies (7/94-6/00)	**6.8±** 0.2
This study (11/00-11/02)	**6.8±** 0.4
t-test result	n.s.
Before enlargement (7/94-7/01)	**6.8±** 0.2
After enlargement (9/01-11/02)	**6.8±** 0.5
t-test result	n.s.

b. Trends in the Wetland

Study period	East Cell inlet	East Cell outlet	East Cell t-test	West Cell inlet	West Cell outlet	West Cell t-test	t-test for E vs W outlet
All samples (9/97-11/02)	**6.9+** 0.3	**7.1+** 0.3	P<0.0001	**6.9+** 0.3	**7.0+** 0.3	P=0.017	P<0.0001
Prior studies (9/97-6/00)	**7.0±** 0.2	**7.1±** 0.3	P=0.001	**6.9±** 0.3	**7.0±** 0.3	n.s.	P<0.0001
This study (11/00-11/02)	**6.7±** 0.2	**7.0±** 0.2	P<0.0001	**6.7±** 0.2	**7.0±** 0.3	P=0.0003	n.s.
t-test result	P<0.0001	n.s.		n.s.	n.s.		
Before enlargement (9/97-7/01)	**6.9±** 0.3	**7.1±** 0.3	P<0.0001	**6.9±** 0.3	**7.0±** 0.3	n.s.	P<0.0001
After enlargement (9/01-11/02)	**6.7±** 0.2	**7.0±** 0.2	P<0.0001	**6.7±** 0.2	**7.0±** 0.4	P=0.020	n.s.
t-test result	P=0.001	n.s.		P=0.006	n.s.		

c. Trends in Espy Run

Study period	Above discharge	Below discharge	t-test
All samples (7/94-10/02)	**7.1** ± 0.2	**7.0** ± 0.2	n.s.
Prior studies (7/94-6/00)	**7.0** ± 0.2	**7.1** ± 0.2	n.s.
This study (11/00-11/02)	**7.1** ± 0.3	**7.1** ± 0.2	n.s.
t-test result	n.s.	n.s.	
Before enlargement (7/94-7/01)	**7.1** ± 0.2	**7.0** ± 0.2	n.s.
After enlargement (9/01-11/02)	**7.1** ± 0.3	**7.0** ± 0.2	n.s.
t-test result	n.s.	n.s.	

Table 3 - Summary of Conductivity Trends in the Earth Conservancy Phase I Wetland

Espy Run, Hanover Township, Luzerne County, PA

Values given as mean (in μmho/cm) ± 1 standard deviation. Data collection and analysis by the Wilkes University Wetland Technical Team

a. Trends at the Espy Run Seep

Study period	Mean ±1 SD
All samples (7/94-11/02)	**1057** ± 125
Prior studies (7/94-6/00)	**1098** ± 99
This study (11/00-11/02)	**1025** ± 133
t-test result	P=0.025
Before enlargement (7/94-7/01)	**1091** ± 107
After enlargement (9/01-11/02)	**985** ± 133
t-test result	P=0.013

b. Trends in the Wetland

Study period	East Cell inlet	East Cell outlet	East Cell t-test	West Cell inlet	West Cell outlet	West Cell t-test	t-test for E vs W outlet
All samples (9/97-11/02)	**1063** ± 93	**1026**± 104	P=0.0004	**1055** ± 84	**1051** ± 111	n.s.	P<0.0001
Prior studies (9/97-6/00)	**1079** ± 87	**1050**± 82	P=0.01	**1068** ± 74	**1079** ± 91	n.s.	P<0.0001
This study (11/00-11/02)	**1020** ± 94	**961**± 127	P=0.017	**1021** ± 99	**977** ± 126	P=0.039	n.s.
t-test result	P=0.02	P=0.009		n.s.	P=0.003		
Before enlargement (9/97-7/01)	**1071** ± 91	**1038**± 95	P=0.002	**1063** ± 81	**1068** ± 99	n.s.	P<0.0001
After enlargement (9/01-11/02)	**1024** ± 96	**967**± 126	n.s.	**1017** ± 92	**971** ± 134	n.s.	n.s.
t-test result	n.s.	n.s.		n.s.	P=0.03		

c. Percent Removal Trends

Study period	East Cell	West Cell	t-test
All samples (7/94-10/02)	**3.3** ± 7.6	**0.5** ± 6.1	P=0.0002
Prior studies (7/94-6/00)	**2.5** ± 6.6	**-1.0** ± 4.1	P=0.0005
This study (11/00-11/02)	**5.7** ± 9.5	**4.3** ± 8.5	n.s.
t-test result	n.s.	P=0.018	
Before enlargement (7/94-7/01)	**2.9** ± 6.9	**-0.4** ± 4.5	P=0.0003
After enlargement (9/01-11/02)	**5.4** ± 10.5	**4.5** ±10.2	n.s.
t-test result	n.s.	n.s.	

d. Trends in Espy Run

Above discharge	Below discharge	t-test
575 ± 188	**837** ± 171	P<0.0001
646 ± 194	**899** ± 159	P<0.0001
500 ± 151	**761** ± 158	P<0.0001
P=0.005	P=0.002	
617 ± 186	**867** ± 174	P<0.0001
493 ± 171	**765** ± 147	P=0.0001
P=0.03	P=0.04	

Table 4 - Summary of Dissolved Oxygen Trends in the Earth Conservancy Phase I Wetland

Espy Run, Hanover Township, Luzerne County, PA

Values given as mean (in mg/L) ± 1 standard deviation. Data collection and analysis by the Wilkes University Wetland Technical Team

a. Trends at the Espy Run Seep

Study period	Mean ± 1 SD
All samples (7/99-11/02)	**3.4**± 1.8
Prior studies (7/99-6/00)	**3.4**± 1.1
This study (11/00-11/02)	**3.5**± 2.2
t-test result	n.s.
Before enlargement (7/99-7/01)	**3.3**± 1.2
After enlargement (9/01-11/02)	**3.6**± 2.5
t-test result	n.s.

b. Trends in the Wetland

Study period	East Cell inlet	East Cell outlet	East Cell t-test	West Cell inlet	West Cell outlet	West Cell t-test	t-test for E vs W outlet
All samples (8/99-11/02)	**4.7** ± 1.6	**7.2** ± 1.7	P<0.0001	**4.8**± 1.7	**7.1** ± 1.7	P<0.0001	n.s.
Prior studies (8/99-6/00)	**4.5** ± 0.8	**6.7** ± 0.7	P<0.0001	**4.4**± 0.9	**6.8** ± 0.6	P<0.0001	n.s.
This study (11/00-11/02)	**4.9** ± 2.0	**7.5** ± 2.1	P<0.0001	**5.0**± 2.0	**7.2** ± 2.1	P<0.0001	n.s.
t-test result	n.s.	n.s.		n.s.	n.s.		
Before enlargement (8/99-7/01)	**4.5** ± 1.1	**6.6** ± 1.0	P<0.0001	**4.5**± 1.1	**6.7** ± 0.8	P<0.0001	n.s.
After enlargement (9/01-11/02)	**5.1** ± 2.2	**8.1** ± 2.1	P<0.0001	**5.3**± 2.3	**7.6** ± 2.5	P<0.0001	n.s.
t-test result	n.s.	P=0.038		n.s.	n.s.		

c. Trends in Espy Run

Study period	Above discharge	Below discharge	t-test
All samples (7/99-10/02)	**8.3** ± 2.4	**8.2** ± 2.0	n.s.
Prior studies (7/99-6/00)	**6.9** ± 1.3	**7.3** ± 0.8	n.s.
This study (11/00-11/02)	**9.2** ± 2.6	**9.2** ± 2.4	n.s.
t-test result	P=0.002	P=0.01	
Before enlargement (7/99-7/01)	**7.2** ± 1.7	**7.5** ± 1.1	n.s.
After enlargement (9/01-11/02)	**9.6** ± 2.6	**9.6** ± 2.4	n.s.
t-test result	P=0.005	P=0.006	

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

Espy Run, Hanover Township, Luzerne County, PA

Values given as mean (in mg/L) ± 1 standard deviation. Data collection and analysis by the Wilkes University Wetland Technical Team

a. Trends at the Espy Run Seep

Study period	Mean ± 1 SD
All samples (7/94-11/02)	**20.0** ± 5.0
Prior studies (7/94-6/00)	**20.4** ± 5.2
This study (11/00-11/02)	**20.0** ± 4.4
t-test result	n.s.
Before enlargement (7/94-7/01)	**20.1** ± 5.2
After enlargement (9/01-11/02)	**19.6** ± 4.4
t-test result	n.s.

b. Trends in the Wetland

Study period	East Cell inlet	East Cell outlet	East Cell t-test	West Cell inlet	West Cell outlet	West Cell t-test	t-test for E vs W outlet
All samples (9/97-11/02)	**19.8** ± 4.0	**3.1** ± 3.6	P<0.0001	**19.5** ± 3.9	**14.7** ± 5.1	P<0.0001	P<0.0001
Prior studies (9/97-6/00)	**20.1** ± 3.9	**3.6** ± 3.9	P<0.0001	**19.7** ± 3.7	**16.6** ± 2.6	P<0.0001	P<0.0001
This study (11/00-11/02)	**19.0** ± 4.4	**1.7** ± 2.2	P<0.0001	**18.9** ± 4.4	**9.7** ± 6.5	P<0.0001	P<0.0001
t-test result	n.s.	P=0.012		n.s.	P<0.0001		
Before enlargement (9/97-7/01)	**20.1** ± 4.1	**3.6** ± 3.7	P<0.0001	**19.7** ± 3.8	**16.6** ± 3.0	P<0.0001	P<0.0001
After enlargement (9/01-11/02)	**18.3** ± 3.3	**0.7** ± 0.9	P<0.0001	**18.3** ± 4.3	**6.0** ± 3.8	P<0.0001	P<0.0001
t-test result	n.s.	P<0.0001		n.s.	P<0.0001		

c. Percent Removal Trends

Study period	East Cell	West Cell	t-test
All samples (7/94-10/02)	**84.0** ± 18.7	**24.0** ± 22.8	P<0.0001
Prior studies (7/94-6/00)	**81.5** ± 20.2	**14.8** ± 8.9	P<0.0001
This study (11/00-11/02)	**90.4** ± 12.5	**48.0** ± 30.0	P<0.0001
t-test result	n.s.	P=0.002	
Before enlargement (7/94-7/01)	**81.5** ± 19.6	**15.7** ± 9.6	P<0.0001
After enlargement (9/01-11/02)	**95.9** ± 5.4	**63.2** ± 26.6	P=0.001
t-test result	P<0.0001	P<0.0001	

d. Trends in Espy Run

Above discharge	Below discharge	t-test
2.8 ± 2.9	**8.3** ± 4.5	P<0.0001
2.6 ± 2.4	**9.9** ± 4.4	P<0.0001
3.2 ± 3.5	**6.0** ± 3.7	n.s.
n.s.	P=0.002	
3.0 ± 3.2	**9.4** ± 4.3	P<0.0001
2.4 ± 2.1	**5.6** ± 3.6	P=0.008
n.s.	P=0.003	

Table 6 - Summary of Dissolved / Total Iron Trends in the Earth Conservancy Phase I Wetland

Espy Run, Hanover Township, Luzerne County, PA

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

a. Concentrations of Dissolved Iron (mg/L)

Study period	East Cell inlet	East Cell outlet	East Cell t-test	West Cell inlet	West Cell outlet	West Cell t-test	t-test for E vs W outlet
All samples (9/97-11/02)	**17.7** ± 3.8	**1.9** ± 2.6	P<0.0001	**17.5** ± 3.8	**10.5** ± 4.7	P<0.0001	P<0.0001
Prior studies (9/97-6/00)	**17.8** ± 3.9	**2.3** ± 2.9	P<0.0001	**17.6** ± 3.7	**12.1** ± 2.6	P<0.0001	P<0.0001
This study (11/00-11/02)	17.4 ± 3.8	**0.9** ± 1.6	P<0.0001	**17.1** ± 4.1	**6.6** ± 6.6	P<0.0001	P<0.0001
t-test result	n.s.	P=0.017		n.s.	P=0.002		
Before enlargement (9/97-7/01)	**17.8** ± 4.0	**2.2** ± 2.8	P<0.0001	**17.8** ± 3.9	**12.2** ± 3.1	P<0.0001	P<0.0001
After enlargement (9/01-11/02)	**17.0** ± 2.8	**0.3** ± 0.6	P<0.0001	**16.1** ± 3.3	**2.5** ± 2.3	P<0.0001	P=0.010
t-test result	n.s.	P<0.0001		n.s.	P<0.0001		

b. Percentage of Suspended Iron as Particulate

Study period	East Cell inlet	East Cell outlet	East Cell t-test	West Cell inlet	West Cell outlet	West Cell t-test	t-test for E vs W outlet
All samples (9/97-11/02)	**10.2** ± 10.1	**55.3** ± 33.1	P<0.0001	**10.0** ± 9.7	**31.7** ± 19.9	P<0.0001	P<0.0001
Prior studies (9/97-6/00)	**11.2** ± 11.1	**54.0** ± 32.4	P<0.0001	**10.4** ± 9.8	**27.3** ± 12.2	P<0.0001	P<0.0001
This study (11/00-11/02)	**7.5** ± 6.6	**58.9** ± 35.4	P<0.0001	**9.1** ± 9.7	**43.3** ± 29.8	P<0.0001	n.s.
t-test result	n.s.	n.s.		n.s.	P=0.034		
Before enlargement (9/97-7/01)	**10.9** ± 10.7	**53.0** ± 32.4	P<0.0001	**9.9** ± 9.4	**26.2** ± 13.0	P<0.0001	P<0.0001
After enlargement (9/01-11/02)	**6.7** ± 5.8	**66.4** ± 35.3	P<0.0001	**11.0** ± 11.4	**57.6** ± 26.3	P<0.0001	n.s.
t-test result	n.s.	n.s.		n.s.	P=0.002		

c. Percentage of Total Iron as Particulate

Study period	East Cell inlet	East Cell outlet	East Cell t-test	West Cell inlet	West Cell outlet	West Cell t-test	t-test for E vs W outlet
All samples (9/97-11/02)	**10.2** ± 10.1	**90.4** ± 13.0	P<0.0001	**10.0** ± 9.7	**46.2** ± 21.6	P<0.0001	P<0.0001
Prior studies (9/97-6/00)	**11.2** ± 11.1	**88.6** ± 14.2	P<0.0001	**10.4** ± 9.8	**38.3** ± 10.6	P<0.0001	P<0.0001
This study (11/00-11/02)	**7.5** ± 6.6	**95.3** ± 7.3	P<0.0001	**9.1** ± 9.7	**66.9** ± 28.9	P<0.0001	P=0.0002
t-test result	n.s.	P=0.013		n.s.	P=0.0005		
Before enlargement (9/97-7/01)	**10.9** ± 10.7	**88.9** ± 13.6	P<0.0001	**9.9** ± 9.4	**38.0** ± 11.7	P<0.0001	P<0.0001
After enlargement (9/01-11/02)	**6.7** ± 5.8	**97.8** ± 4.5	P<0.0001	**11.0** ± 11.4	**85.1** ± 13.7	P<0.0001	P=0.010
t-test result	n.s.	P<0.0002		n.s.	P<0.0001		

Table 7 - Summary of Iron Loading and Removal
Earth Conservancy Phase I Wetland

Espy Run, Hanover Township, Luzerne County, PA

Data collection and analysis by the Wilkes University Wetland Technical Team

a. Iron Loading into Wetland (lbs/day)

Study period	East Cell	West Cell	Combined	E vs W t-test
All samples (9/97-11/02)	**4.5** ± 2.5	**24.8** ± 7.6	**29.3** ± 8.8	P<0.0001
Prior studies (9/97-6/00)	**4.4** ± 2.5	**26.5** ± 7.3	**30.9** ± 8.5	P<0.0001
This study (11/00-11/02)	**5.0** ± 2.4	**20.2** ± 6.6	**25.2** ± 8.3	P<0.0001
t-test result	n.s.	P=0.001	P=0.016	
Before enlargement (9/97-7/01)	**4.3** ± 2.5	**25.8** ± 7.6	**30.1** ± 9.1	P<0.0001
After enlargement (9/01-11/02)	**5.9** ± 1.5	**19.7** ± 5.2	**25.6** ± 6.4	P<0.0001
t-test result	P=0.005	P=0.003	n.s.	

b. Iron Removal by Wetland (lbs/day)

Study period	East Cell	West Cell	Combined	E vs W t-test
All samples (9/97-11/02)	**3.7** ± 2.0	**5.5** ± 5.0	**9.2** ± 6.1	P=0.001
Prior studies (9/97-6/00)	**3.3** ± 1.8	**3.9** ± 2.9	**7.2** ± 3.6	n.s.
This study (11/00-11/02)	**4.5** ± 2.1	**9.7** ± 6.8	**14.2** ± 8.3	P=0.001
t-test result	P=0.03	P=0.002	P=0.002	
Before enlargement (9/97-7/01)	**3.3** ± 1.8	**3.9** ± 2.8	**7.2** ± 3.7	n.s.
After enlargement (9/01-11/02)	**5.6** ± 1.4	**12.8** ± 6.5	**18.5** ± 7.1	P=0.002
t-test result	P<0.0001	P=0.0006	P=0.0002	

c. Rate of Iron Removal per Acre (lbs/acre/day)

Study period	East Cell	West Cell	Combined	E vs W t-test
All samples (9/97-11/02)	**28.3** ± 15.2	**33.7** ± 23.4	**31.1** ± 16.6	n.s.
Prior studies (9/97-6/00)	**25.7** ± 14.1	**30.0** ± 22.0	**27.9** ± 14.0	n.s.
This study (11/00-11/02)	**35.0** ± 16.3	**43.5** ± 24.6	**39.7** ± 19.8	n.s.
t-test result	P=0.036	P=0.045	P=0.024	
Before enlargement (9/97-7/01)	**25.1** ± 14.1	**30.4** ± 21.7	**27.7** ± 14.1	n.s.
After enlargement (9/01-11/02)	**43.4** ± 10.6	**49.7** ± 25.4	**47.4** ± 18.2	n.s.
t-test result	P<0.0001	P=0.027	P=0.003	

d. Iron Removal Rate Constant

Study period	East Cell	West Cell	E vs W t-test
All samples (9/97-11/02)	**-0.154** ± 0.14	**-0.055** ± 0.04	P<0.0001
Prior studies (9/97-6/00)	**-0.132** ± 0.13	**-0.051** ± 0.04	P<0.0001
This study (11/00-11/02)	**-0.213** ± 0.15	**-0.065** ± 0.04	P=0.0006
t-test result	P=0.043	n.s.	
Before enlargement (9/97-7/01)	**-0.124** ± 0.13	**-0.052** ± 0.04	P<0.0001
After enlargement (9/01-11/02)	**-0.300** ± 0.11	**-0.068** ± 0.05	P<0.0001
t-test result	P=0.0001	n.s.	

Table 8 - Summary of Sulfate Trends in the Earth Conservancy Phase I Wetland

Espy Run, Hanover Township, Luzerne County, PA

Values given as mean (in mg/L) ± 1 standard deviation. Data collection and analysis by the Wilkes University Wetland Technical Team

a. Trends at the Espy Run Seep

Study period	Mean ± 1 SD
All samples (7/94-11/02)	**301** ± 78
Prior studies (7/94-6/00)	**307** ± 106
This study (11/00-11/02)	**296** ± 35
t-test result	n.s.
Before enlargement (7/94-7/01)	**303** ± 94
After enlargement (9/01-11/02)	**298** ± 24
t-test result	n.s.

b. Trends in the Wetland

Study period	East Cell inlet	East Cell outlet	East Cell t-test	West Cell inlet	West Cell outlet	West Cell t-test	t-test for E vs W outlet
All samples (8/99-11/02)	**330** ± 80	**317** ± 71	P=0.041	**320** ± 82	**321** ± 86	n.s.	n.s.
Prior studies (8/99-6/00)	**368** ± 115	**363** ± 90	n.s.	**350** ± 124	**361** ± 121	n.s.	n.s.
This study (11/00-11/02)	**307** ± 32	**287** ± 34	P=0.005	**301** ± 30	**296** ± 42	n.s.	n.s.
t-test result	n.s.	P=0.012		n.s.	n.s.		
Before enlargement (8/99-7/01)	**350** ± 96	**338** ± 83	n.s.	**336** ± 102	**340** ± 106	n.s.	n.s.
After enlargement (9/01-11/02)	**299** ± 26	**283** ± 23	P=0.004	**294** ± 20	**291** ± 20	n.s.	P<0.035
t-test result	P=0.038	P=0.13		n.s.	n.s.		

c. Percent Removal Trends

Study period	East Cell	West Cell	t-test
All samples (7/94-10/02)	**3.5** ± 10.6	**-1.8** ± 17.9	n.s.
Prior studies (7/94-6/00)	**-0.8** ± 13.2	**-6.6** ± 22.4	n.s.
This study (11/00-11/02)	**6.2** ± 7.8	**1.2** ± 12.0	P=0.039
t-test result	n.s.	n.s.	
Before enlargement (7/94-7/01)	**2.4** ± 13.0	**-3.4** ± 22.7	n.s.
After enlargement (9/01-11/02)	**5.1** ± 4.8	**0.7** ± 3.9	n.s.
t-test result	n.s.	n.s.	

d. Trends in Espy Run

Above discharge	Below discharge	t-test
171 ± 93	**277** ± 100	P<0.0001
220 ± 130	**317** ± 112	n.s.
139 ± 31	**241** ± 78	P<0.0001
P=0.036	P=0.018	
198 ± 114	**299** ± 100	P=0.003
136 ± 34	**237** ± 90	P=0.0003
P=0.031	P=0.049	

Table 9 - Summary of Alkalinity Trends in the Earth Conservancy Phase I Wetland

Espy Run, Hanover Township, Luzerne County, PA

Values given as mean (in mg/L) ± 1 standard deviation. Data collection and analysis by the Wilkes University Wetland Technical Team

a. Trends at the Espy Run Seep

Study period	Mean ± 1 SD
All samples (7/99-11/02)	**291** ± 58
Prior studies (7/99-6/00)	**304** ± 13
This study (11/00-11/02)	**283** ± 74
t-test result	n.s.
Before enlargement (7/99-7/01)	**296** ± 30
After enlargement (9/01-11/02)	**284** ± 83
t-test result	n.s.

b. Trends in the Wetland

Study period	East Cell inlet	East Cell outlet	East Cell t-test	West Cell inlet	West Cell outlet	West Cell t-test	t-test for E vs W outlet
All samples (8/99-11/02)	**298** ± 61	**284** ± 65	n.s.	**293** ± 59	**295** ± 61	n.s.	n.s.
Prior studies (8/99-6/00)	**298** ± 18	**277** ± 56	n.s.	**276** ± 63	**283** ± 61	n.s.	n.s.
This study (11/00-11/02)	**298** ± 77	**288** ± 71	n.s.	**303** ± 56	**303** ± 62	n.s.	n.s.
t-test result	n.s.	n.s.		n.s.	n.s.		
Before enlargement (8/99-7/01)	**295** ± 44	**283** ± 55	n.s.	**281** ± 60	**284** ± 60	n.s.	n.s.
After enlargement (9/01-11/02)	**302** ± 83	**284** ± 80	n.s.	**312** ± 56	**314** ± 60	n.s.	n.s.
t-test result	n.s.	n.s.		n.s.	n.s.		

c. Percent Removal Trends

Study period	East Cell	West Cell	t-test
All samples (7/99-10/02)	**1.1** ± 31.0	**-4.8** ± 33.9	n.s.
Prior studies (7/99-6/00)	**7.0** ± 18.2	**-12.8** ± 53.7	n.s.
This study (11/00-11/02)	**-2.7** ± 36.9	**0.3** ± 9.1	n.s.
t-test result	n.s.	n.s.	
Before enlargement (7/99-7/01)	**3.0** ± 17.3	**-7.3** ± 42.7	n.s.
After enlargement (9/01-11/02)	**-2.0** ± 46.0	**-0.8** ± 10.7	n.s.
t-test result	n.s.	n.s.	

d. Trends in Espy Run

Above discharge	Below discharge	t-test
128 ± 53	**206** ± 63	P<0.0001
125 ± 56	**198** ± 66	P=0.012
131 ± 54	**209** ± 62	P<0.0001
n.s.	n.s.	
119 ± 48	**201** ± 61	P=0.0002
140 ± 58	**215** ± 68	P=0.0002
n.s.	n.s.	

Table 10 - Summary of Acidity Trends in the Earth Conservancy Phase I Wetland

Espy Run, Hanover Township, Luzerne County, PA

Values given as mean (in mg $CaCO_3$/L) ± 1 std. deviation. Data collection and analysis by the Wilkes University Wetland Technical Team

a. Trends at the Espy Run Seep

Study period	Mean ±1 SD
All samples (7/99-11/02)	**10.5** ± 11.7
Prior studies (7/99-6/00)	**10.4** ± 7.9
This study (11/00-11/02)	**10.2** ± 13.9
t-test result	n.s.
Before enlargement (7/99-7/01)	**12.8** ± 9.2
After enlargement (9/01-11/02)	**7.5** ± 14.2
t-test result	n.s.

b. Trends in the Wetland

	East Cell			West Cell			t-test for
Study period	inlet	outlet	t-test	inlet	outlet	t-test	E vs W outlet
All samples (8/99-11/02)	**9.0** ± 9.4	**5.8** ± 6.6	P=0.015	**8.3** ± 11.5	**8.0** ± 8.4	n.s.	n.s.
Prior studies (8/99-6/00)	**11.2** ± 10.7	**8.9** ± 8.3	n.s.	**8.8** ± 7.9	**10.7** ± 9.3	n.s.	n.s.
This study (11/00-11/02)	**7.7** ± 8.5	**3.8** ± 4.5	P=0.042	**8.0** ± 13.5	**6.3** ± 7.5	n.s.	n.s.
t-test result	n.s.	n.s.		n.s.	n.s.		
Before enlargement (8/99-7/01)	**11.5** ± 9.1	**8.6** ± 6.8	P=0.037	**9.5** ± 7.5	**10.5** ± 7.7	n.s.	n.s.
After enlargement (9/01-11/02)	**5.2** ± 9.0	**1.3** ± 2.6	n.s.	**6.4** ± 16.1	**4.0** ± 8.0	n.s.	n.s.
t-test result	n.s.	P=0.0003		n.s.	P=0.035		

c. Percent Removal Trends

Study period	East Cell	West Cell	t-test
All samples (7/99-10/02)	**23.0** ± 65.4	**-14.5** ± 86.1	P=0.003
Prior studies (7/99-6/00)	**6.1** ± 89.7	**-48.6** ± 125.0	n.s.
This study (11/00-11/02)	**33.7** ± 43.5	**7.1** ± 39.1	P=0.020
t-test result	n.s.	n.s.	
Before enlargement (7/99-7/01)	**13.9** ± 73.9	**-26.3** ± 103.5	P=0.034
After enlargement (9/01-11/02)	**37.5** ± 48.3	**4.2** ± 45.1	P=0.025
t-test result	n.s.	n.s.	

d. Trends in Espy Run

Above discharge	Below discharge	t-test
4.3 ± 4.3	**5.4** ± 5.7	n.s.
6.8 ± 4.9	**8.6** ± 6.1	n.s.
2.8 ± 3.2	**2.5** ± 3.7	n.s.
P=0.018	P=0.001	
6.3 ± 4.4	**8.2** ± 5.4	P=0.046
1.8 ± 2.5	**0.9** ± 1.6	n.s.
P=0.0007	P<0.0001	

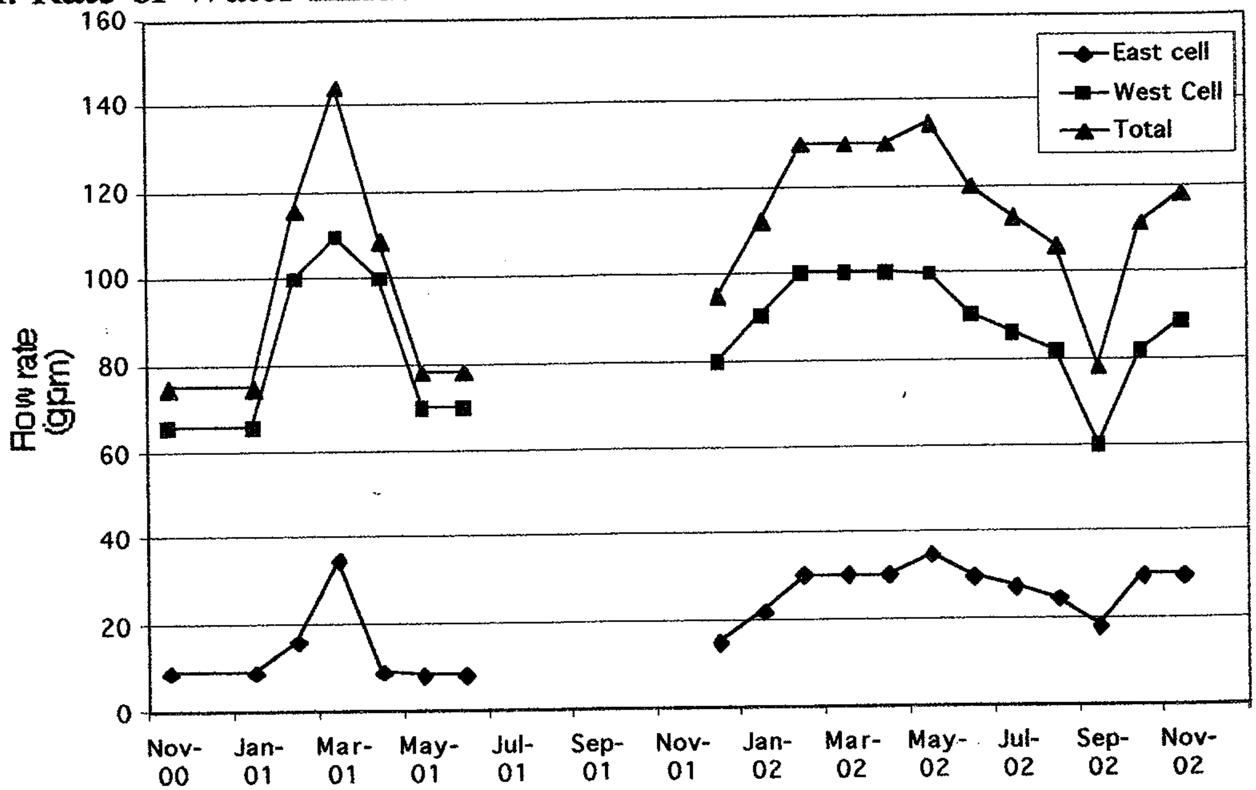
Time Series Diagrams

Figure 3. Wetland Hydrology: 11/00 - 11/02

Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

A. Rate of Water Influx



B. Estimated Detention Time

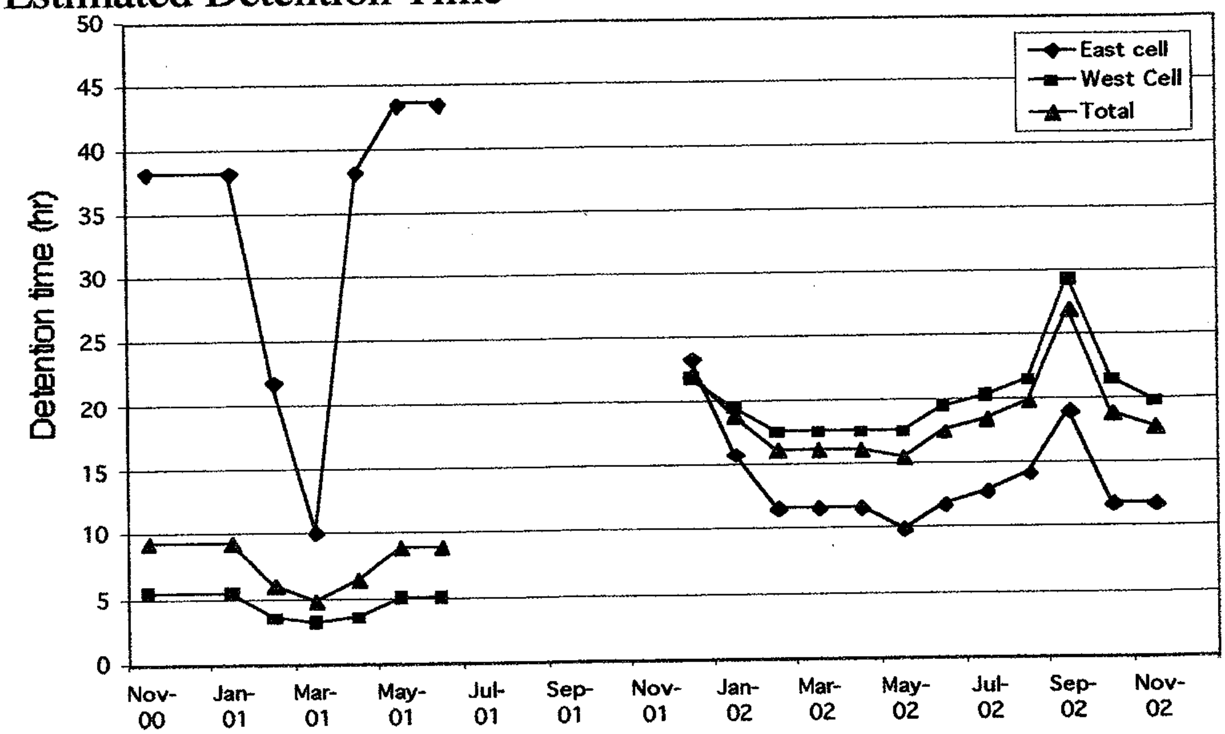
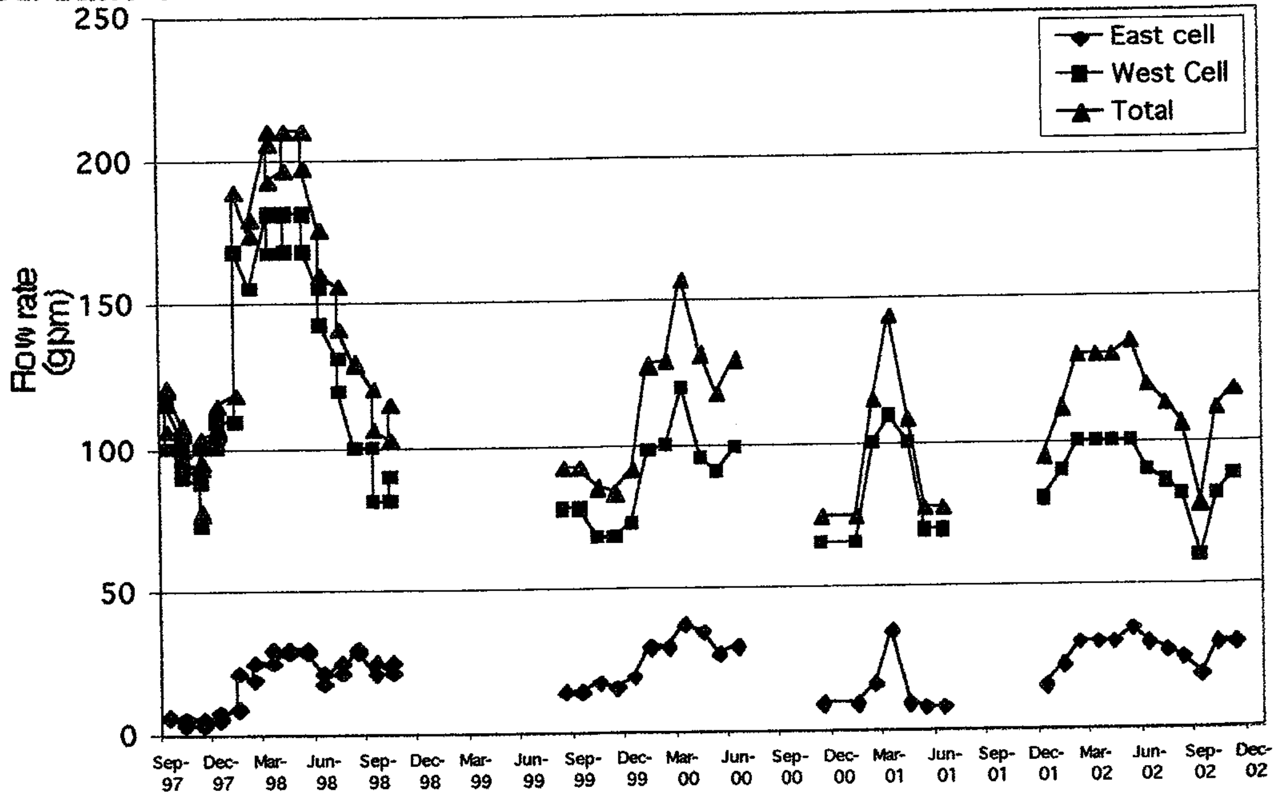


Figure 4. Wetland Hydrology: 9/97 - 11/02

Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

A. Rate of Water Influx



B. Estimated Detention Time

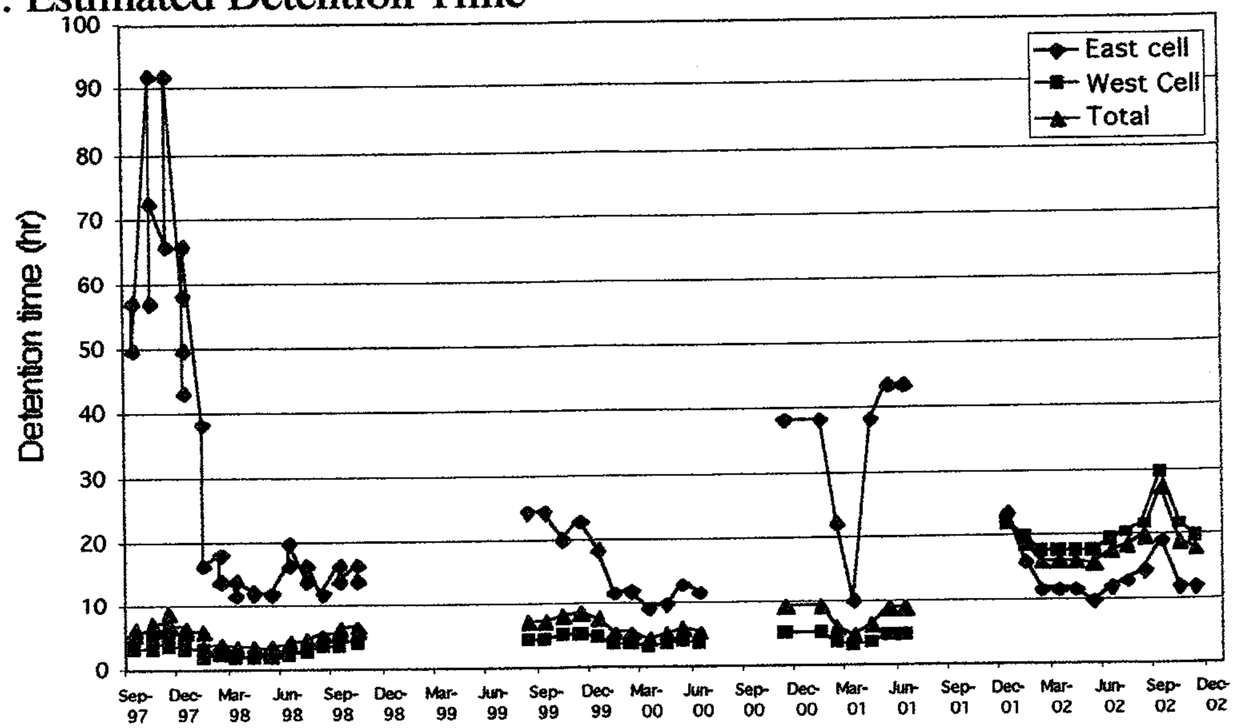
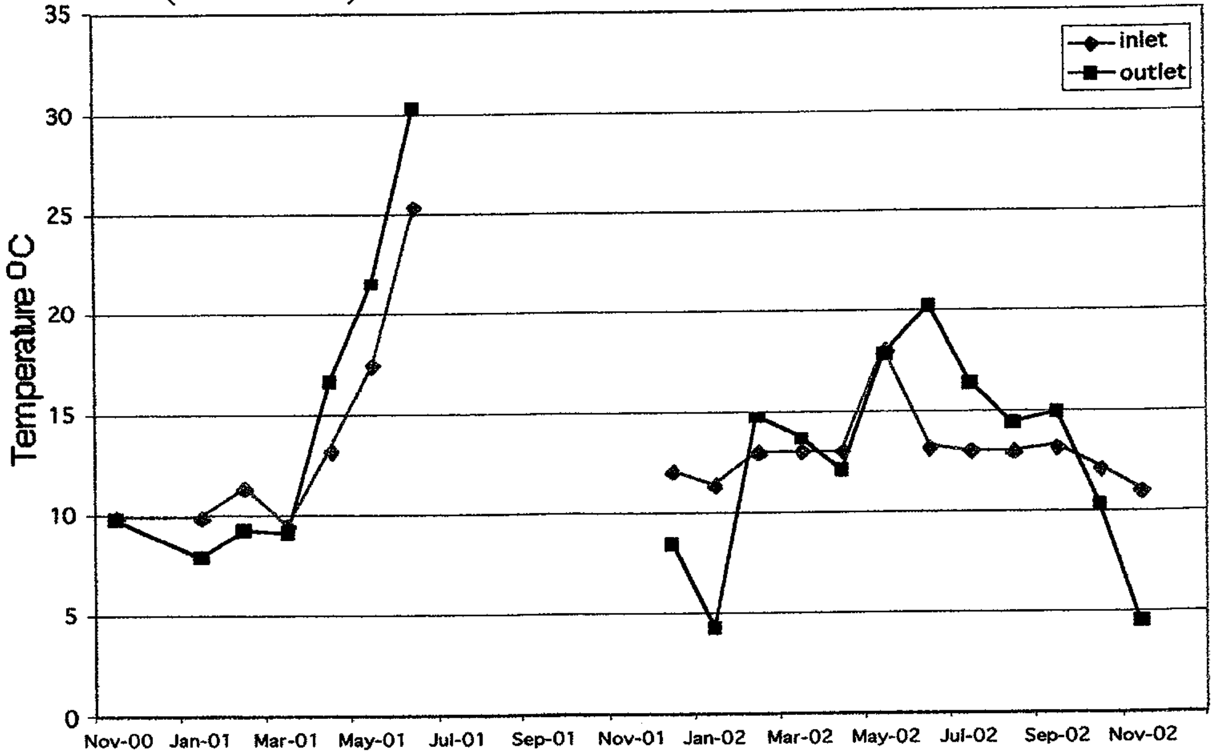


Figure 5. Course of Temperature: 11/00 - 11/02

Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

A. East cell (low flow)



B. West cell (high flow)

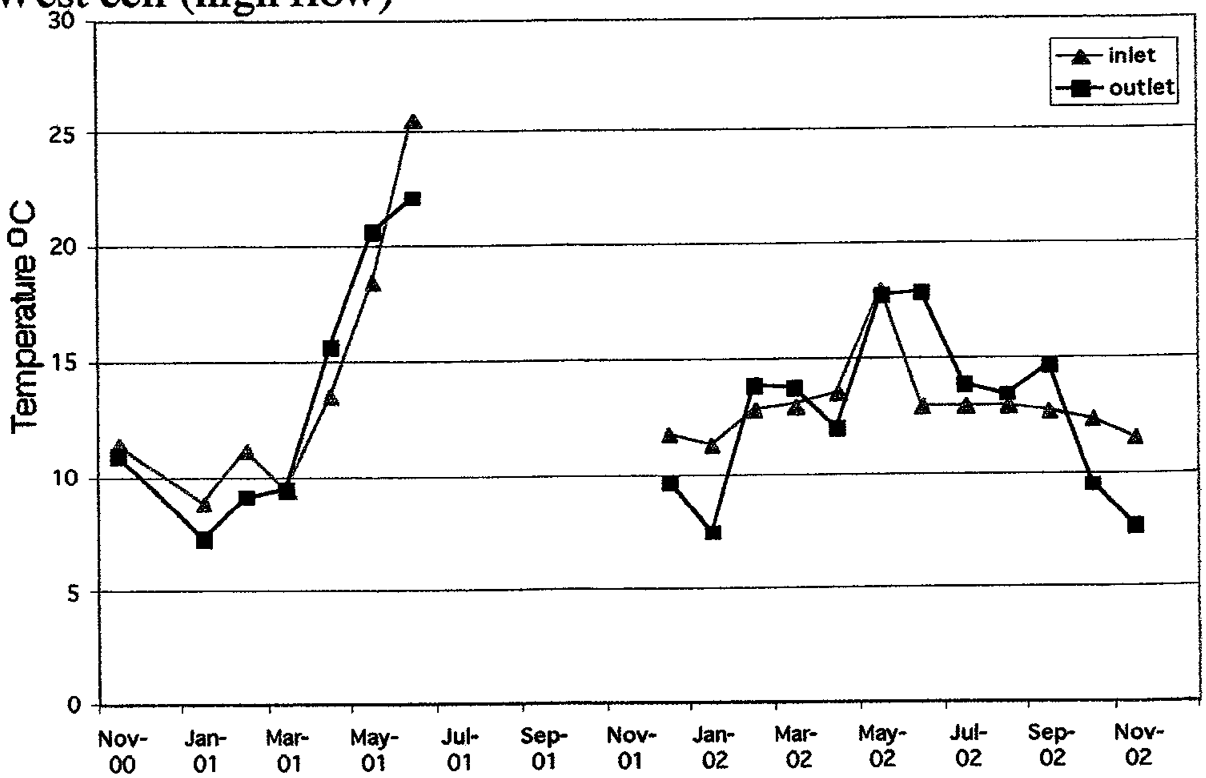
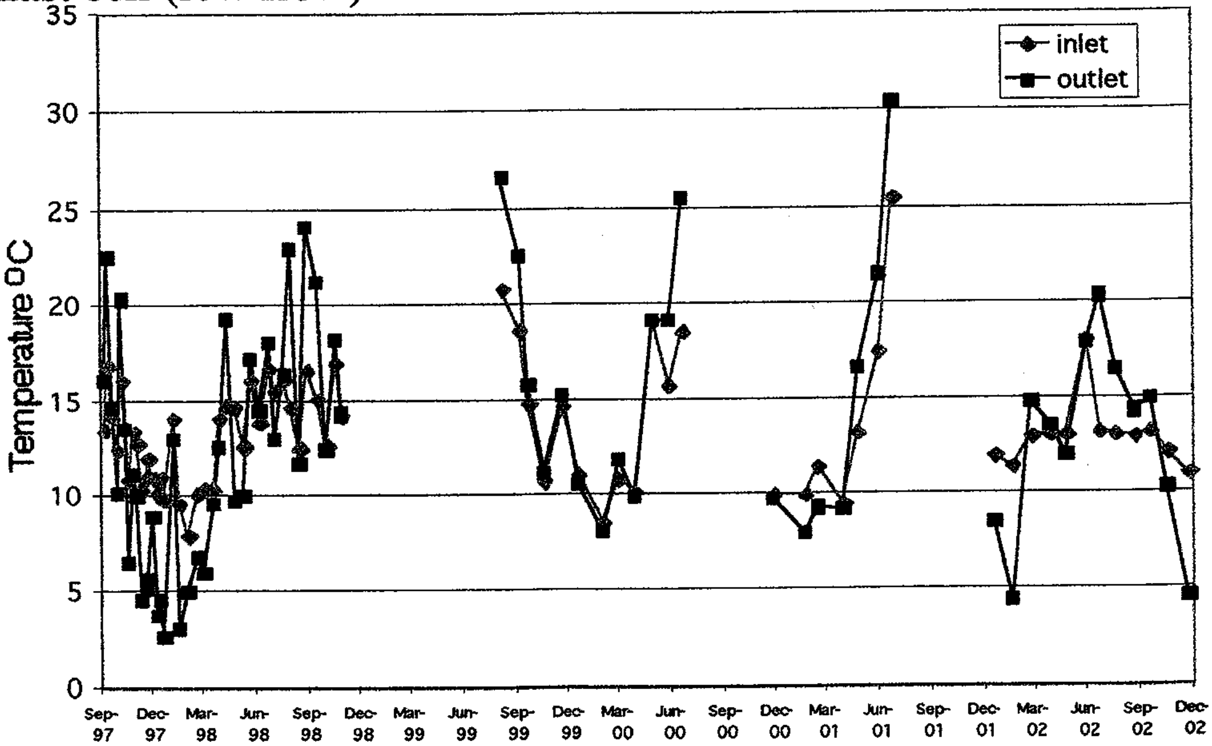


Figure 6. Course of Temperature: 9/97 - 11/02

Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

A. East cell (low flow)



B. West cell (high flow)

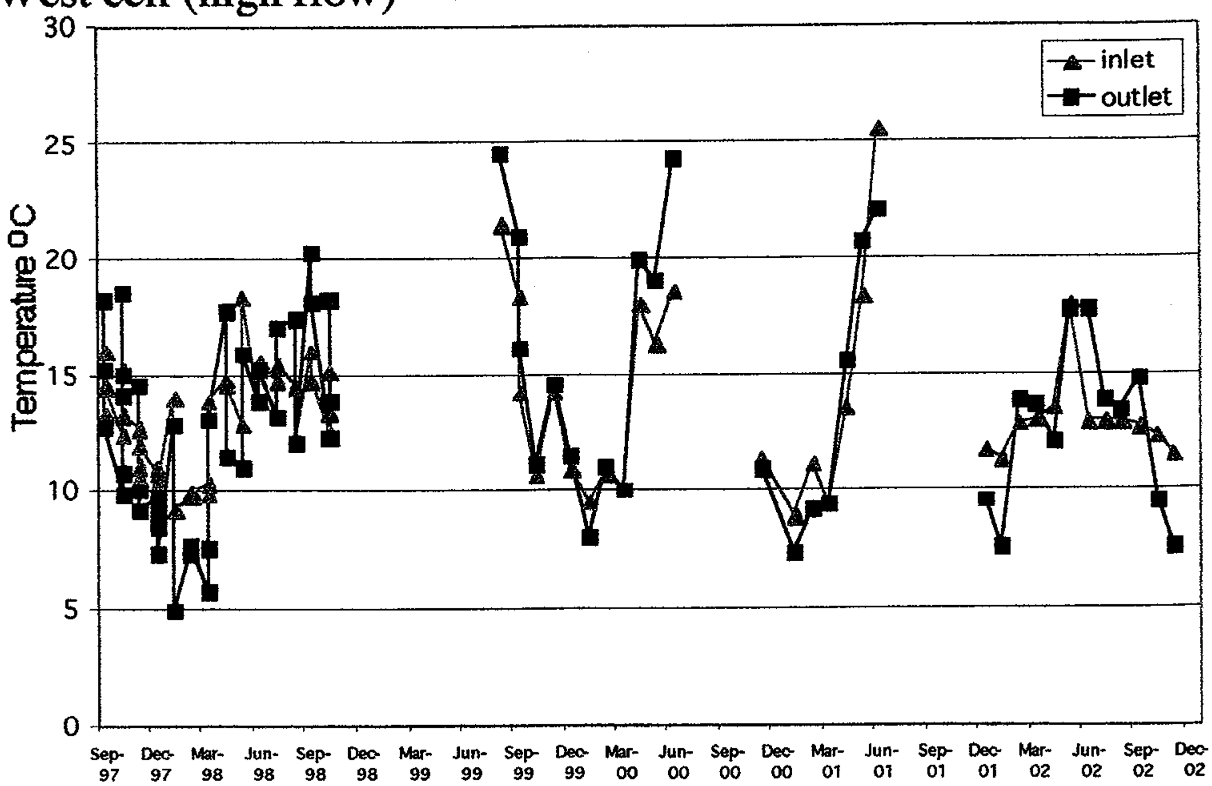
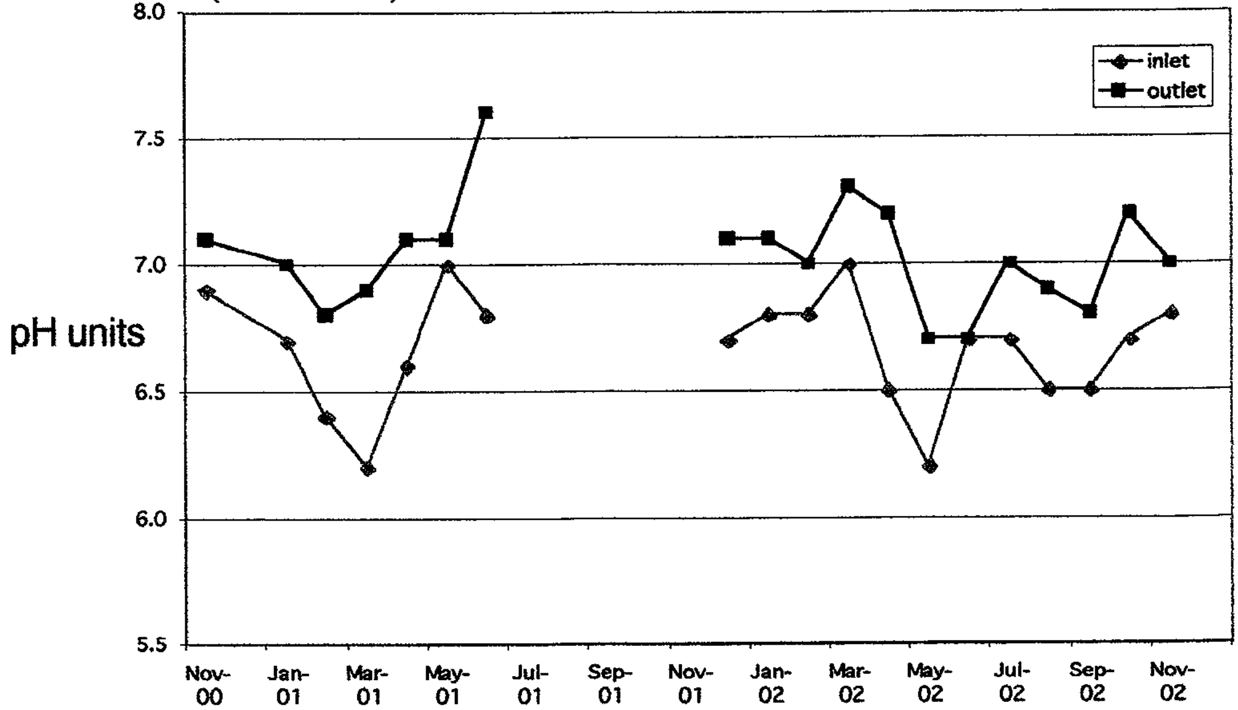


Figure 7. Course of pH: 11/00 - 11/02

Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

A. East cell (low flow)



B. West cell (high flow)

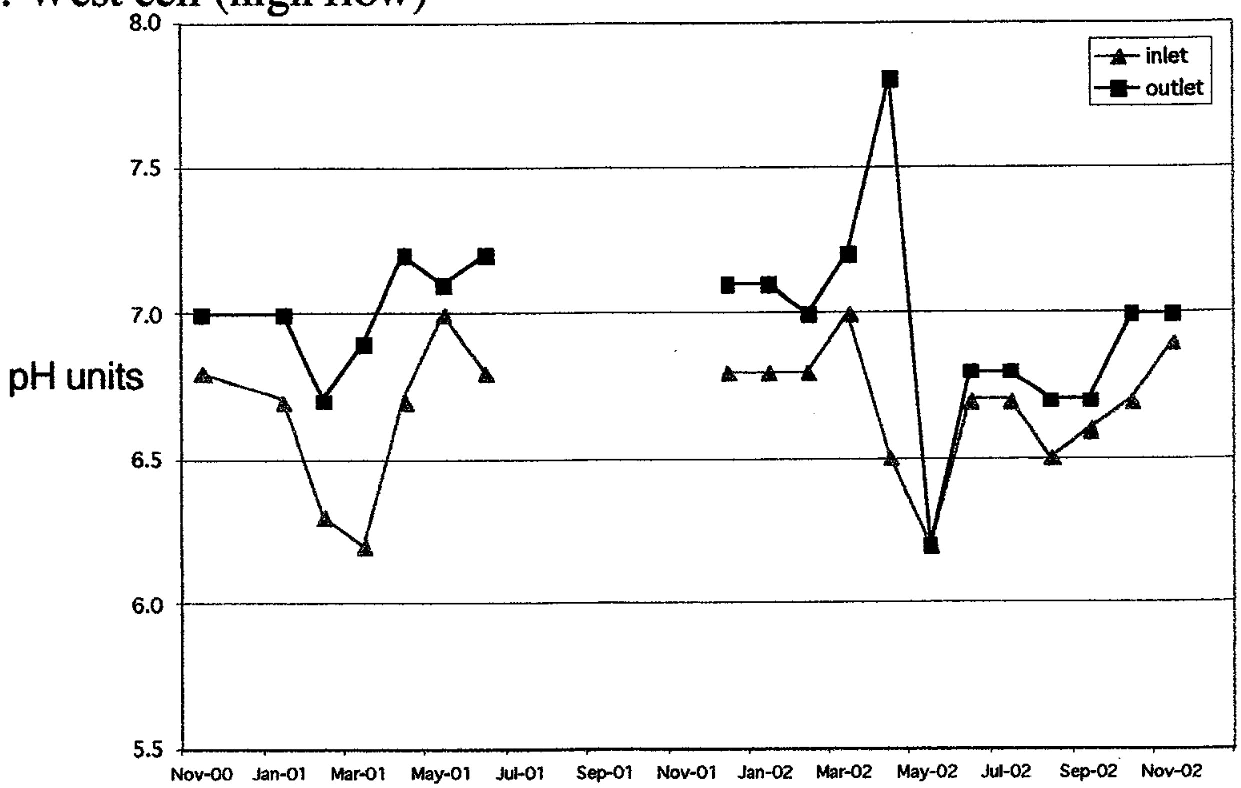
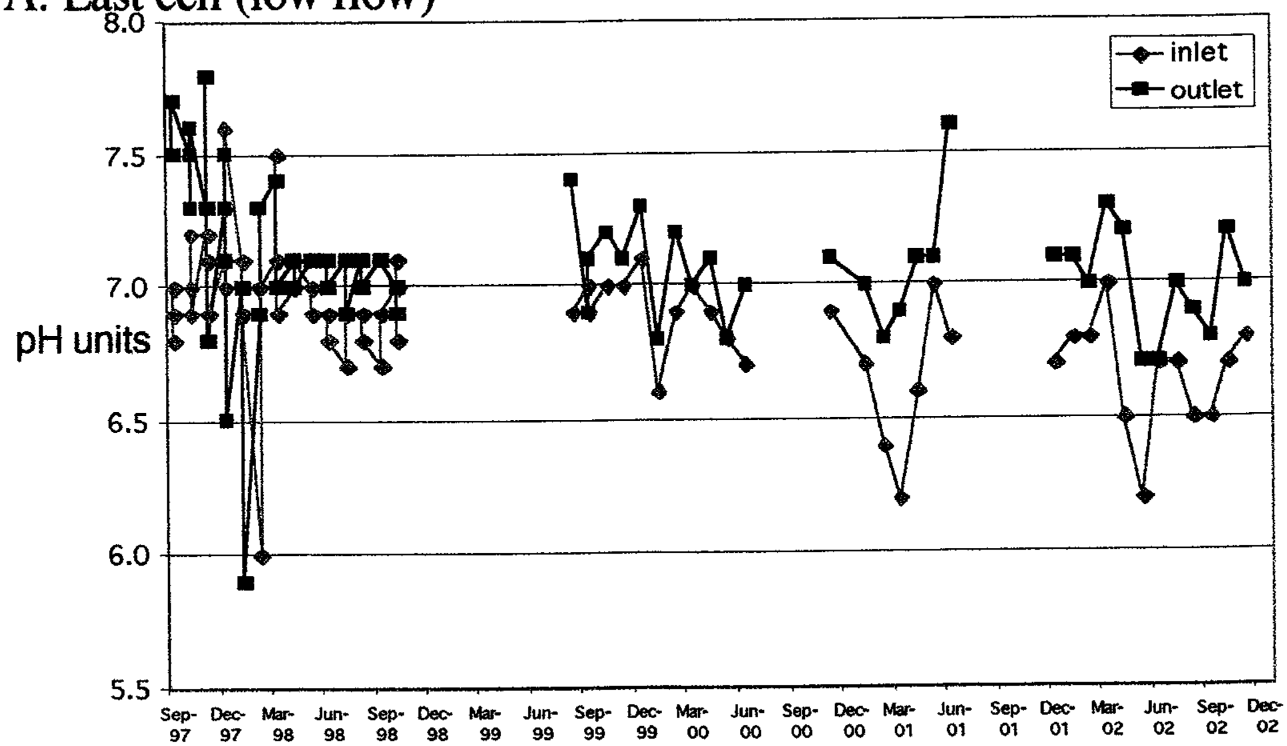


Figure 8. Course of pH: 9/97 - 11/02

Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

A. East cell (low flow)



B. West cell (high flow)

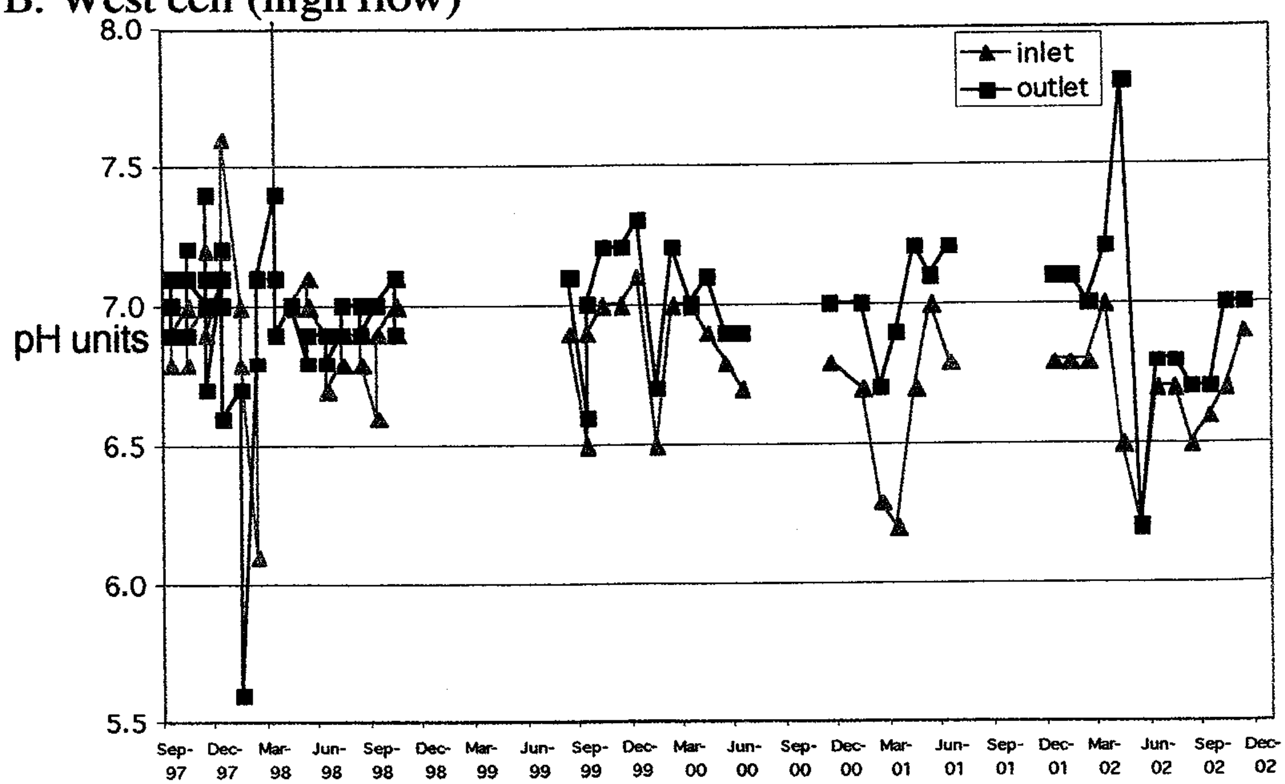
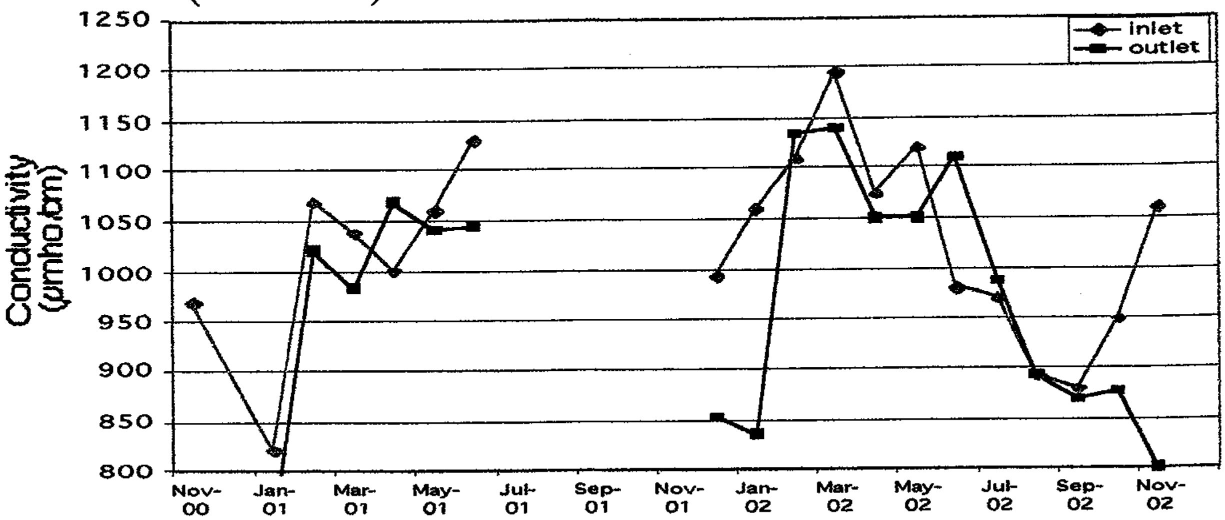


Figure 9. Course of Conductivity: 11/00 - 11/02

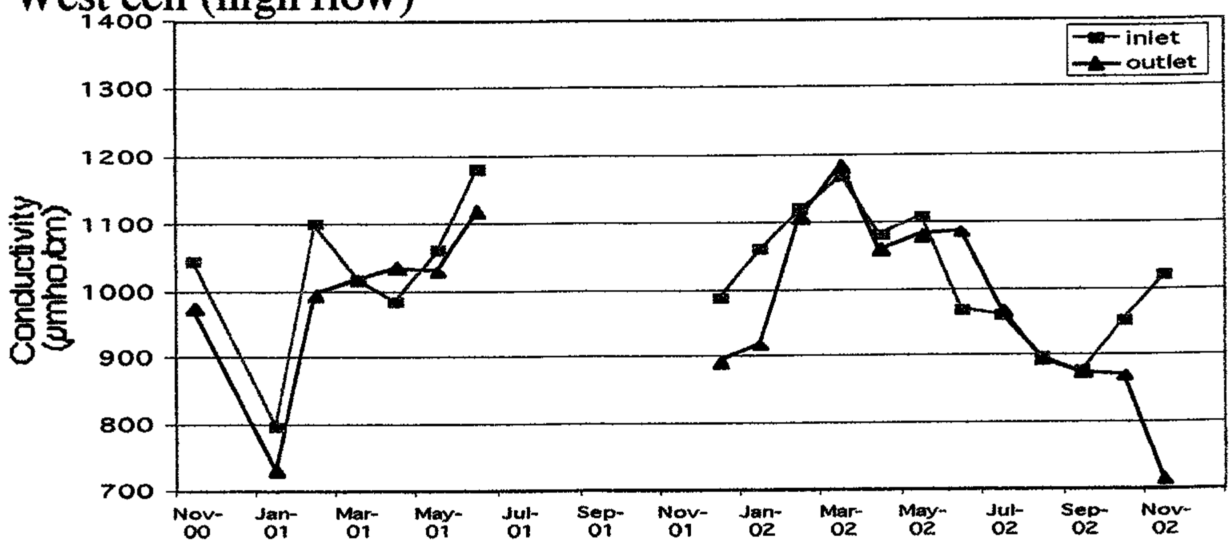
Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

A. East cell (low flow)



B. West cell (high flow)



C. Percent removal

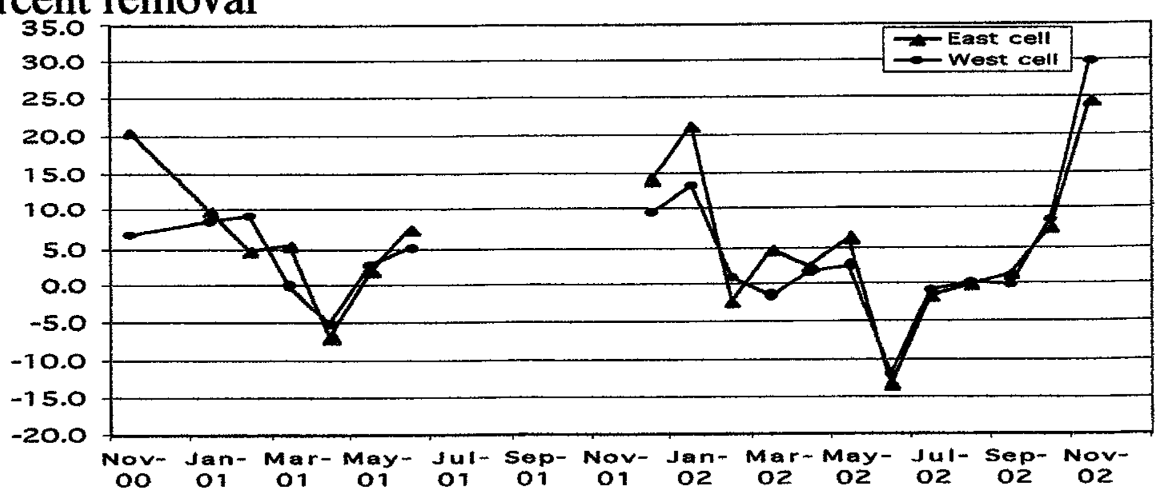
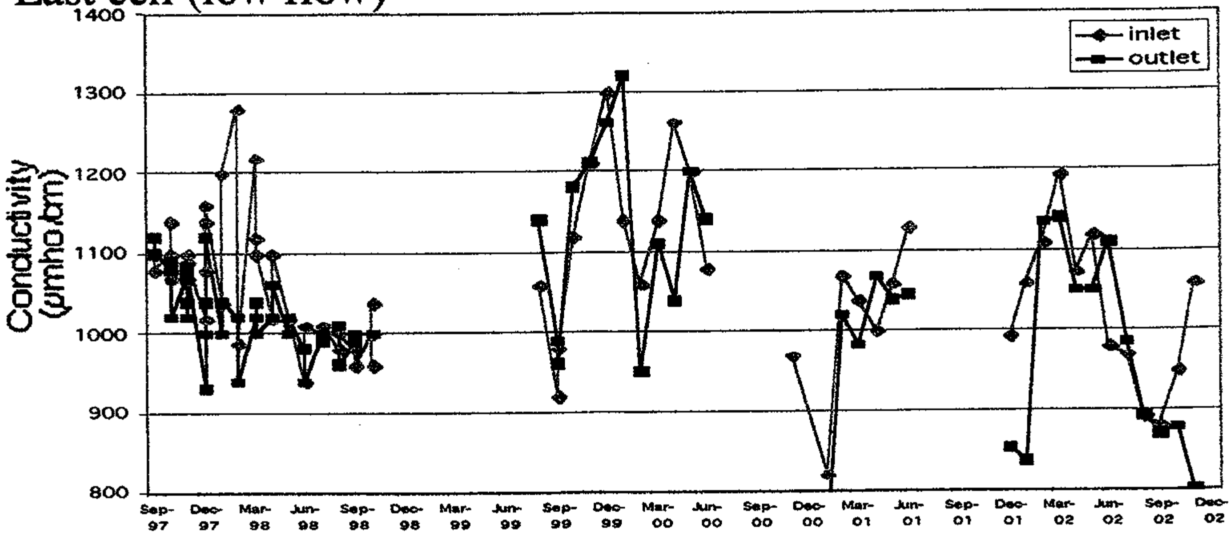


Figure 10. Course of Conductivity: 9/97 - 11/02

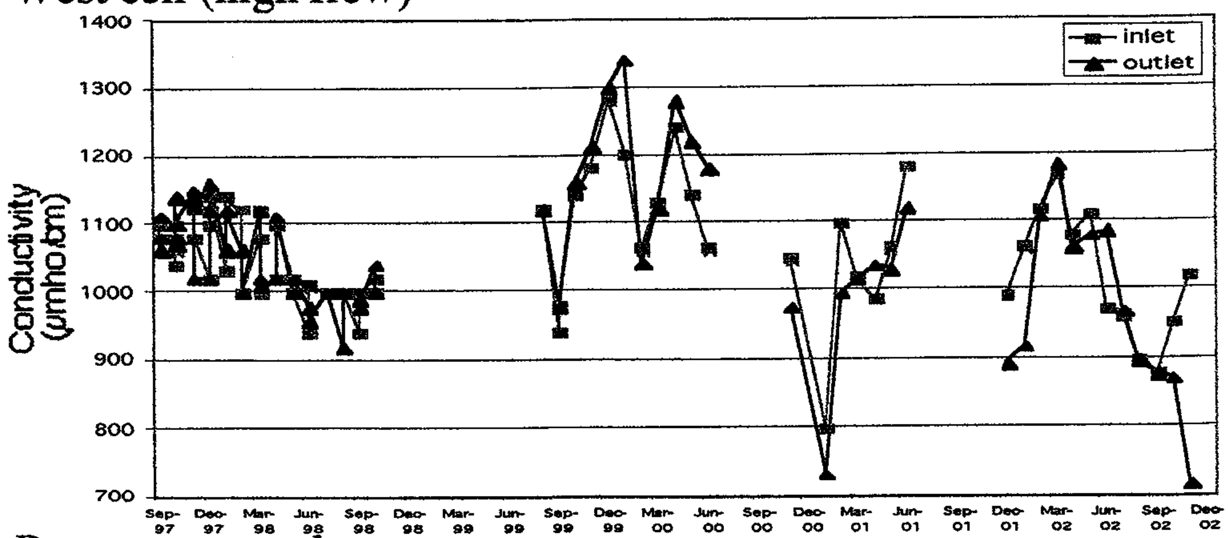
Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

A. East cell (low flow)



B. West cell (high flow)



C. Percent removal

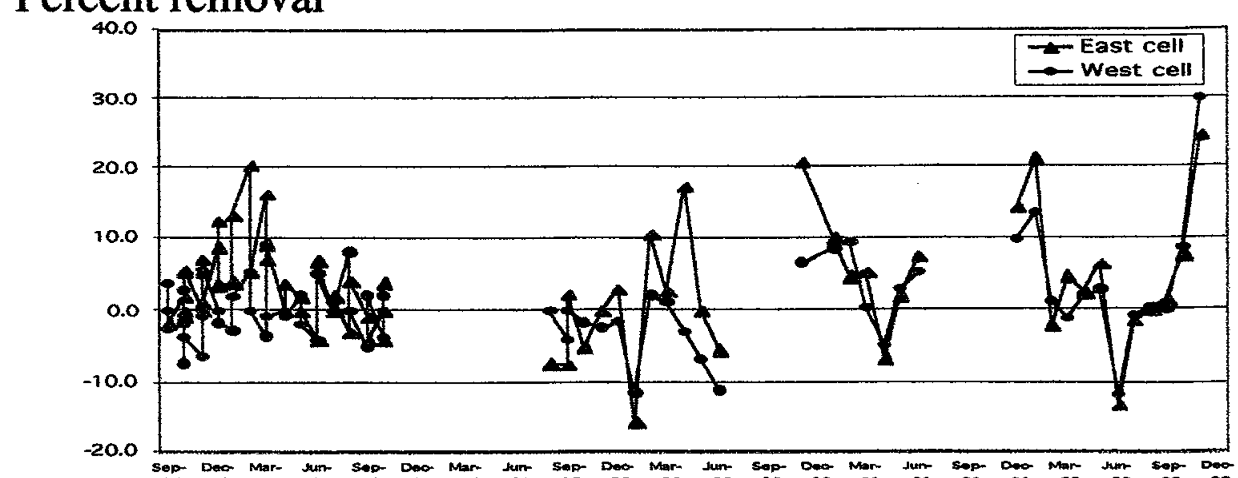


Figure 11. Course of Dissolved O_2: 11/00 - 11/02

Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

A. East cell (low flow)

B. West cell (high flow)

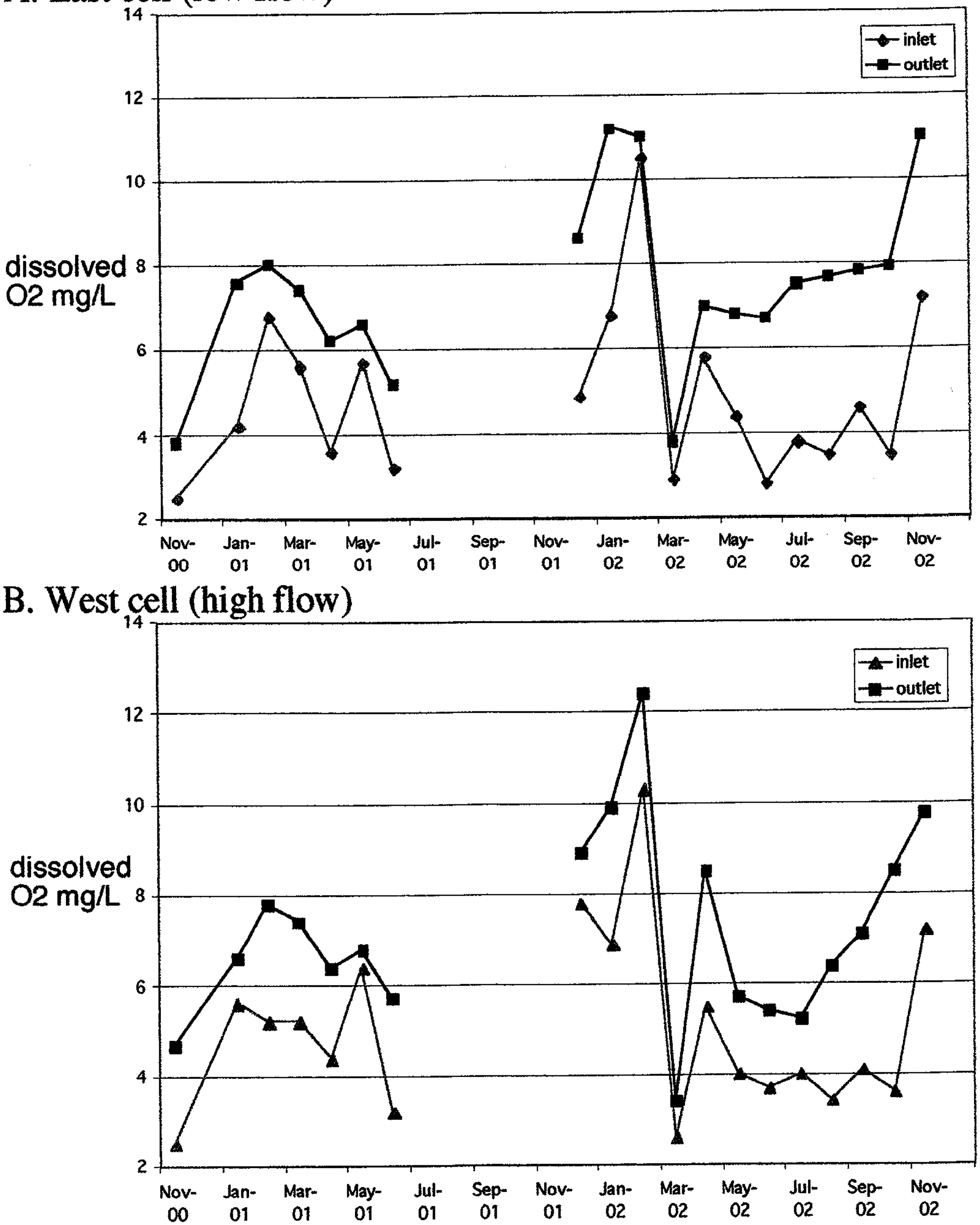


Figure 12. Course of Dissolved O_2: 7/99 - 11/02

Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

A. East cell (low flow)

B. West cell (high flow)

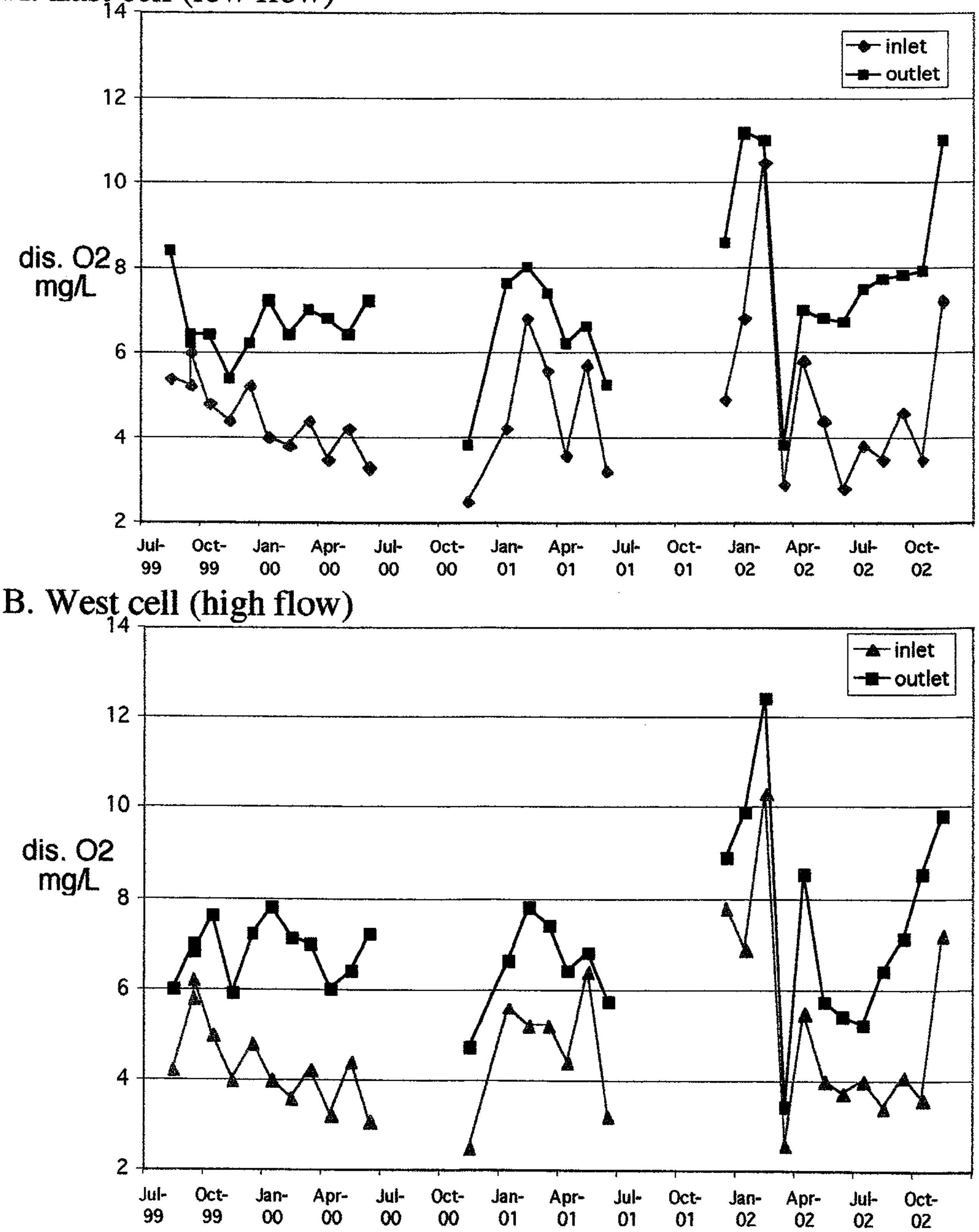


Figure 13. Total Iron: 11/00 - 11/02

Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

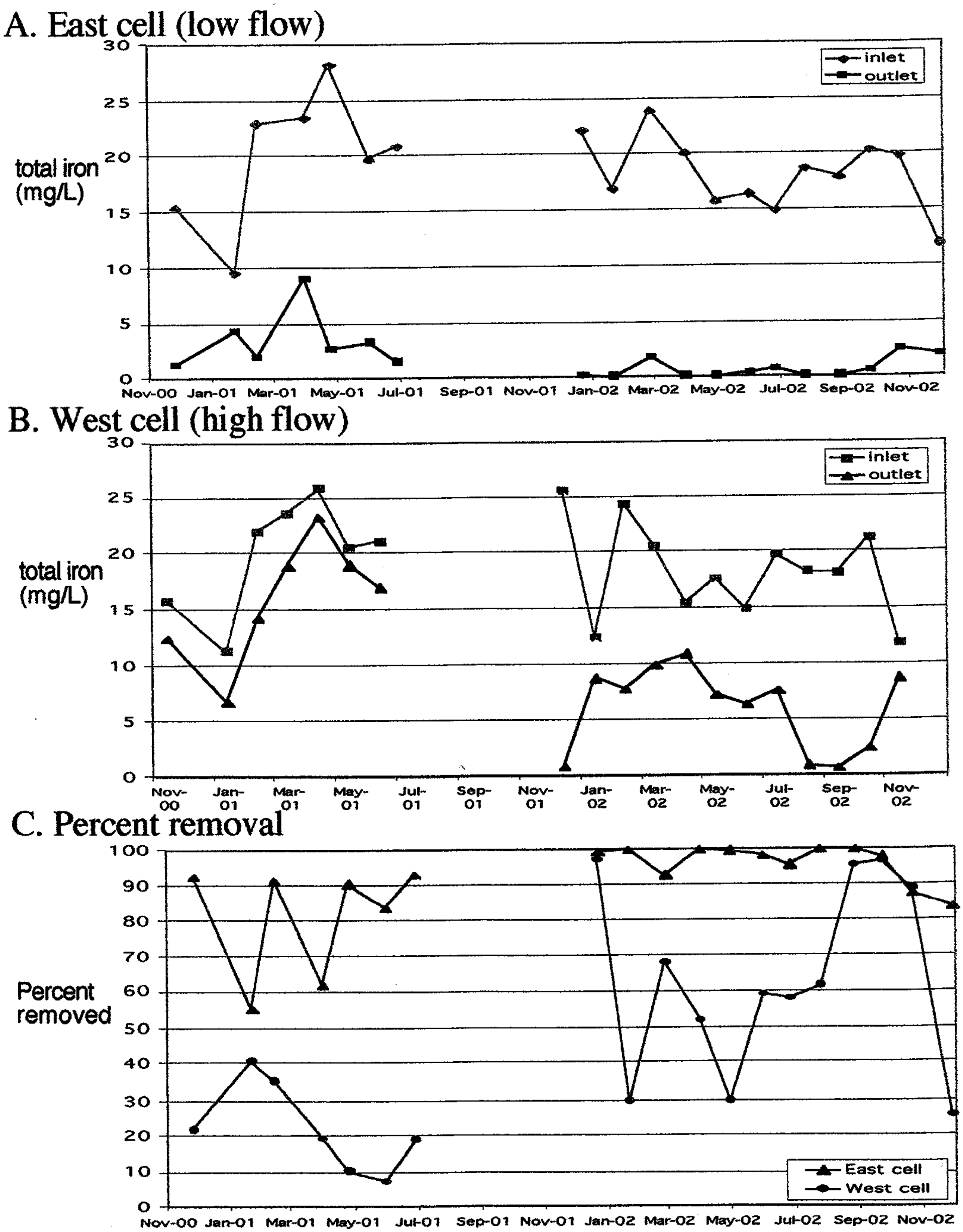


Figure 14. Total Iron: 9/97 - 11/02

Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

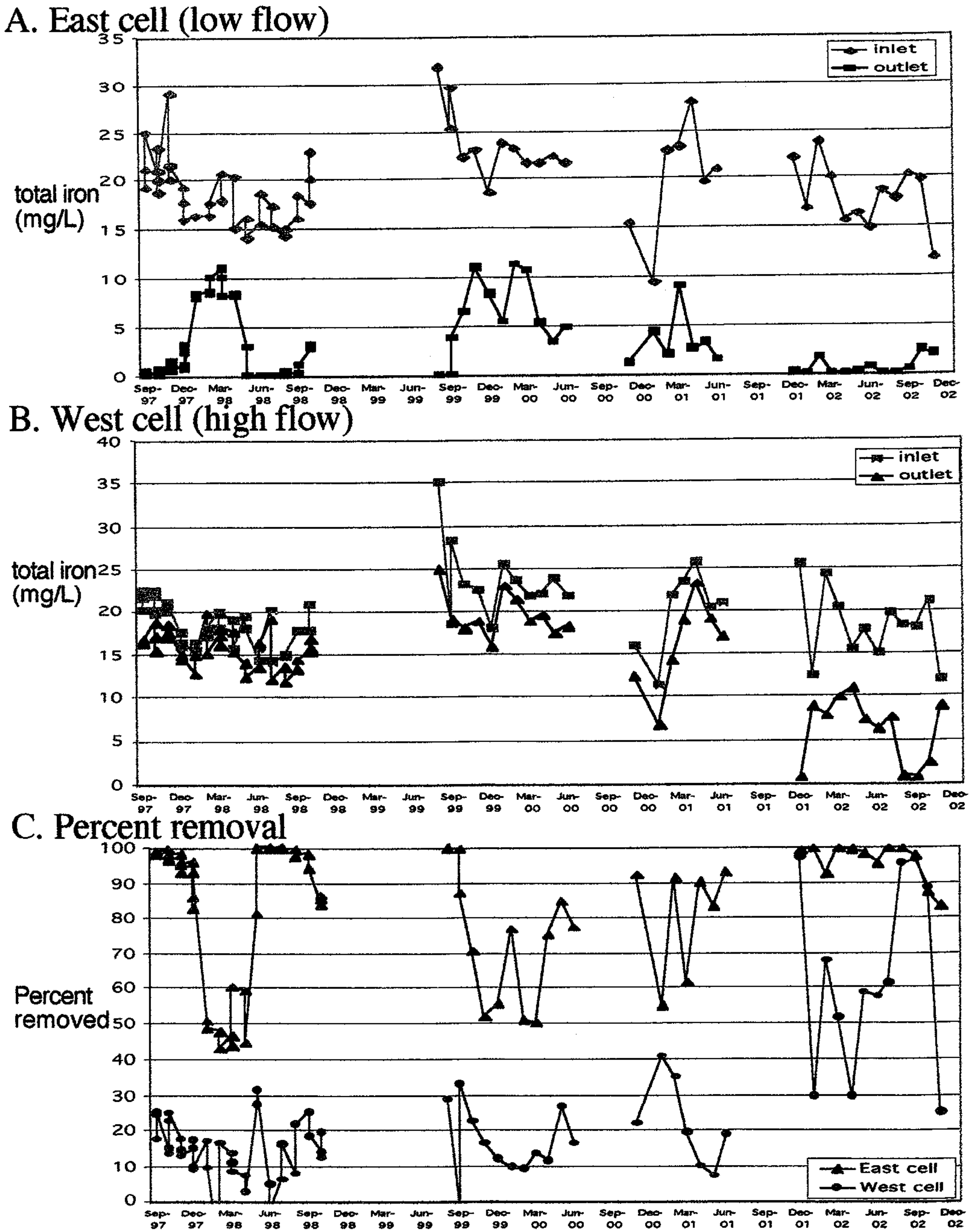


Figure 15. Dissolved Iron: 11/00 - 11/02

Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

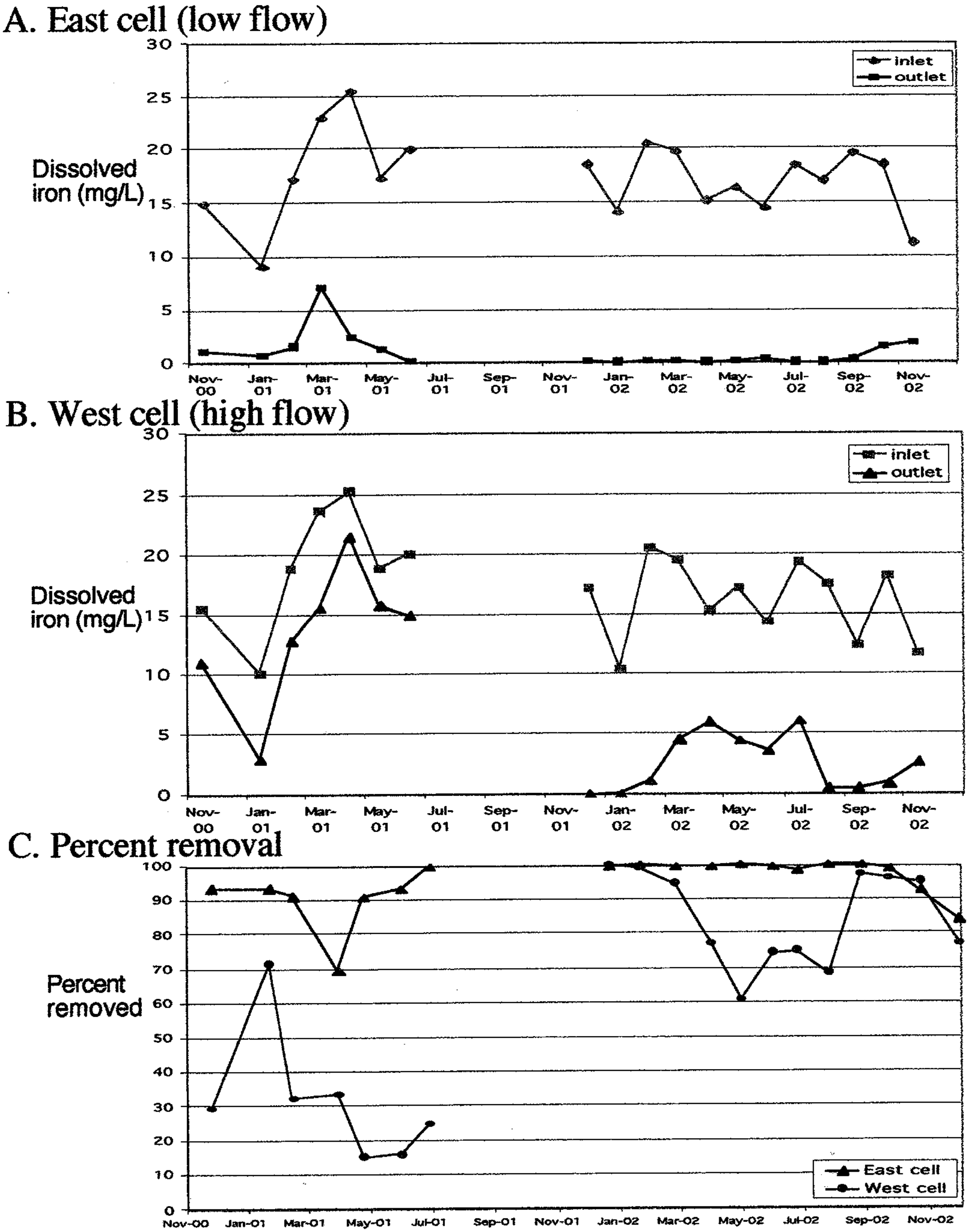


Figure 16. Dissolved Iron: 9/97 - 11/02

Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

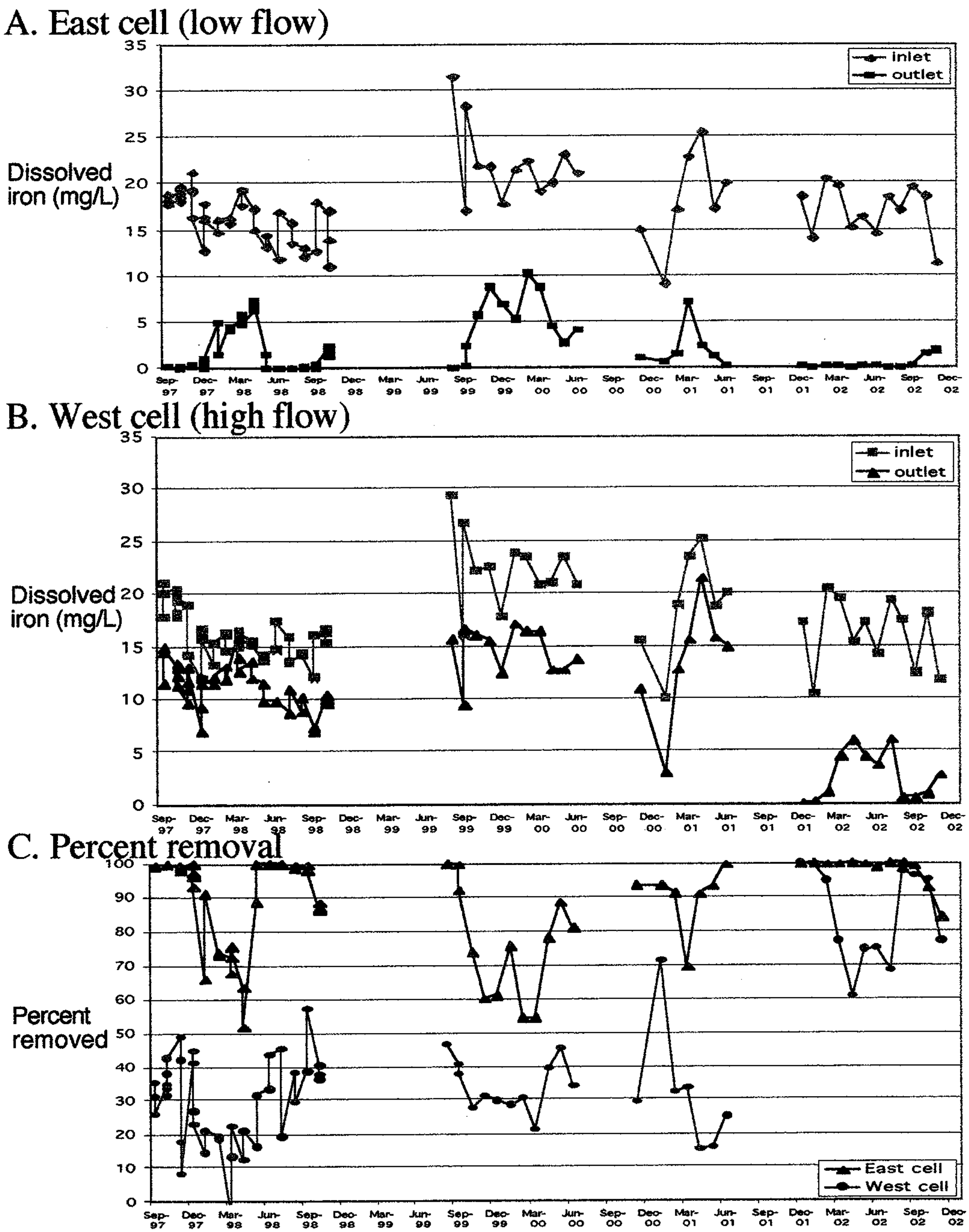
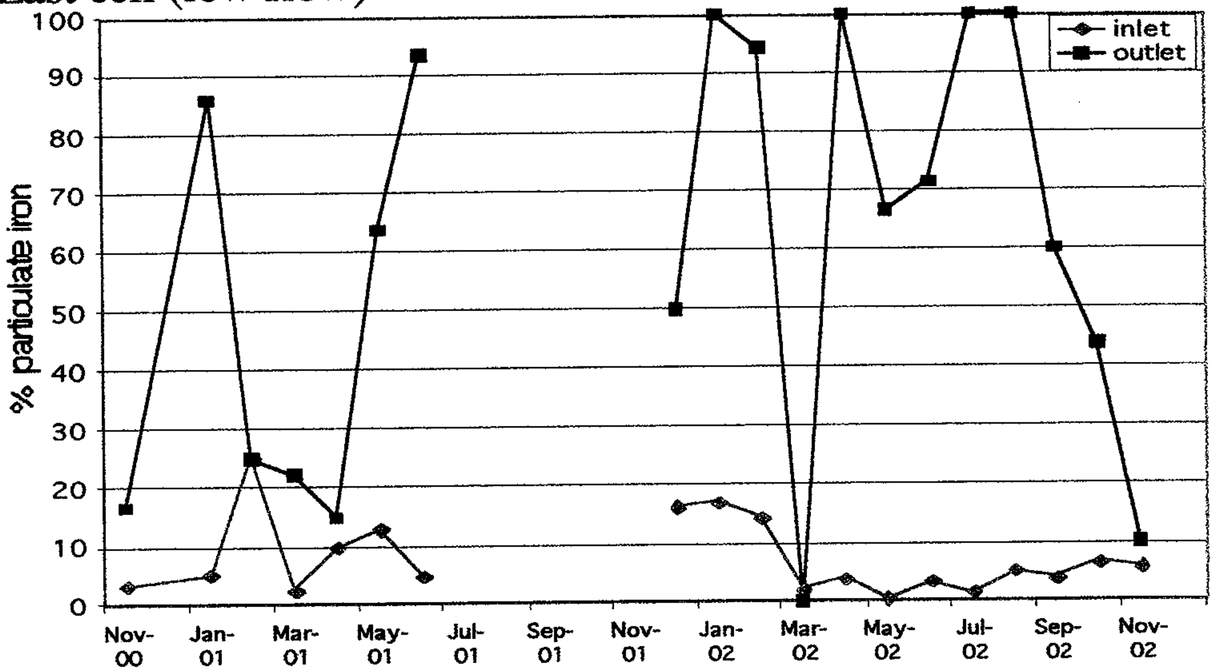


Figure 17. Percentage of Suspended Iron as Particulate: 11/00 - 11/02

Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

A. East cell (low flow)



B. West cell (high flow)

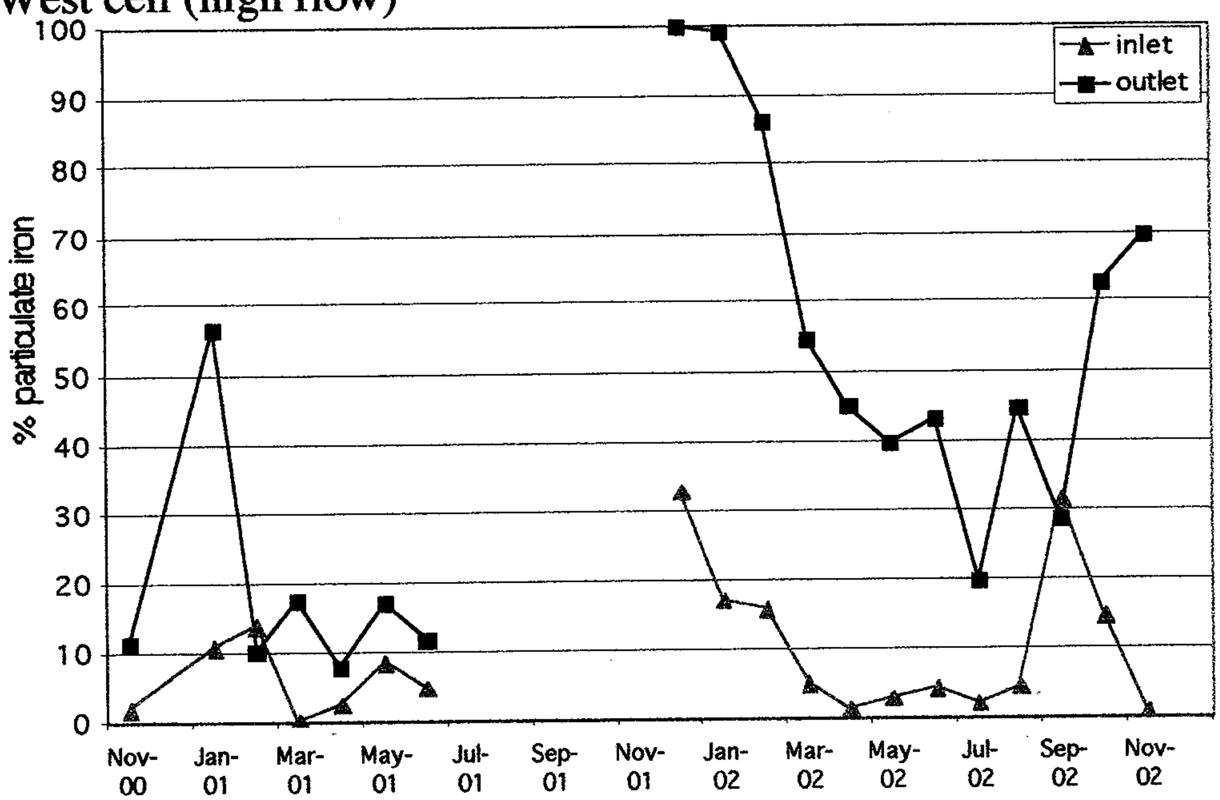
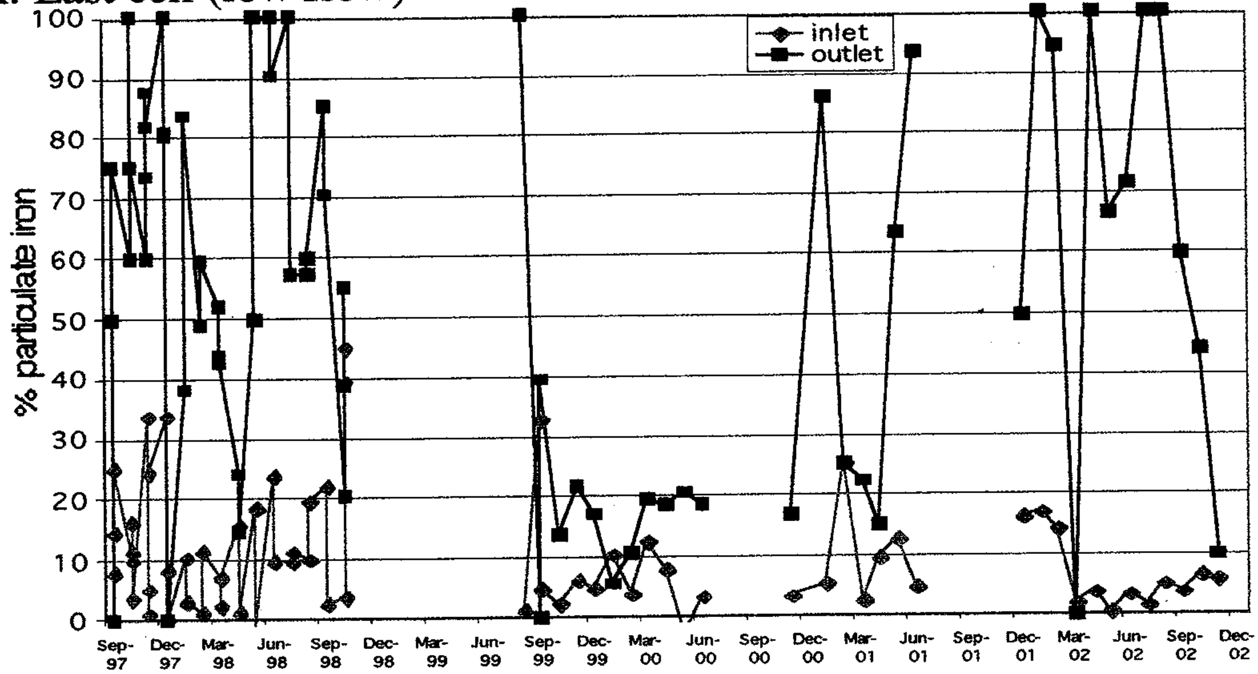


Figure 18. Percentage of Suspended Iron as Particulate: 9/97- 11/02

Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

A. East cell (low flow)



B. West cell (high flow)

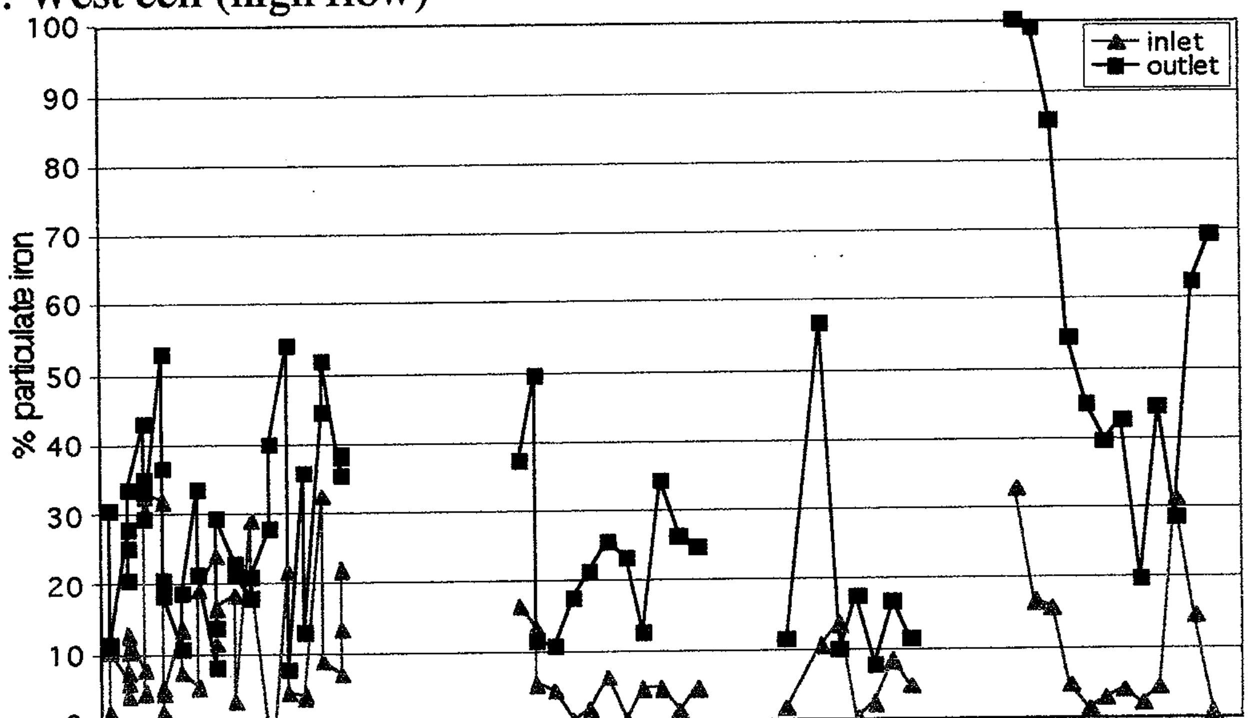


Figure 19. Percentage of Iron Entering Wetland as Solid or Particulate: 11/00 - 11/02

Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

A. East cell (low flow)

B. West cell (high flow)

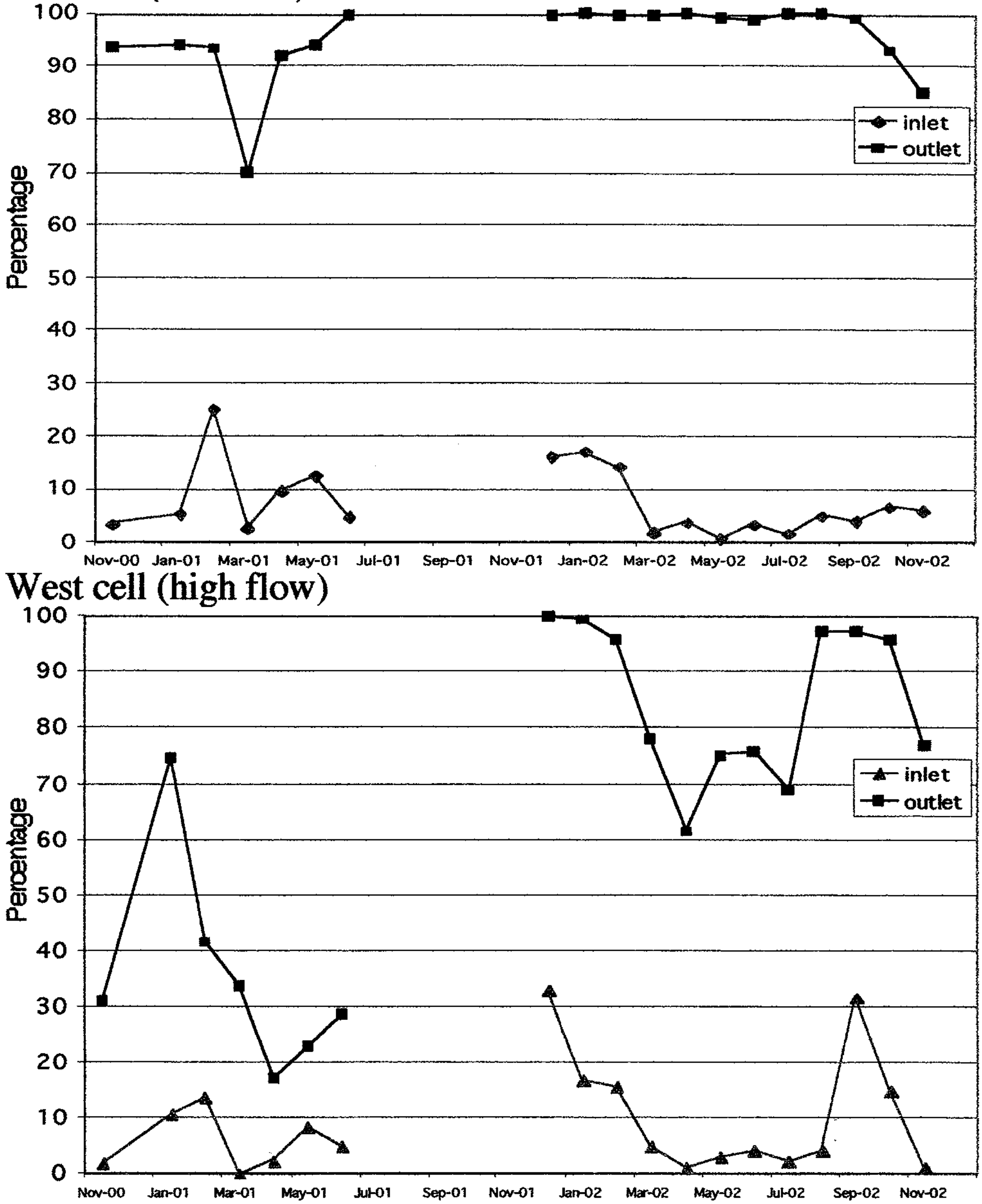


Figure 20. Percentage of Iron Entering Wetland as Solid or Particulate: 9/97 - 11/02

Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

A. East cell (low flow)

B. West cell (high flow)

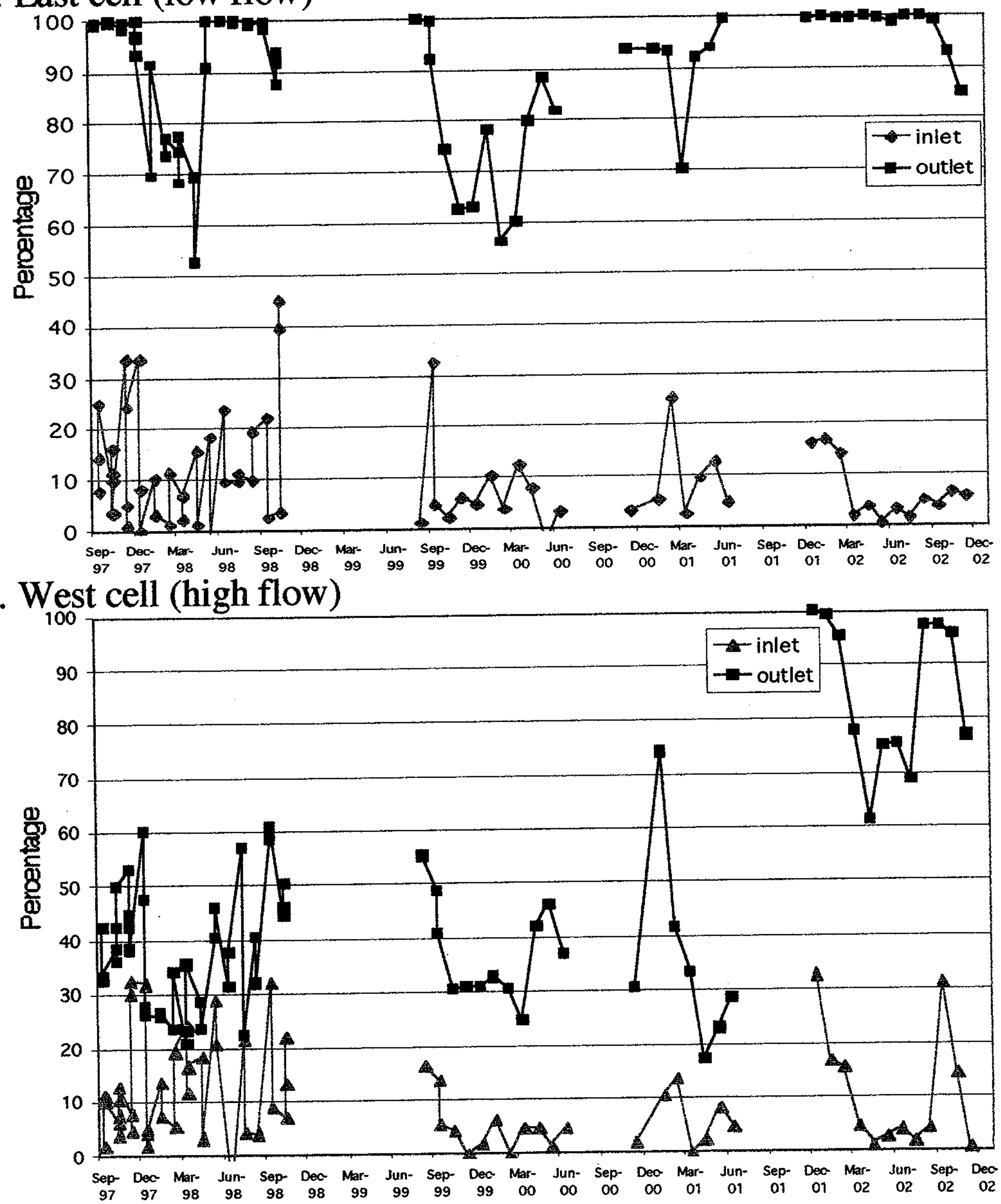
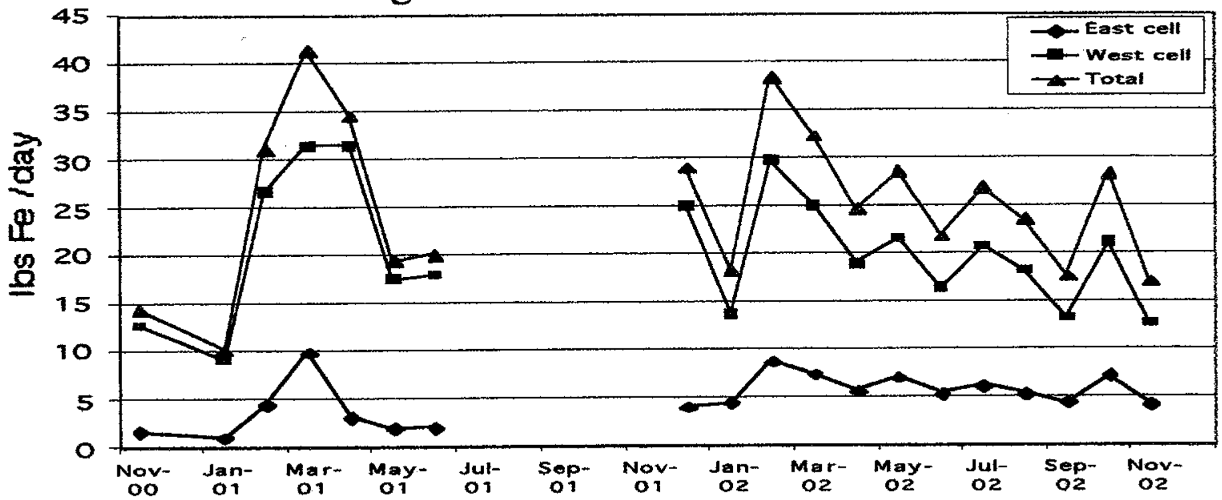


Figure 21. Iron Budget: 11/00 - 11/02

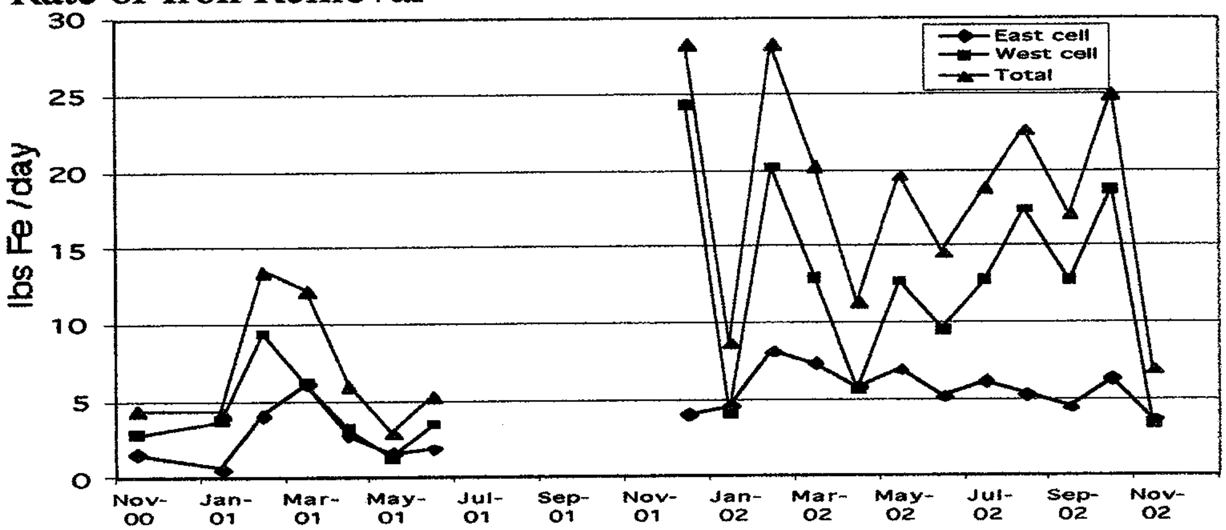
Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

A. Rate of Iron Entering



B. Rate of Iron Removal



C. Rate of Iron Removal per Acre

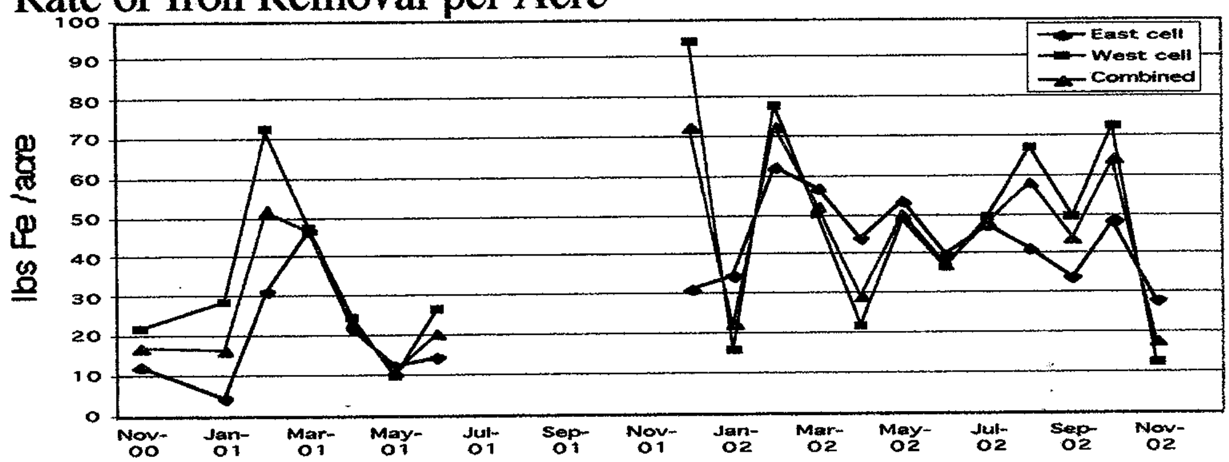
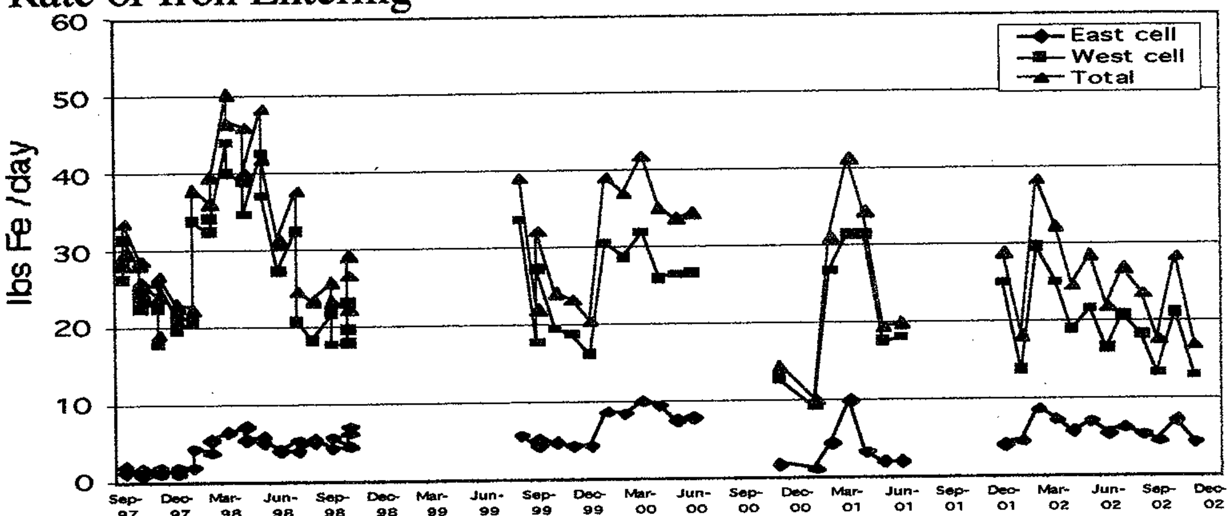


Figure 22. Iron Budget: 9/97 - 11/02

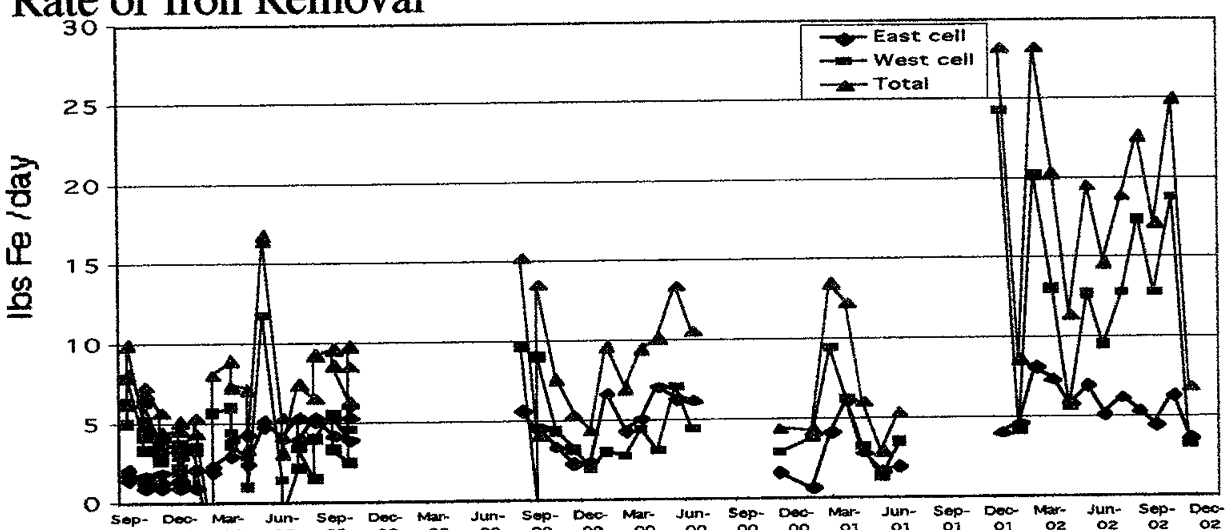
Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

A. Rate of Iron Entering



B. Rate of Iron Removal



C. Rate of Iron Removal per Acre

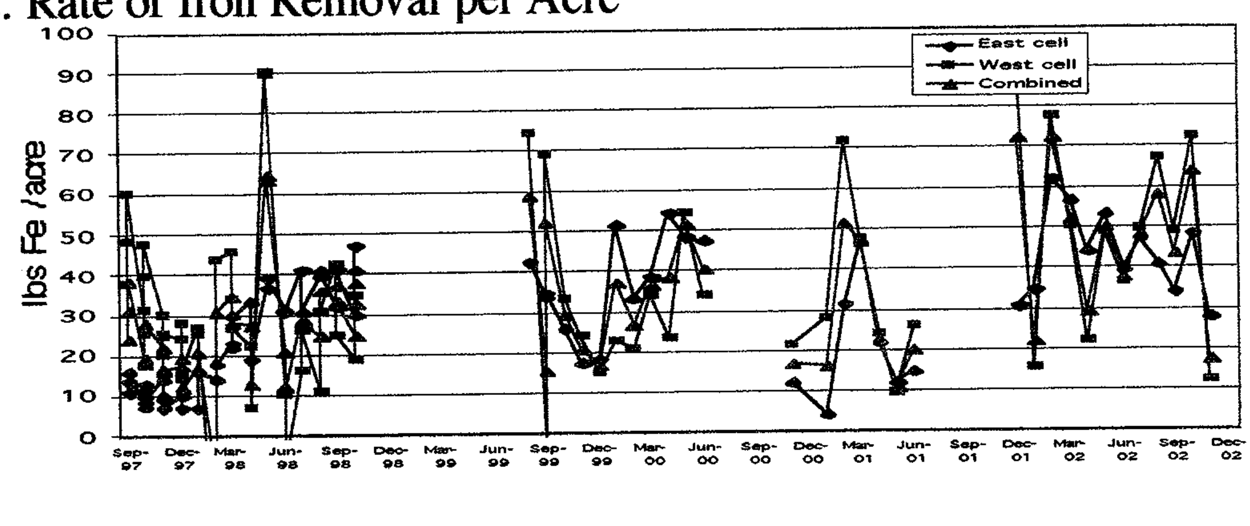


Figure 23. Iron Removal Rate Constants: 11/00 - 11/02

Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team - through June 2000)

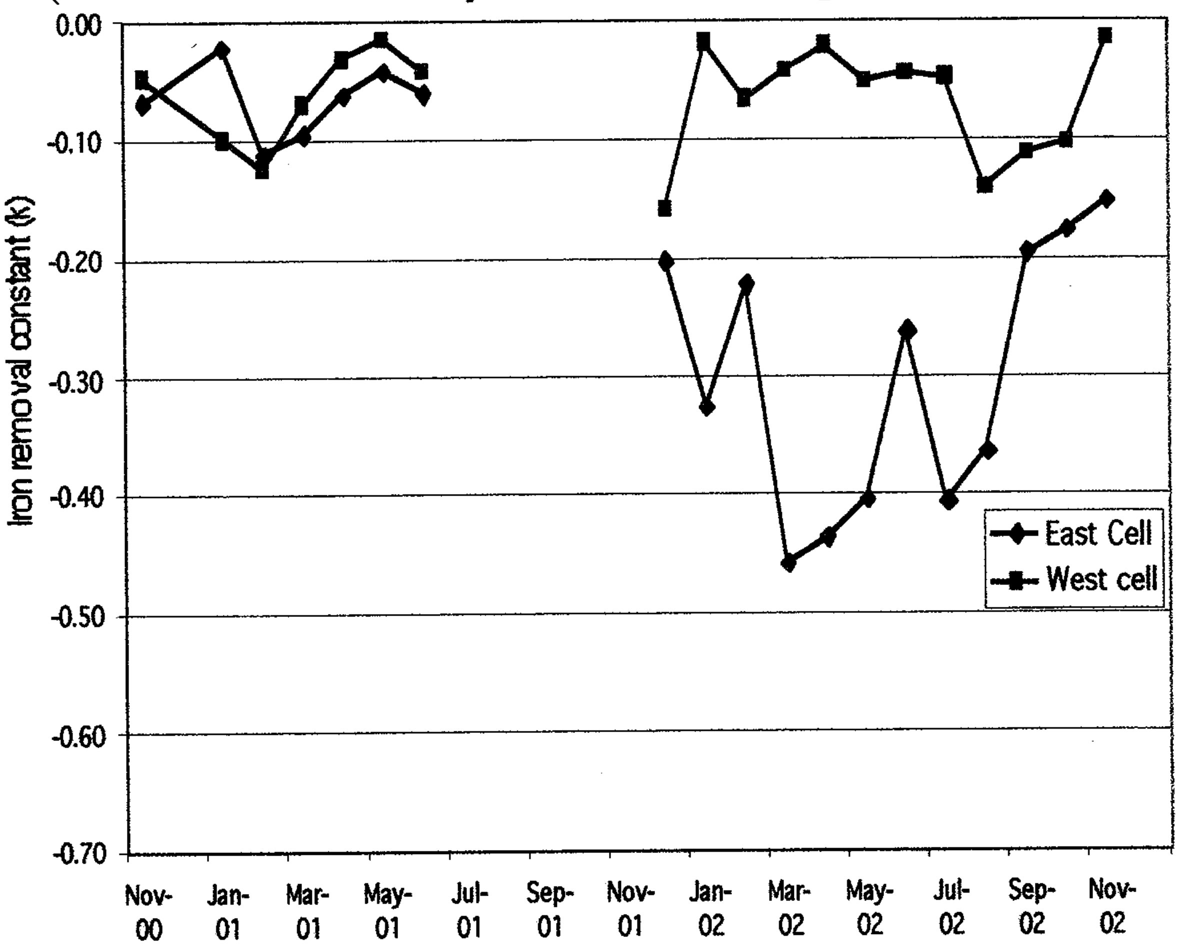


Figure 24. Iron Removal Rate Constants: 9/97 - 11/02

Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

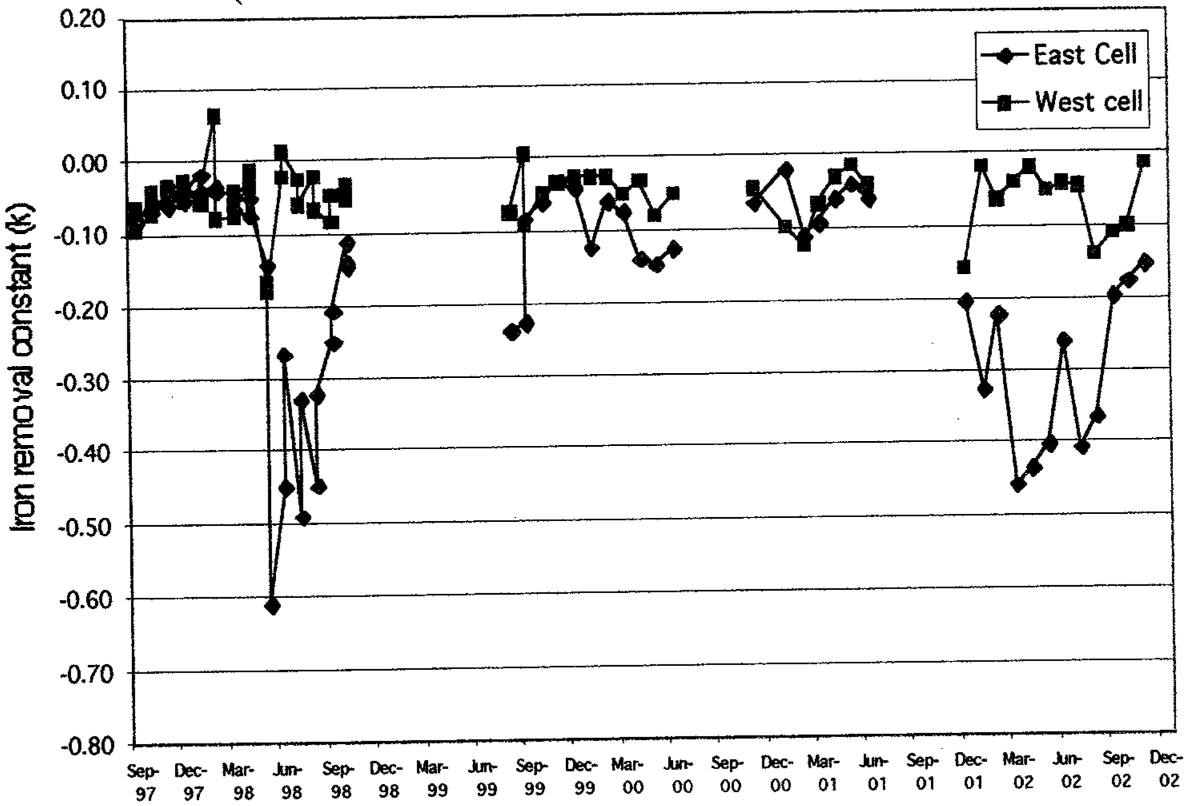
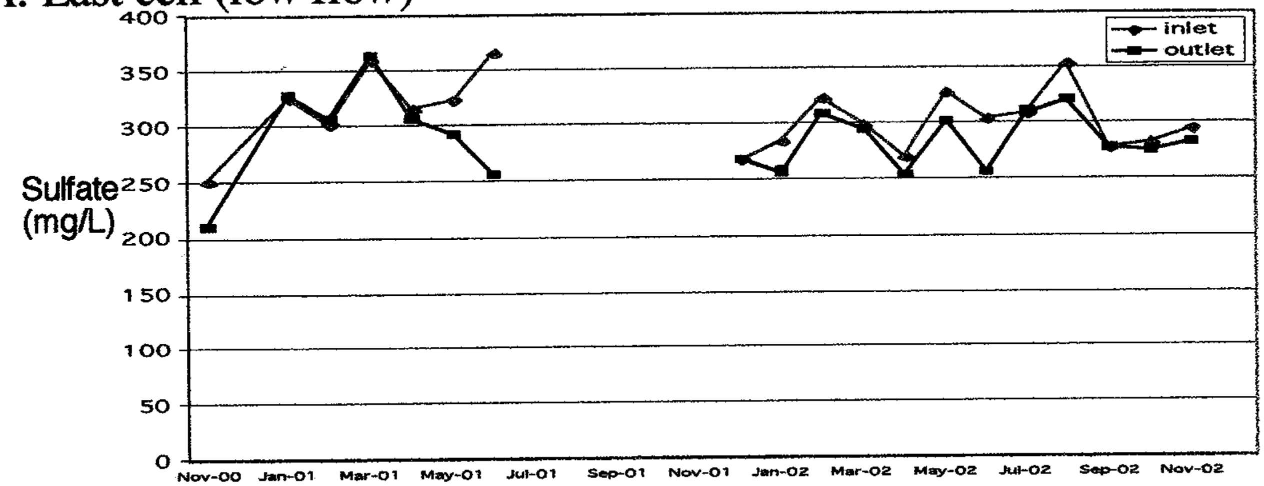


Figure 25. Course of Sulfate: 11/00 - 11/02

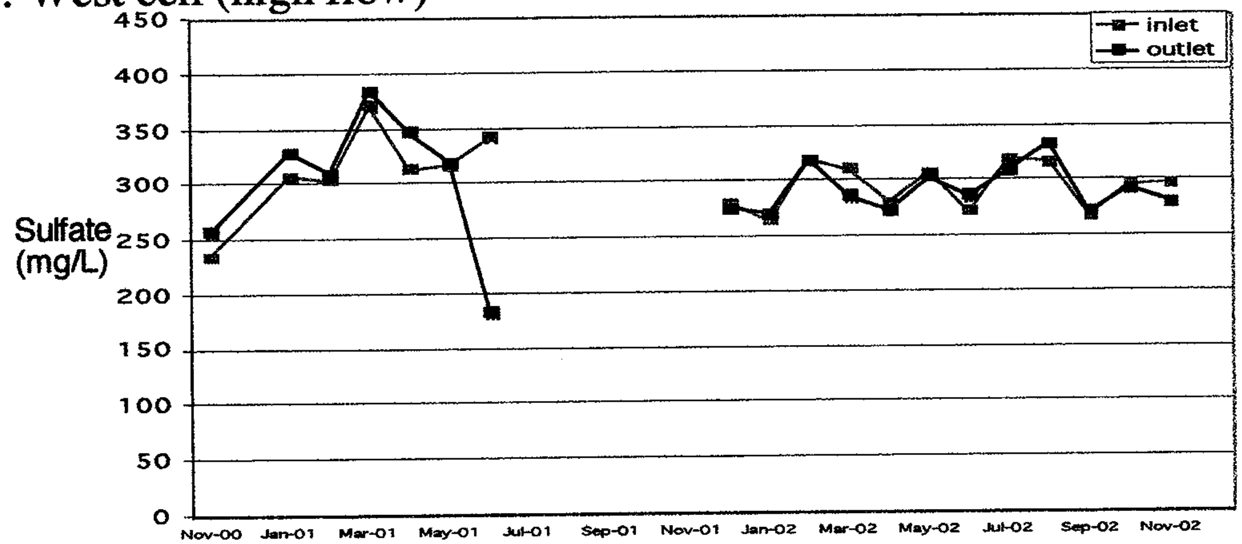
Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

A. East cell (low flow)



B. West cell (high flow)



C. Percent removal

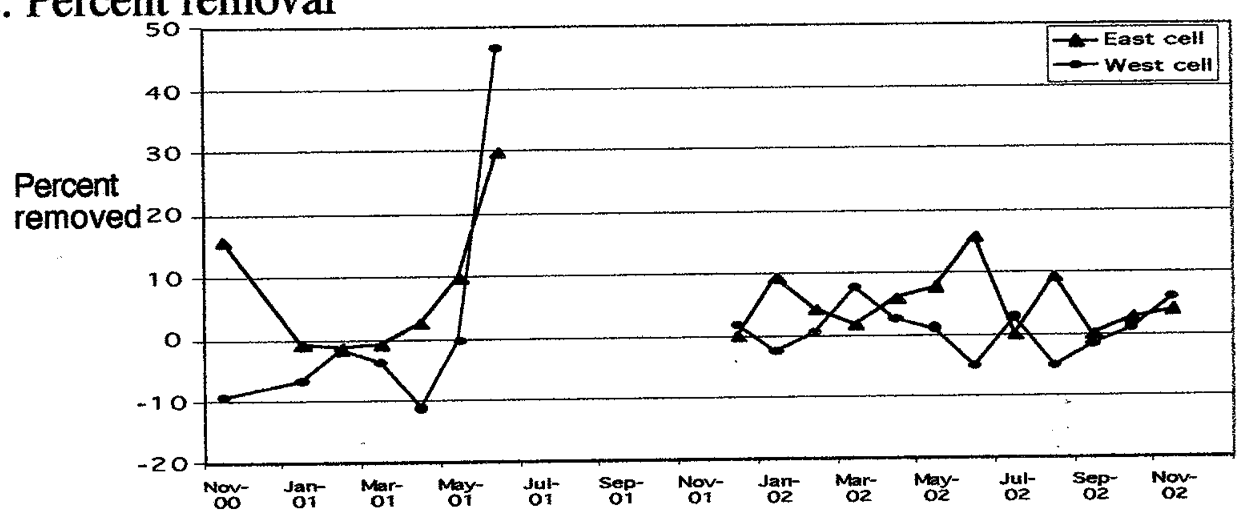
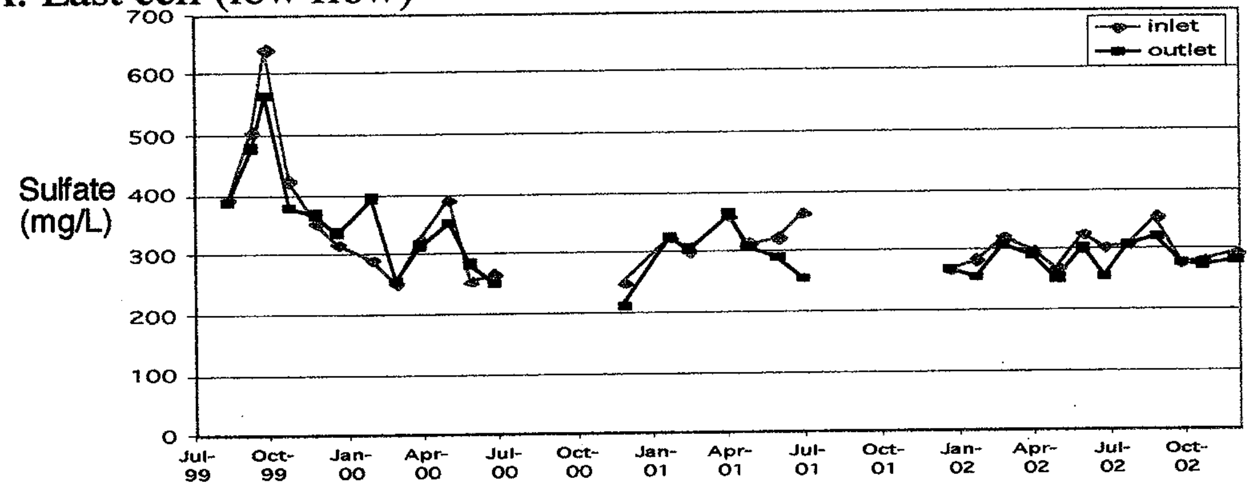


Figure 26. Course of Sulfate: 7/99 - 11/02

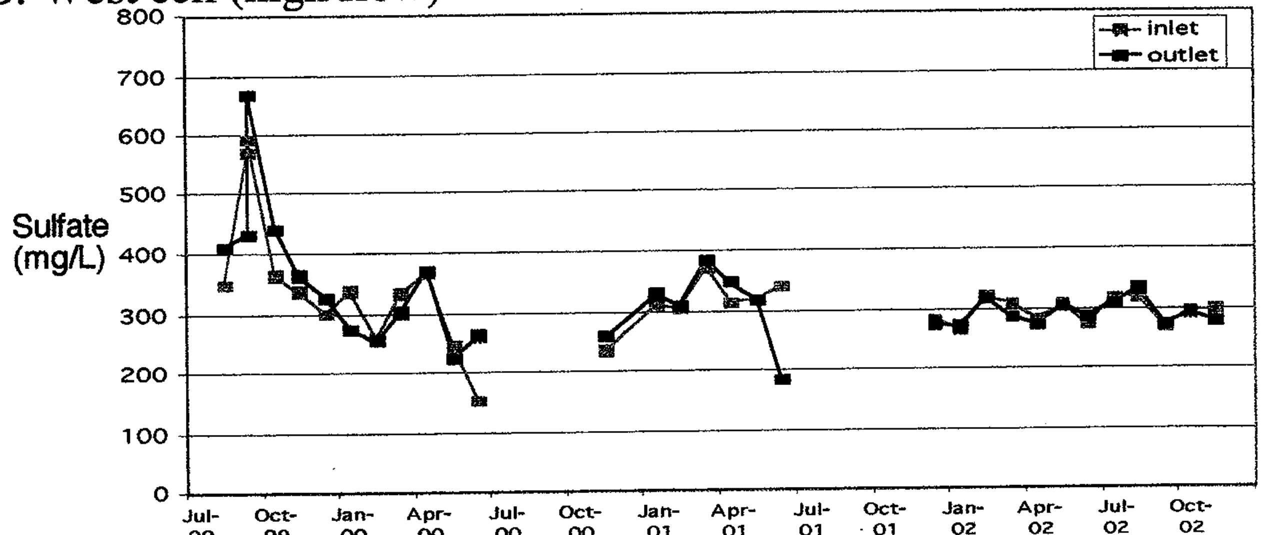
Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

A. East cell (low flow)



B. West cell (high flow)



C. Percent removal

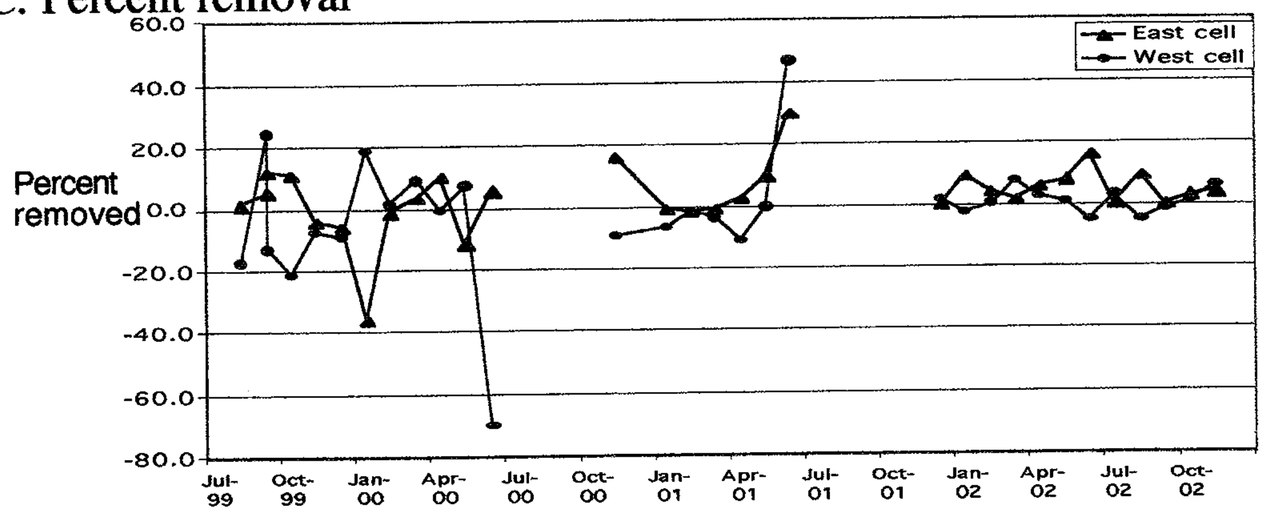
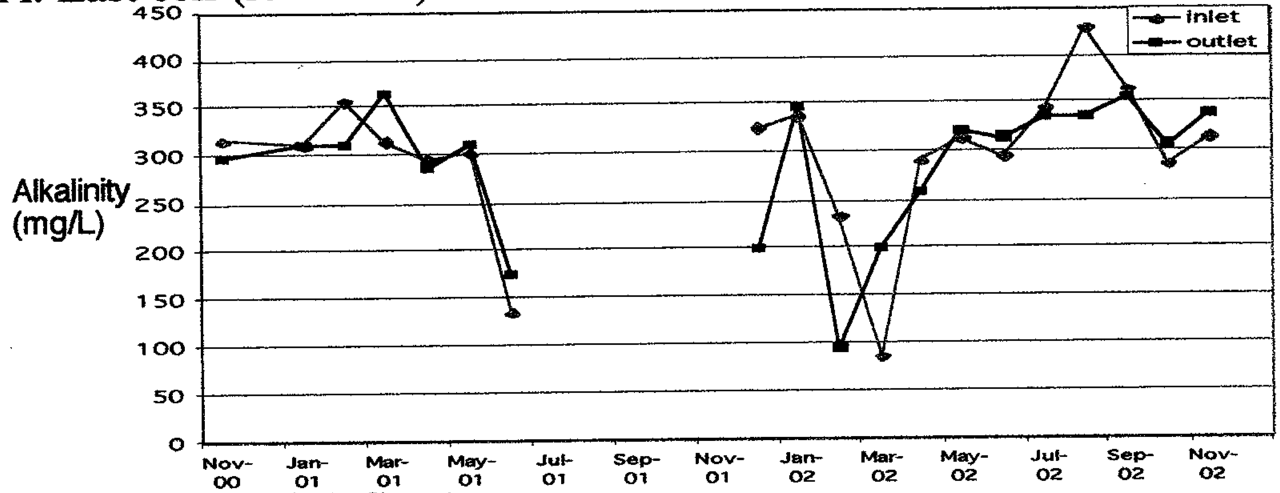


Figure 27. Course of Alkalinity: 11/00 - 11/02

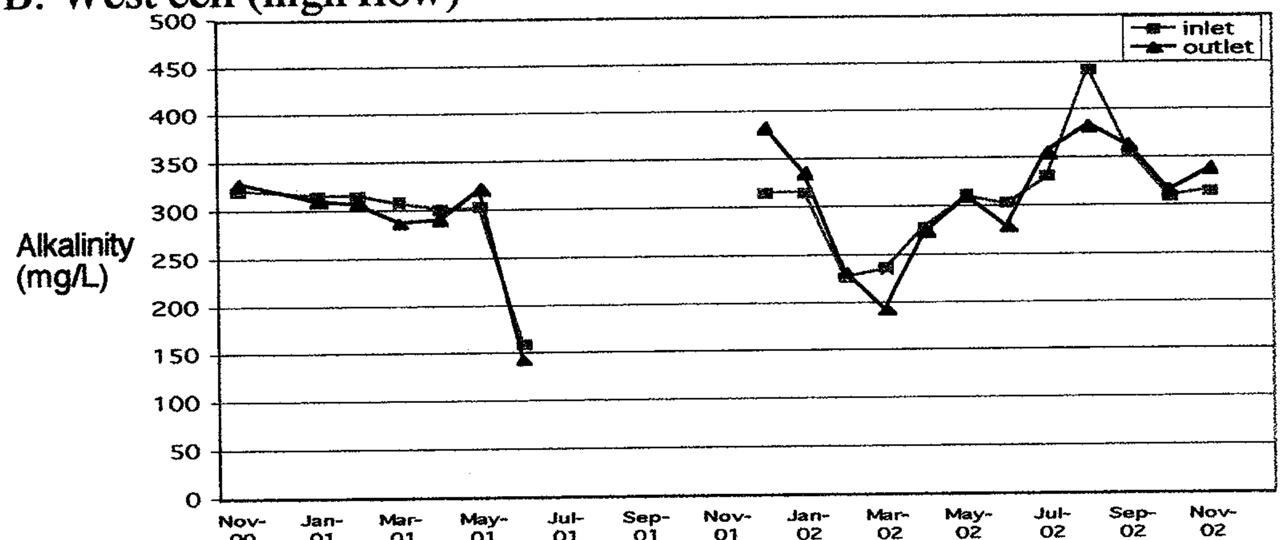
Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

A. East cell (low flow)



B. West cell (high flow)



C. Percent removal

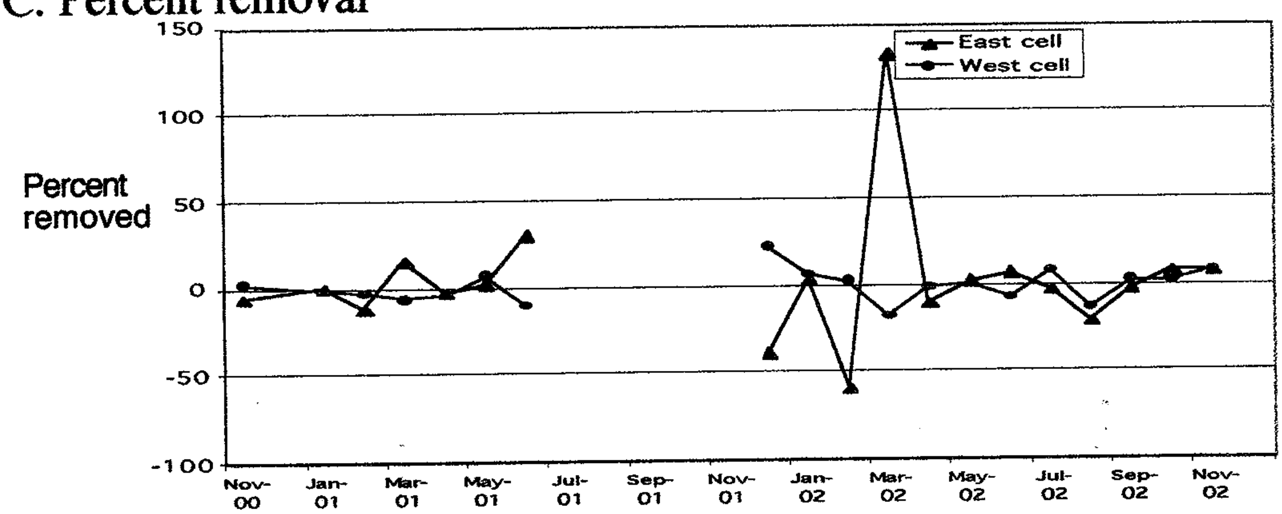
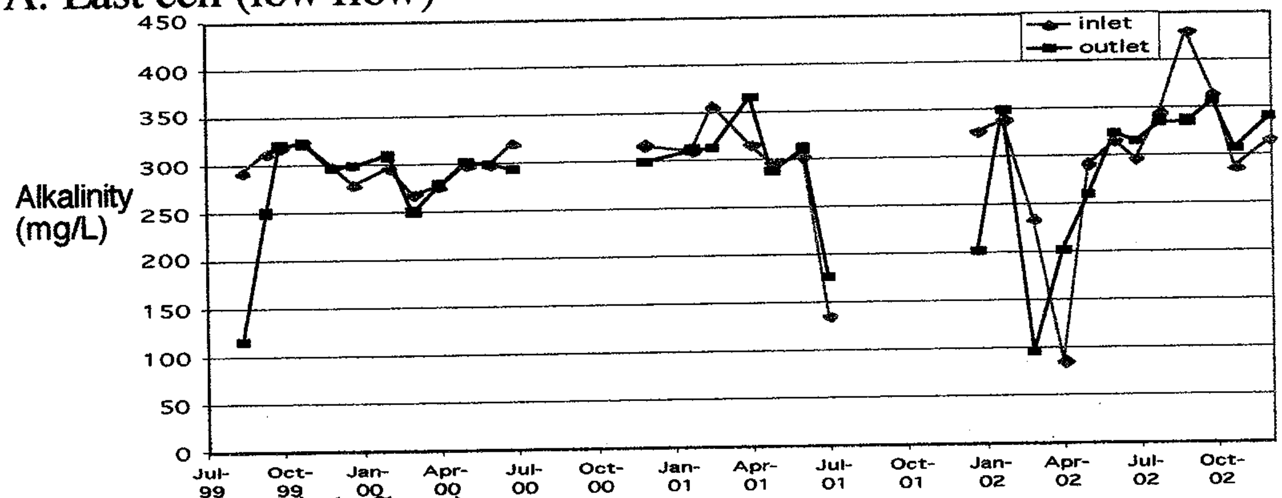


Figure 28. Course of Alkalinity: 7/99 - 11/02

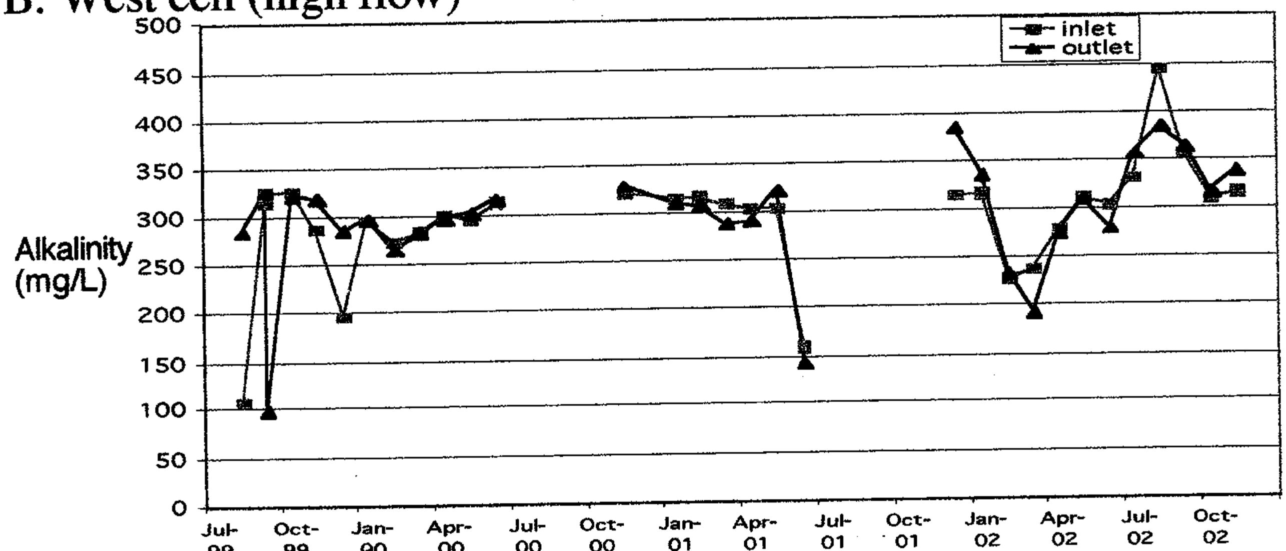
Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

A. East cell (low flow)



B. West cell (high flow)



C. Percent removal

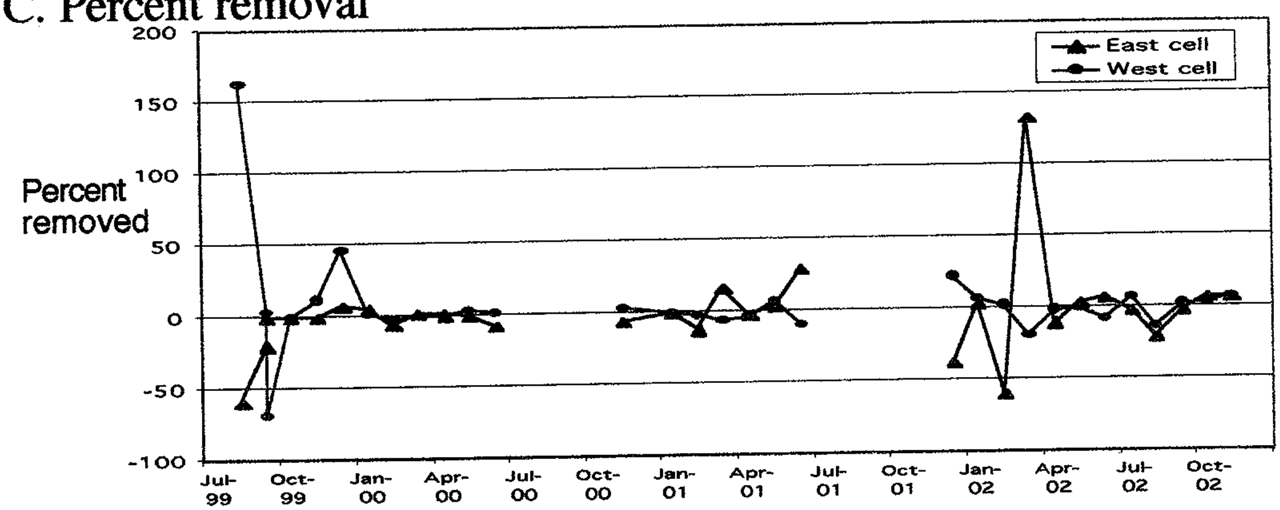
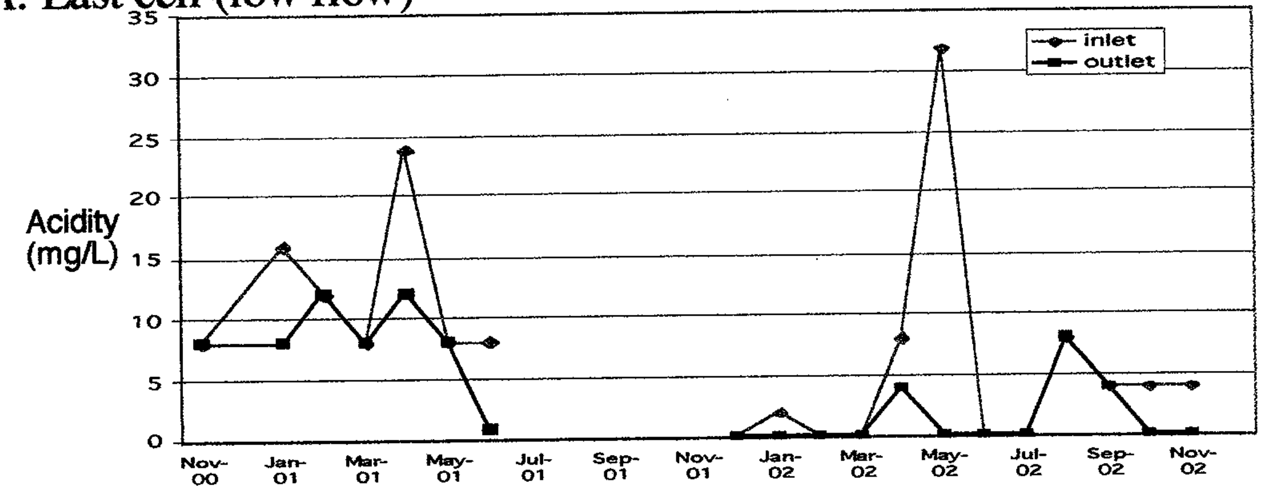


Figure 29. Course of Acidity: 11/00 - 11/02

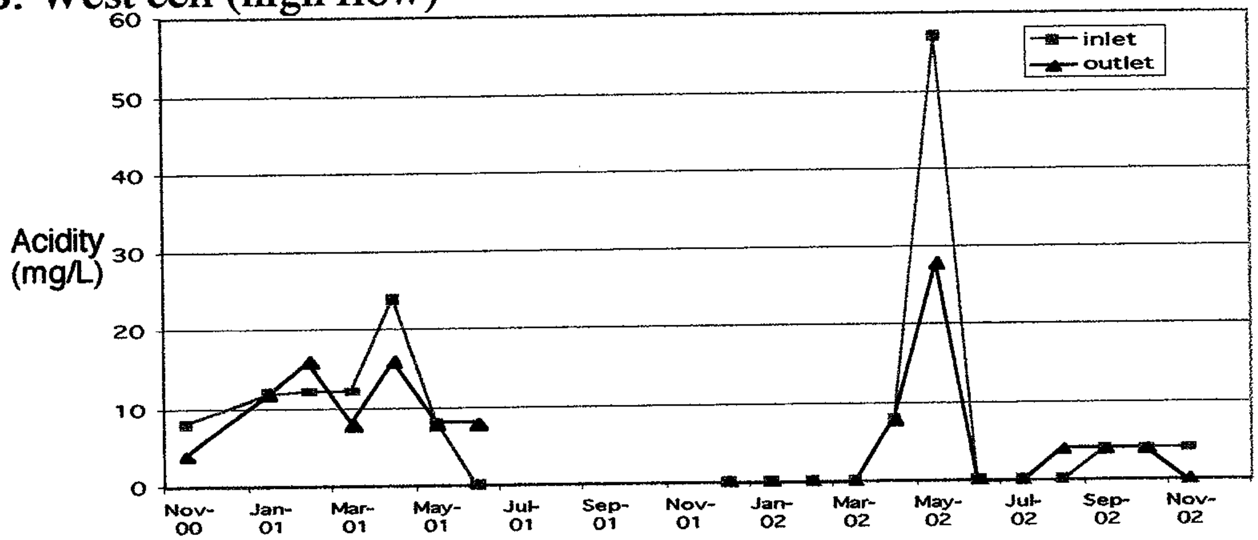
Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)

A. East cell (low flow)



B. West cell (high flow)



C. Percent removal

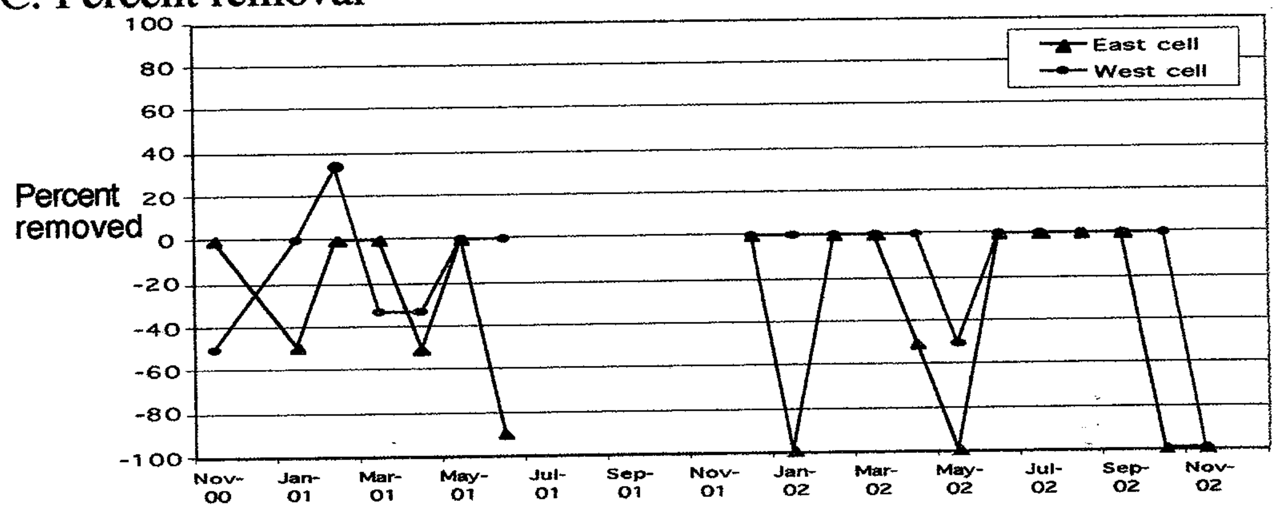
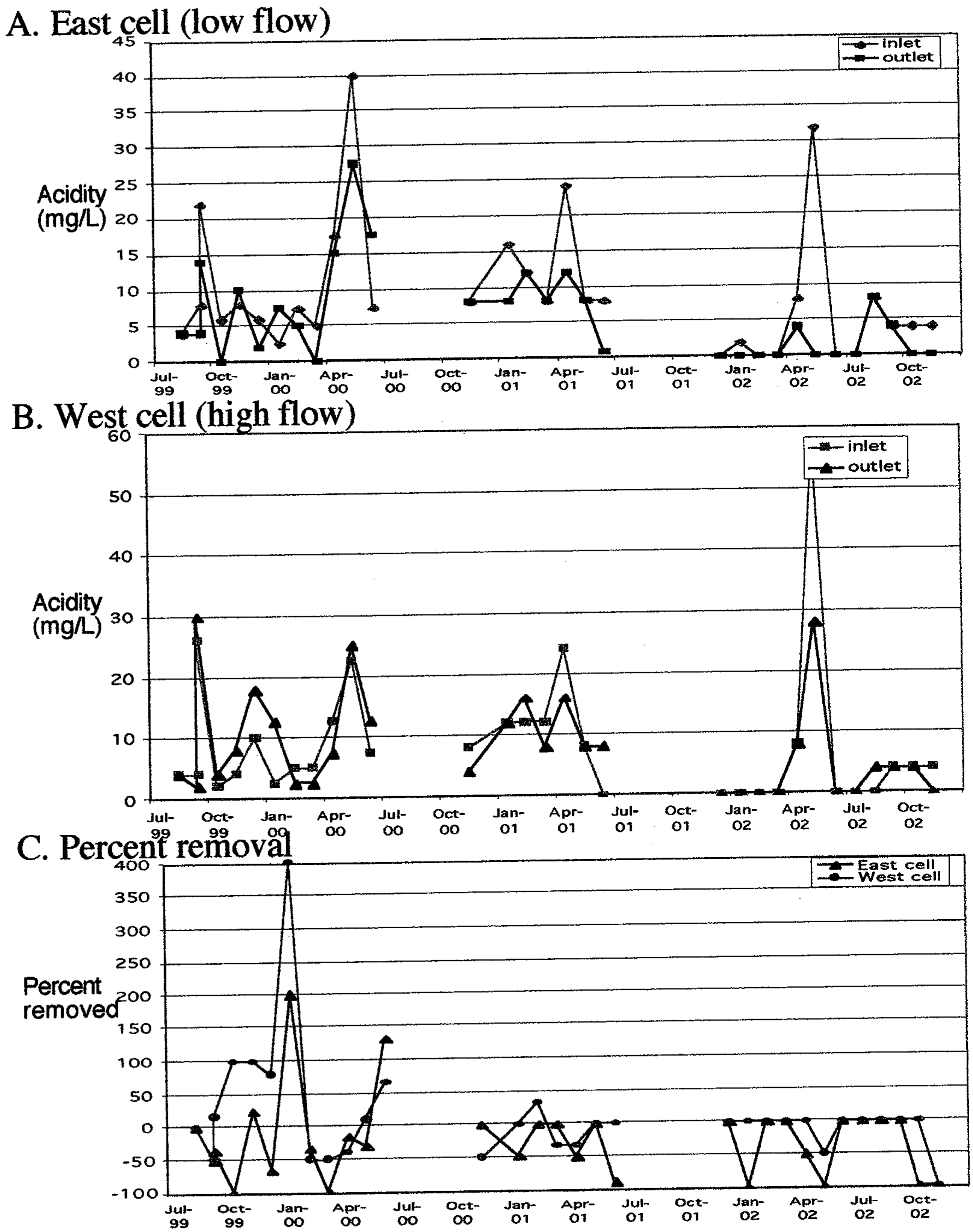


Figure 30. Course of Acidity: 7/99 - 11/02

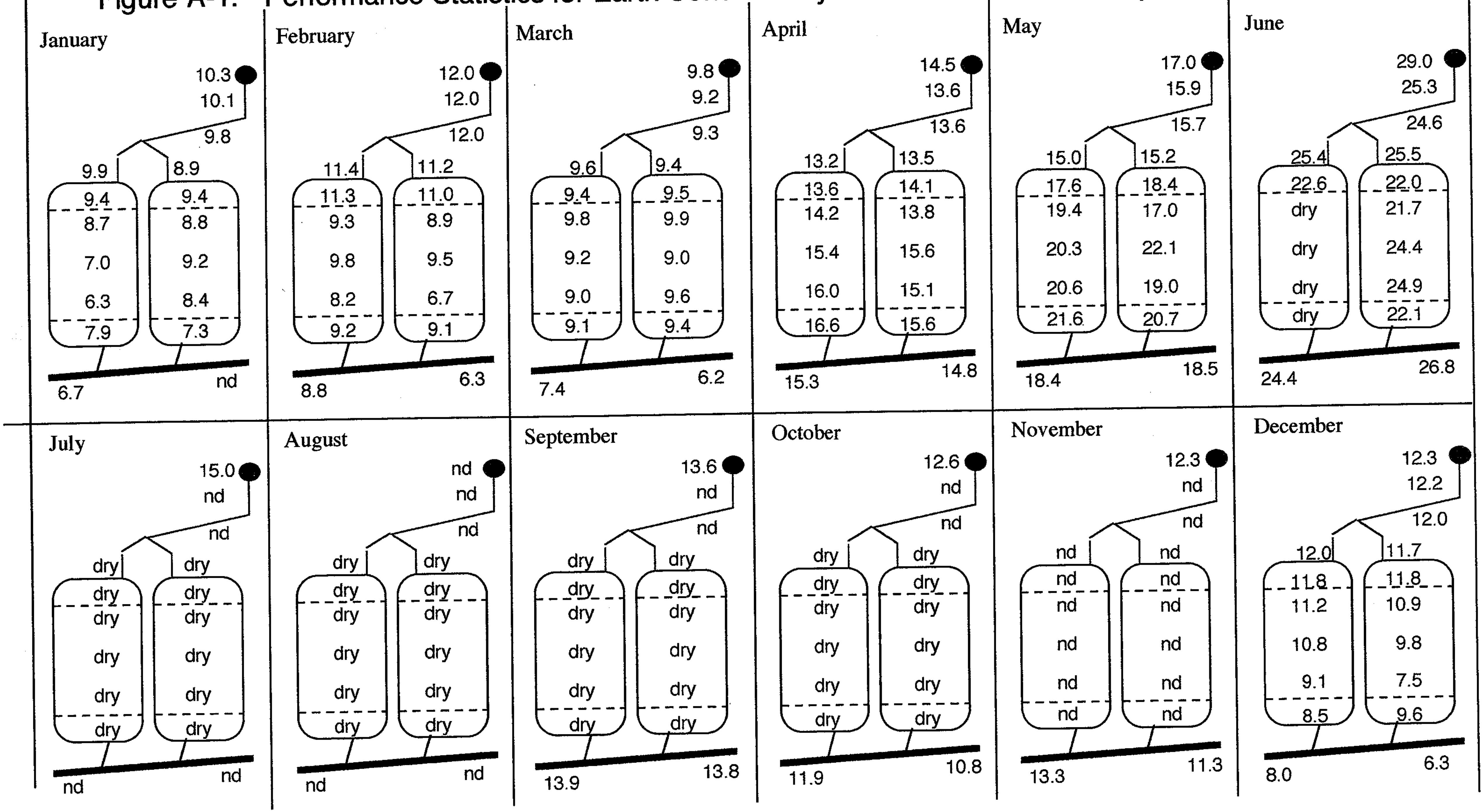
Earth Conservancy Espy Run Wetland - Hanover Twp. PA

(Data from Wilkes University Wetland Team)



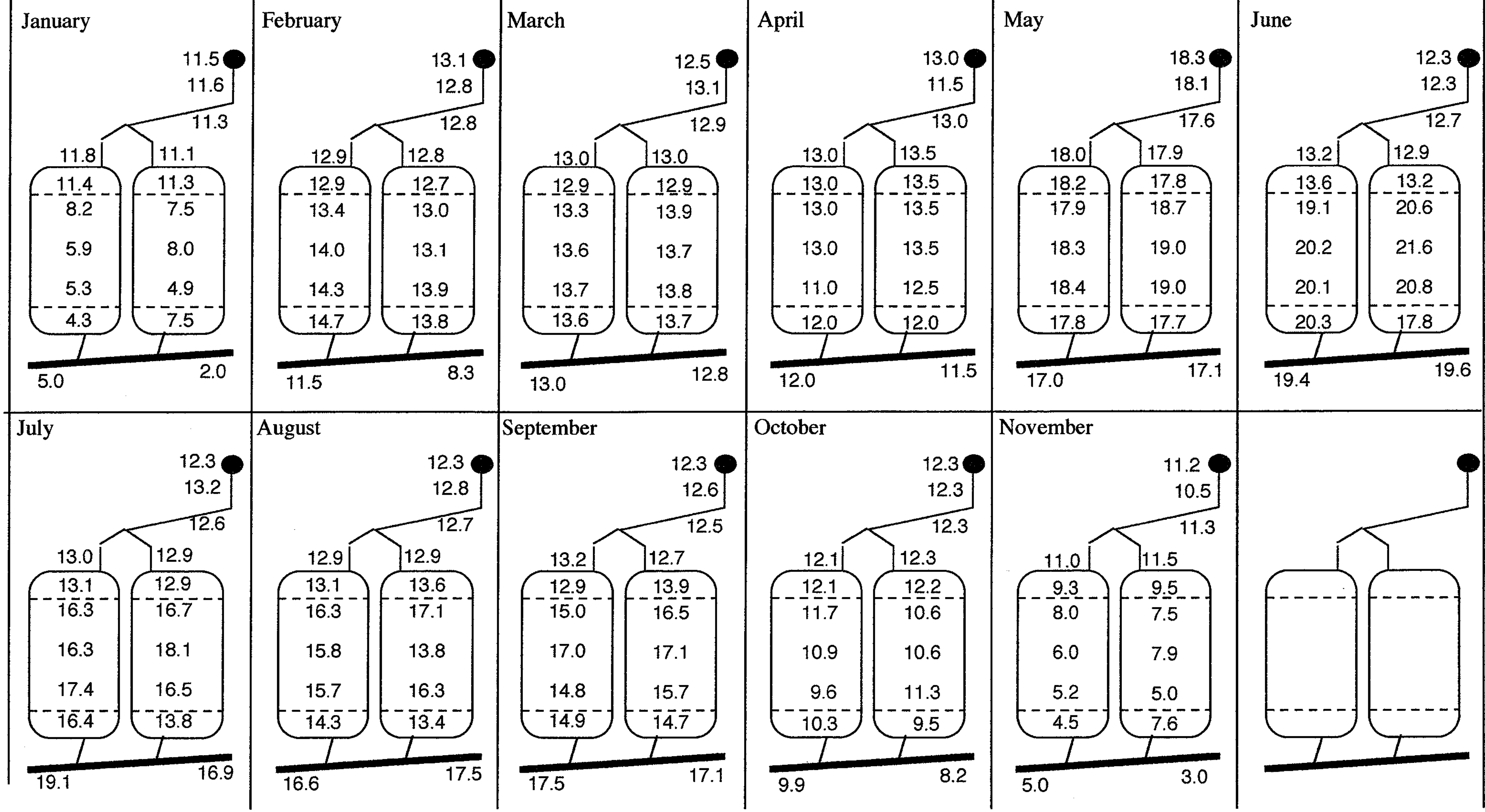
Individual Monthly Readings

Figure A-1. Performance Statistics for Earth Conservancy Phase I 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

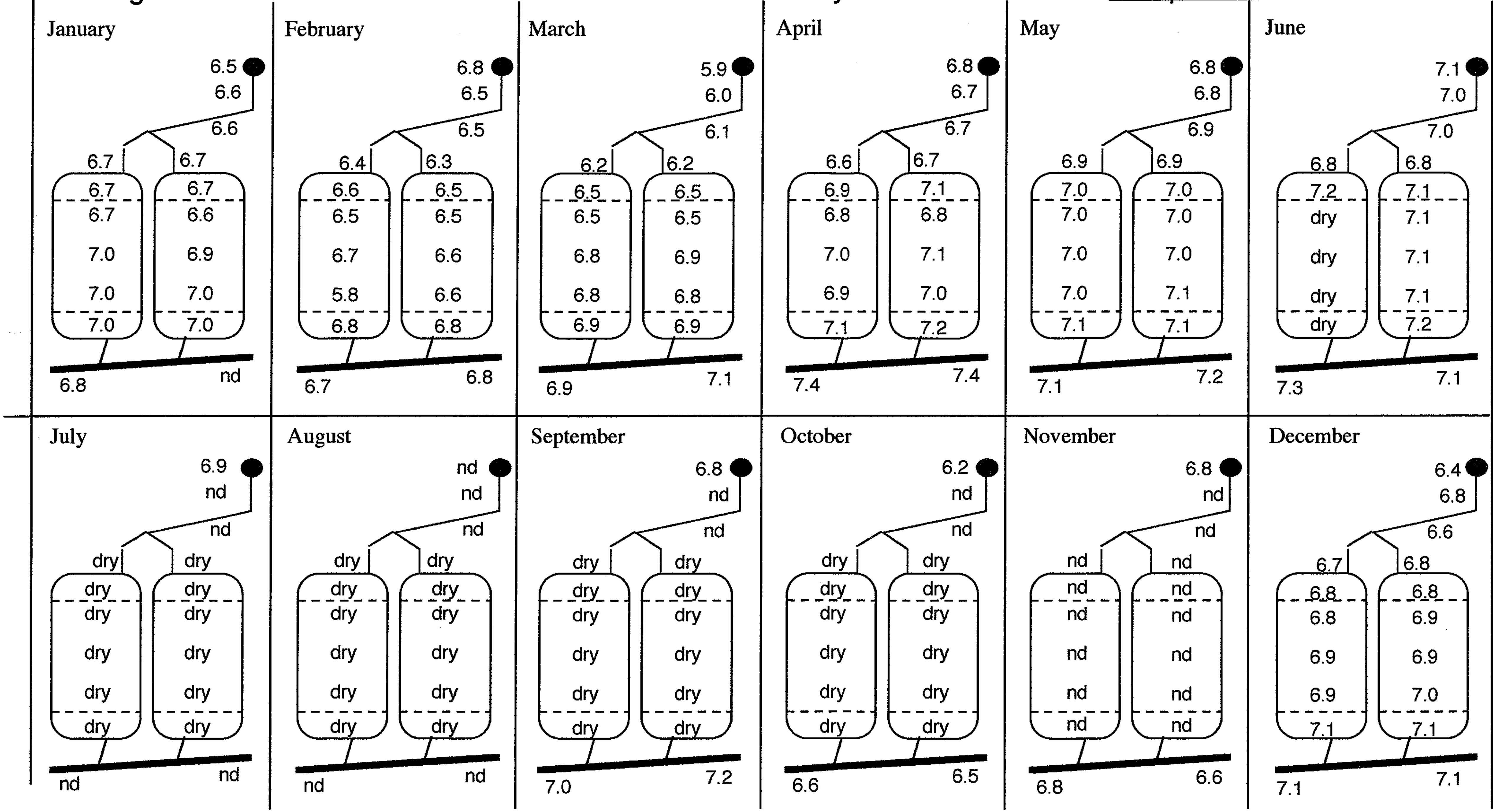
Figure A-2. Performance Statistics for Earth Conservancy Phase I Wetland for <u>temperature</u> in 2002



Data provided by Wilkes University Wetland Team

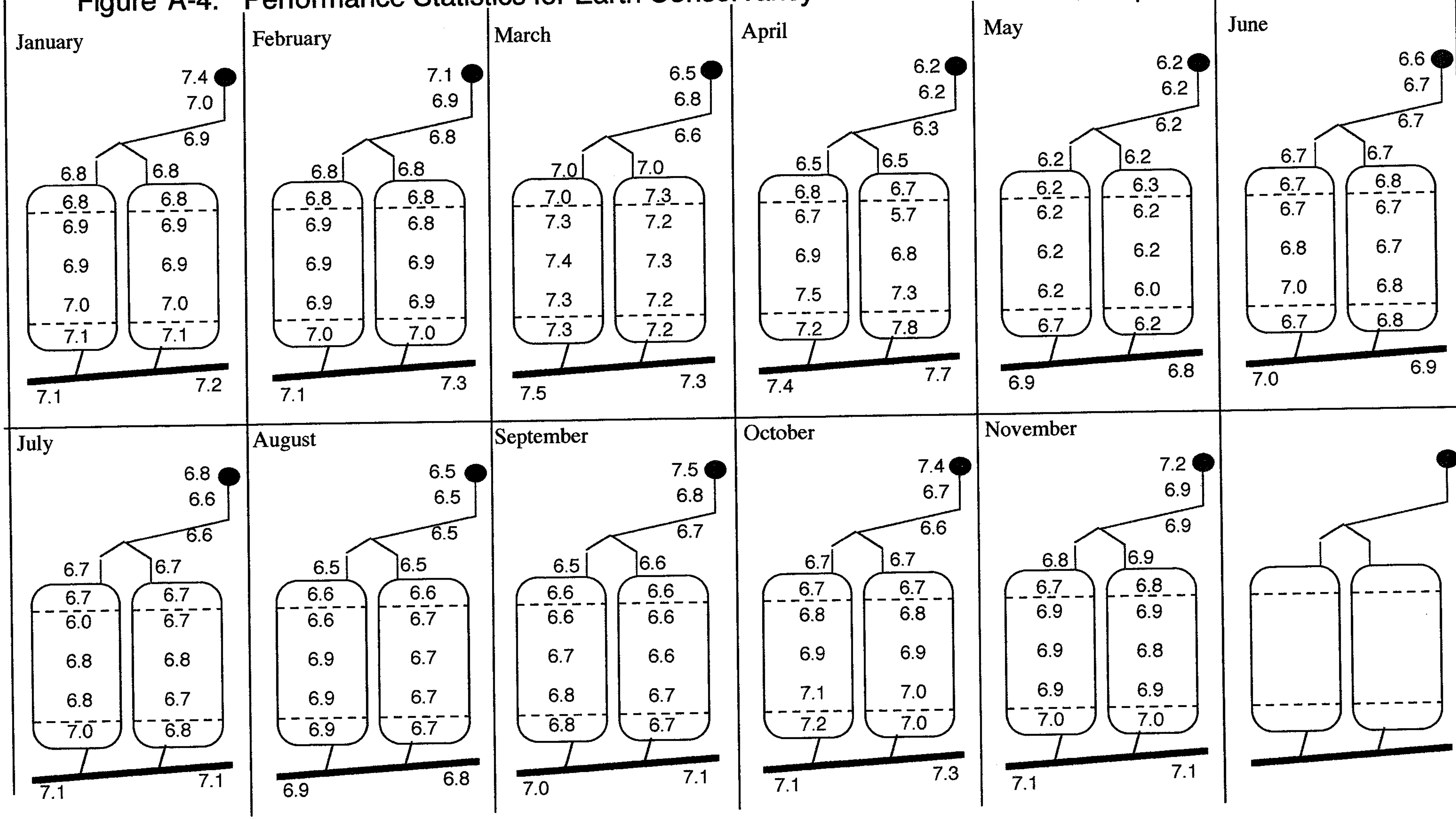
Kenneth M. Klemow, Ph.D. - Project PI, Brian Oram - WQ Lab Supervisor, Chris Watkins, John Pagoda - Technical Associates

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



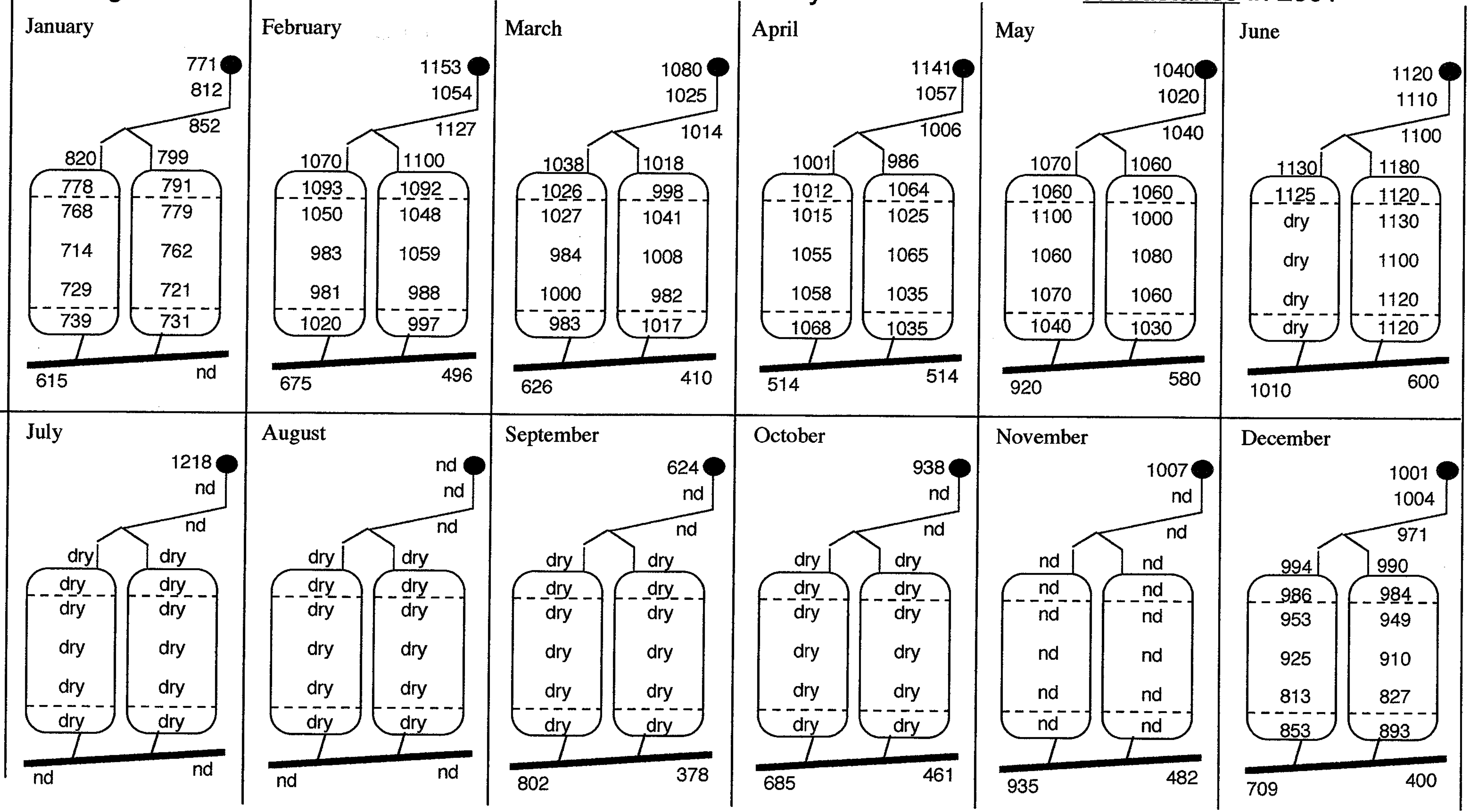
Data provided by Wilkes University Wetland Team
Kenneth M. Klemow, Ph.D. - Project PI, Brian Oram - WQ Lab Supervisor, Chris Watkins, John Pagoda - Technical Associates

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



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

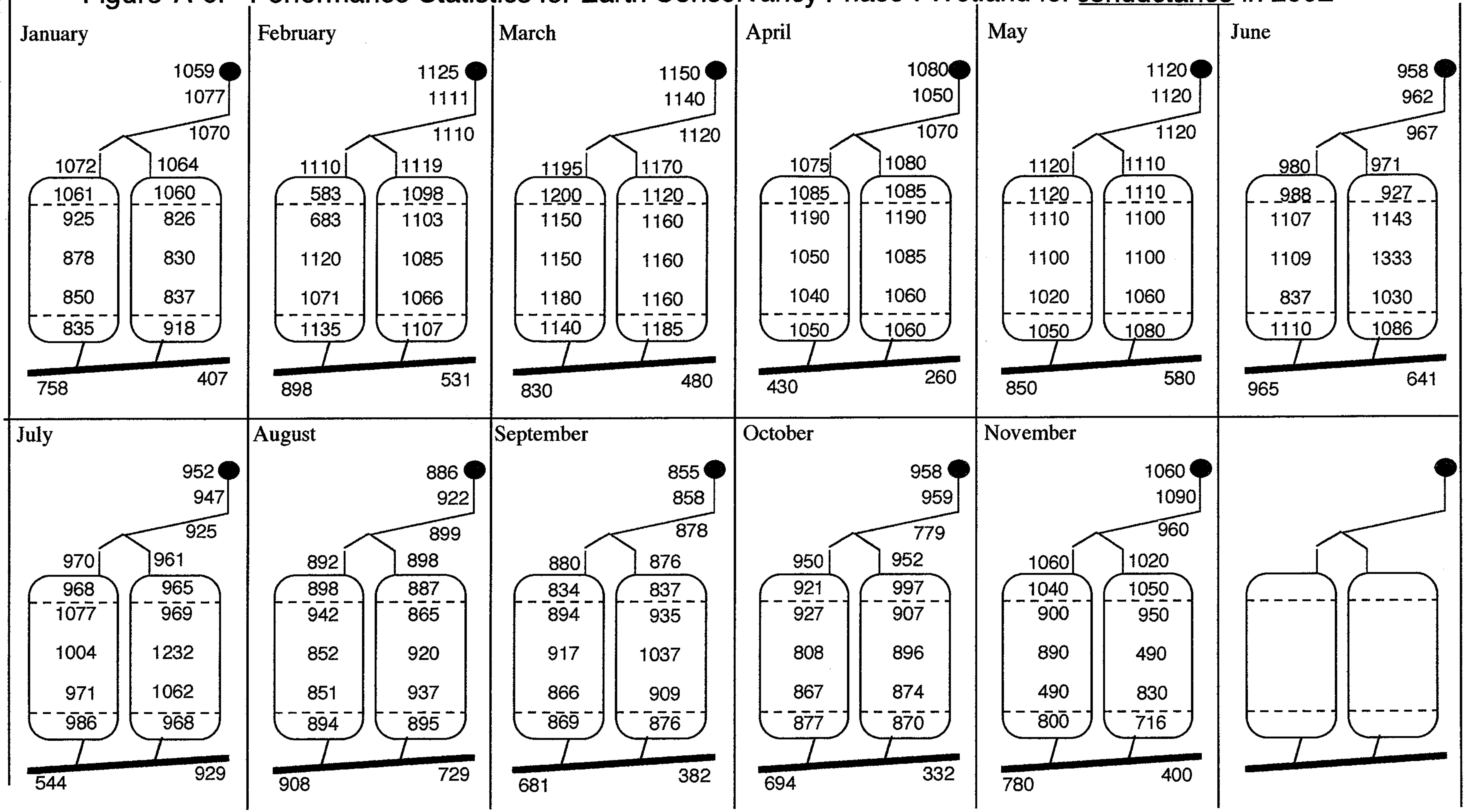
Figure A-5. Performance Statistics for Earth Conservancy Phase I Wetland for conductance in 2001



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

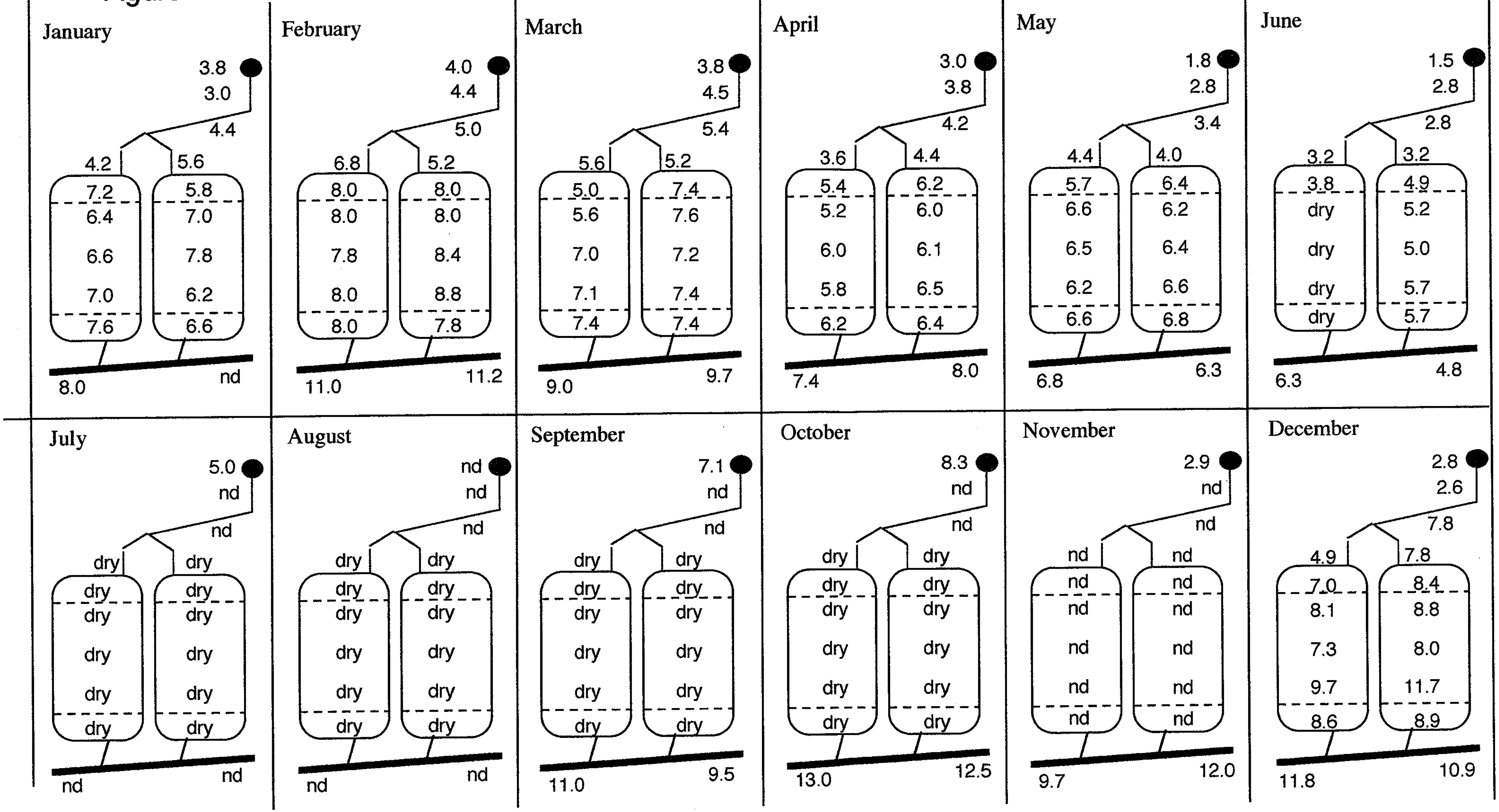
Figure A-6. Performance Statistics for Earth Conservancy Phase I Wetland for conductance in 2002



Data provided by Wilkes University Wetland Team

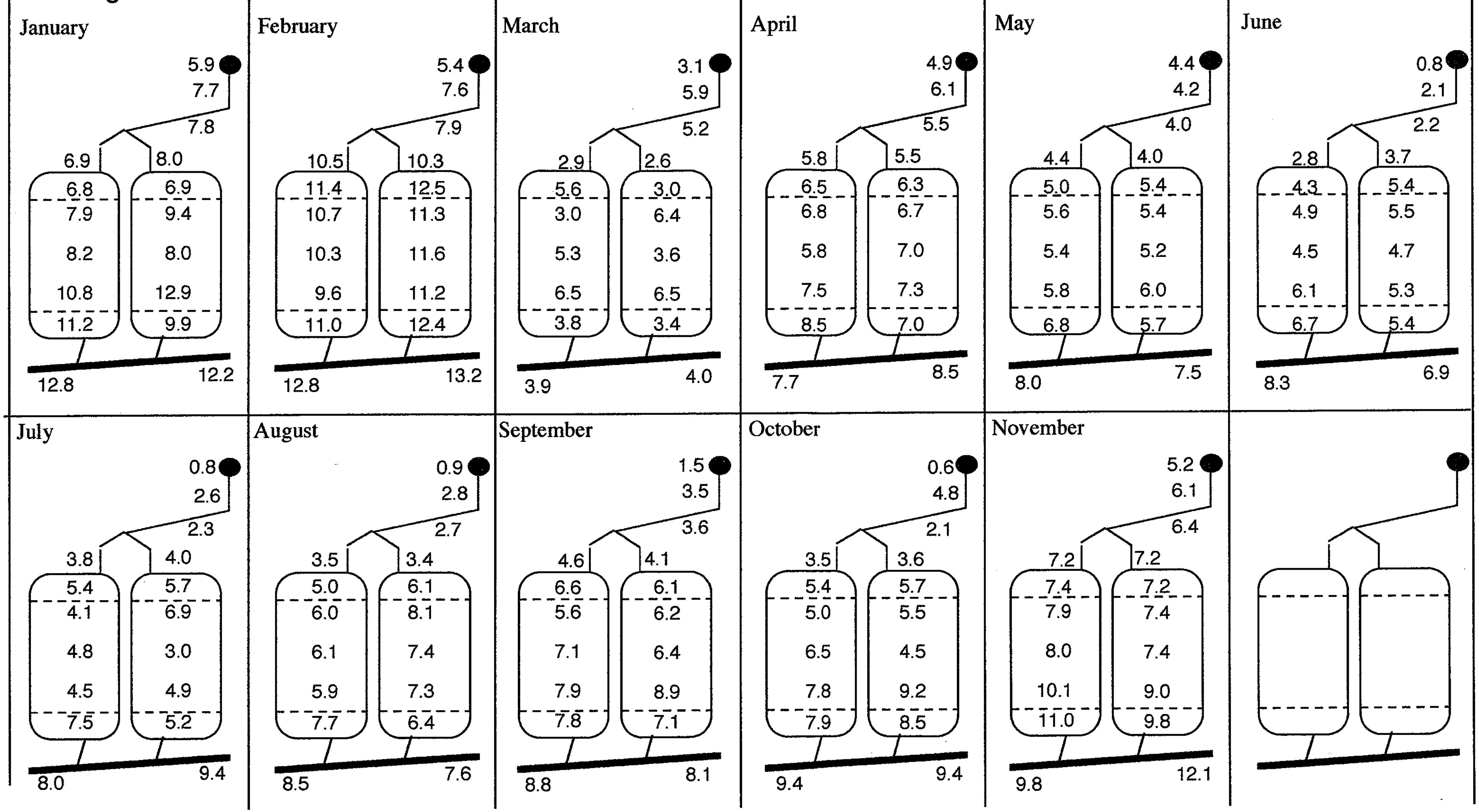
Kenneth M. Klemow, Ph.D. - Project PI, Brian Oram - WQ Lab Supervisor, Chris Watkins, John Pagoda - Technical Associates

Figure A-7. Performance Statistics for Earth Conservancy Phase I 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

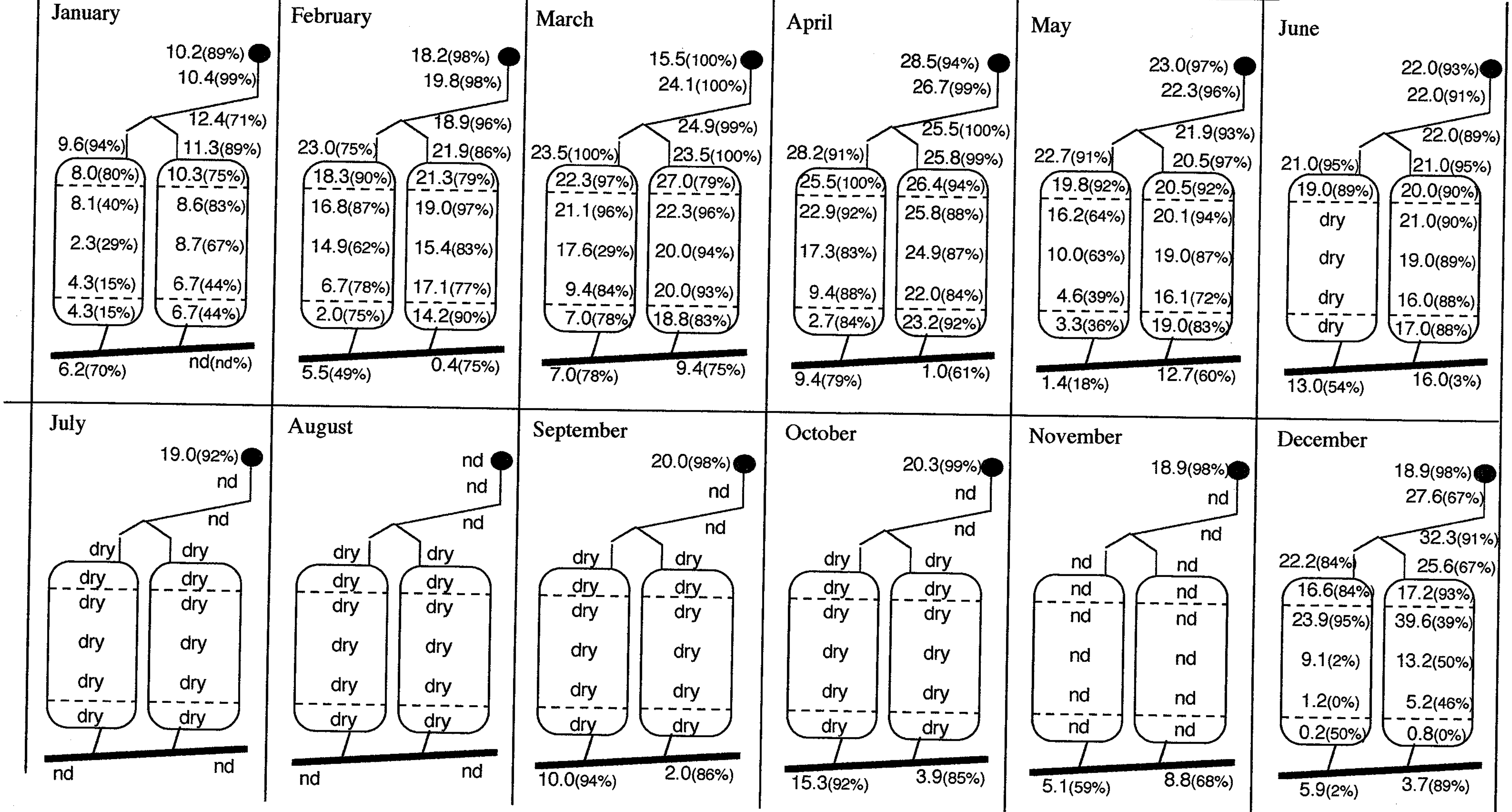
Figure A-8. Performance Statistics for Earth Conservancy Phase I Wetland for diss. oxygen in 2002



Data provided by Wilkes University Wetland Team

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

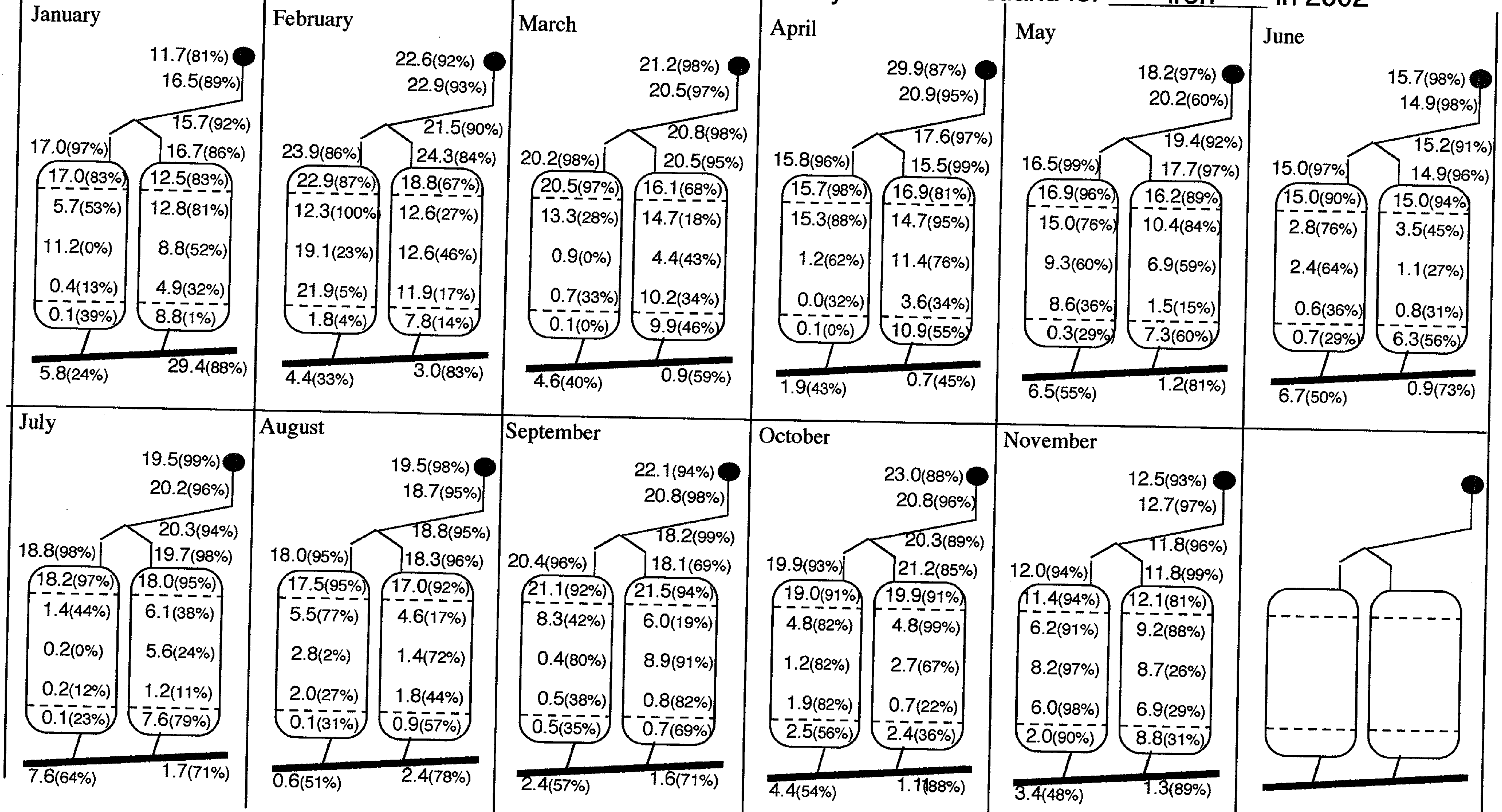
Figure A-9. Performance Statistics for Earth Conservancy Phase I Wetland for iron in 2001



Data provided by Wilkes University Wetland Team

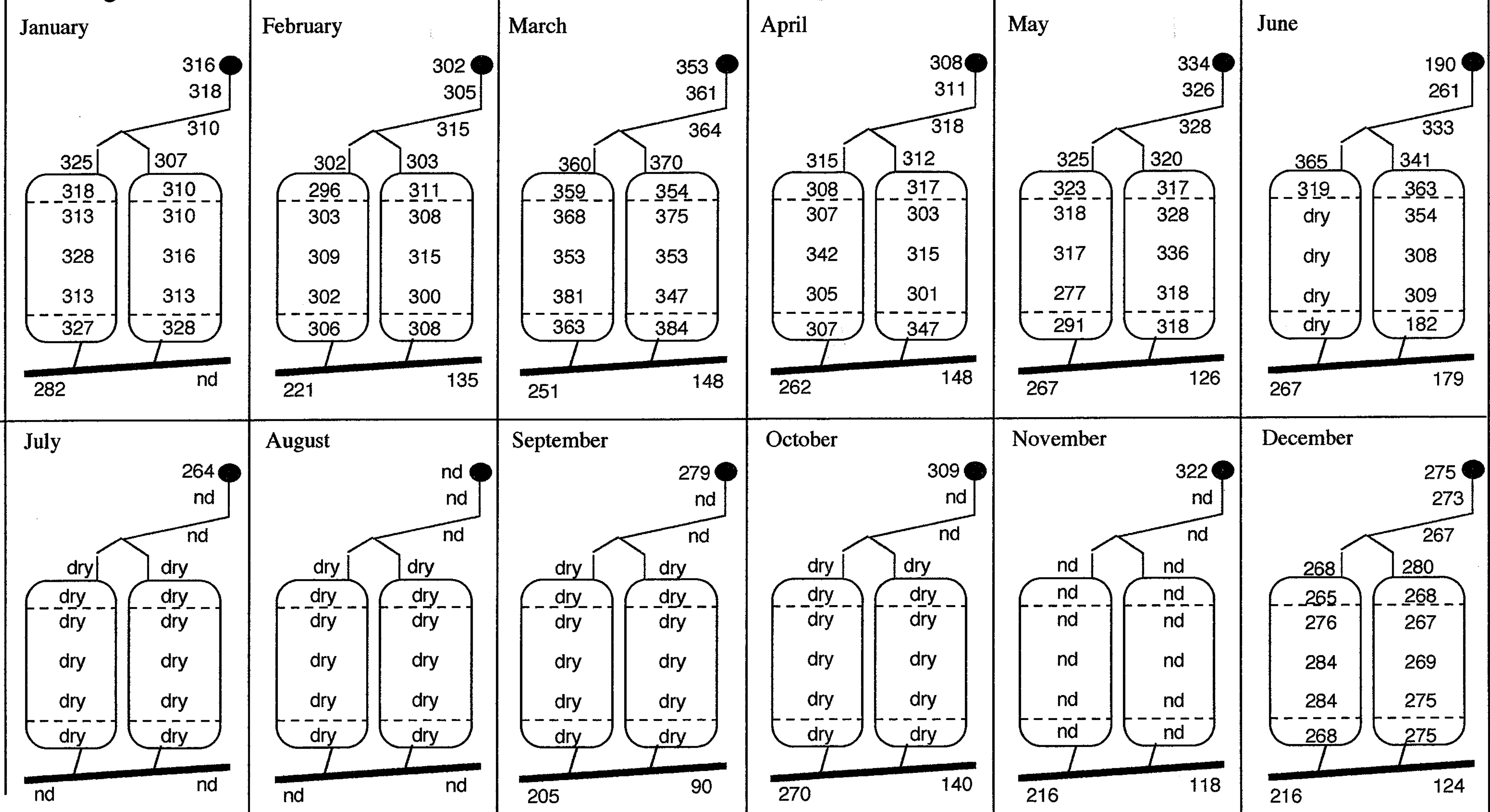
Kenneth M. Klemow, Ph.D. - Project PI, Brian Oram - WQ Lab Supervisor, Chris Watkins, John Pagoda - Technical Associates

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



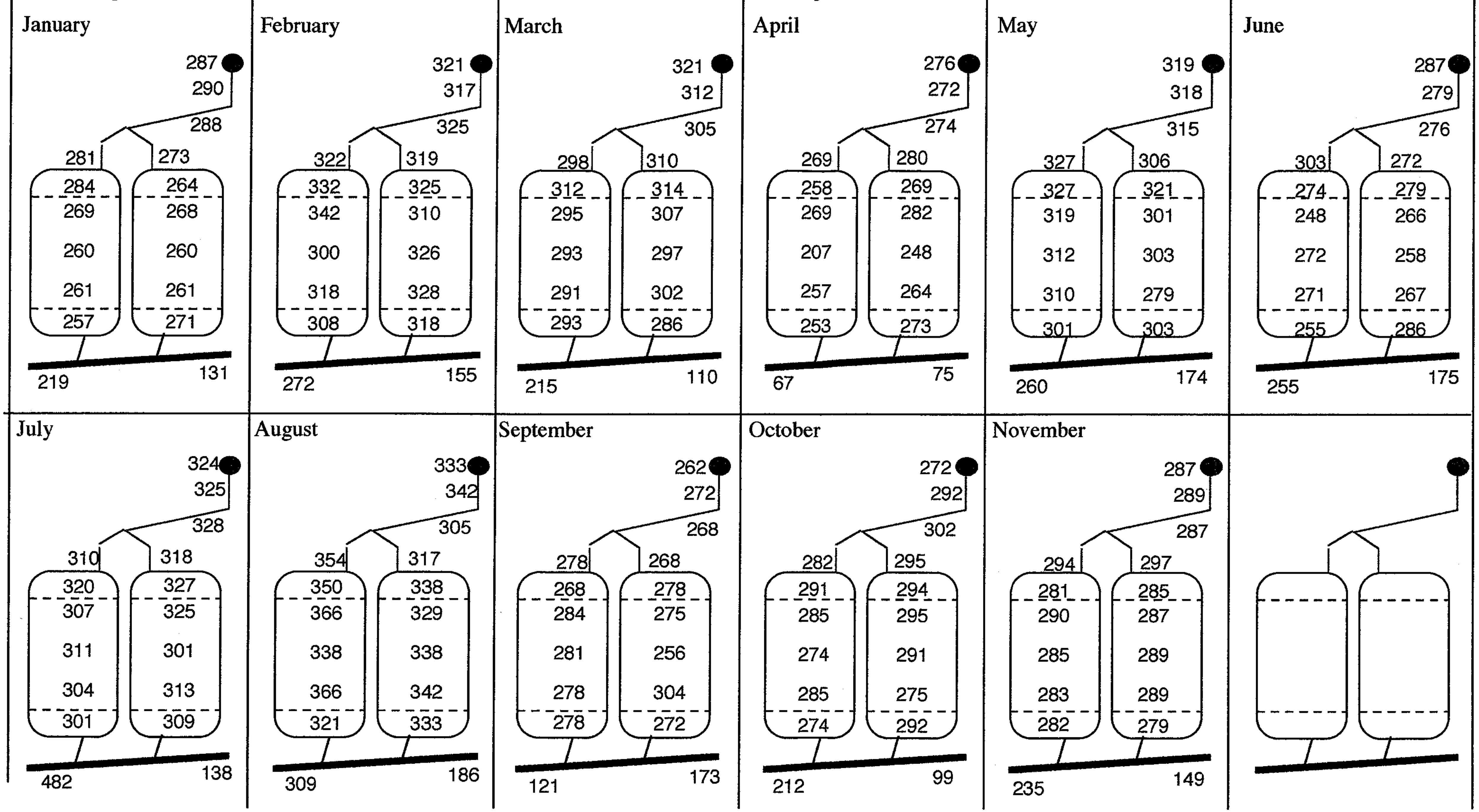
Data provided by Wilkes University Wetland Team
Kenneth M. Klemow, Ph.D. - Project PI, Brian Oram - WQ Lab Supervisor, Chris Watkins, John Pagoda - Technical Associates

Figure A-11. Performance Statistics for Earth Conservancy Phase I 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

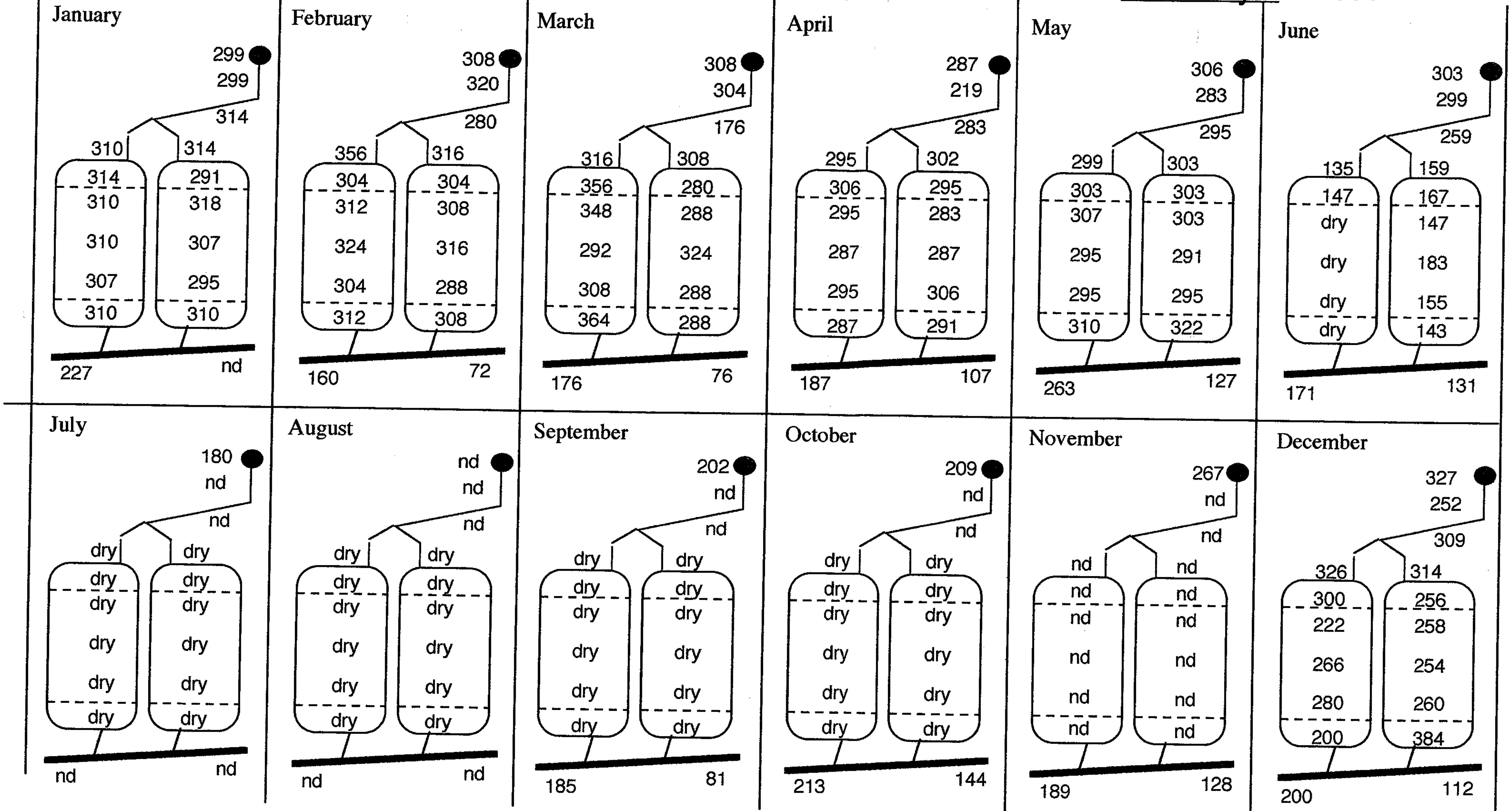
Figure A-12. Performance Statistics for Earth Conservancy Phase I Wetland for sulfate in 2002



Data provided by Wilkes University Wetland Team

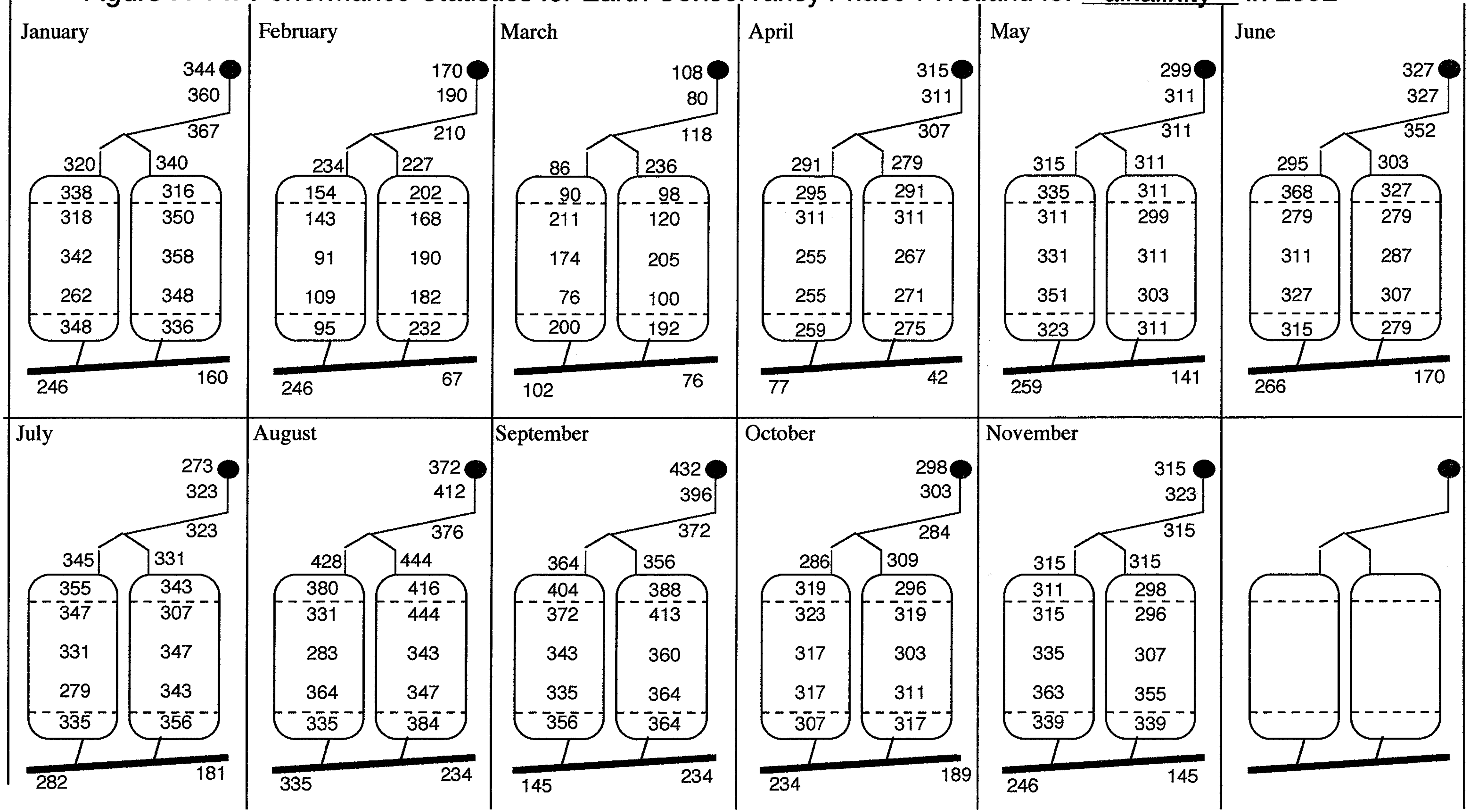
Kenneth M. Klemow, Ph.D. - Project PI, Brian Oram - WQ Lab Supervisor, Chris Watkins, John Pagoda - Technical Associates

Figure A-13. Performance Statistics for Earth Conservancy Phase I 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

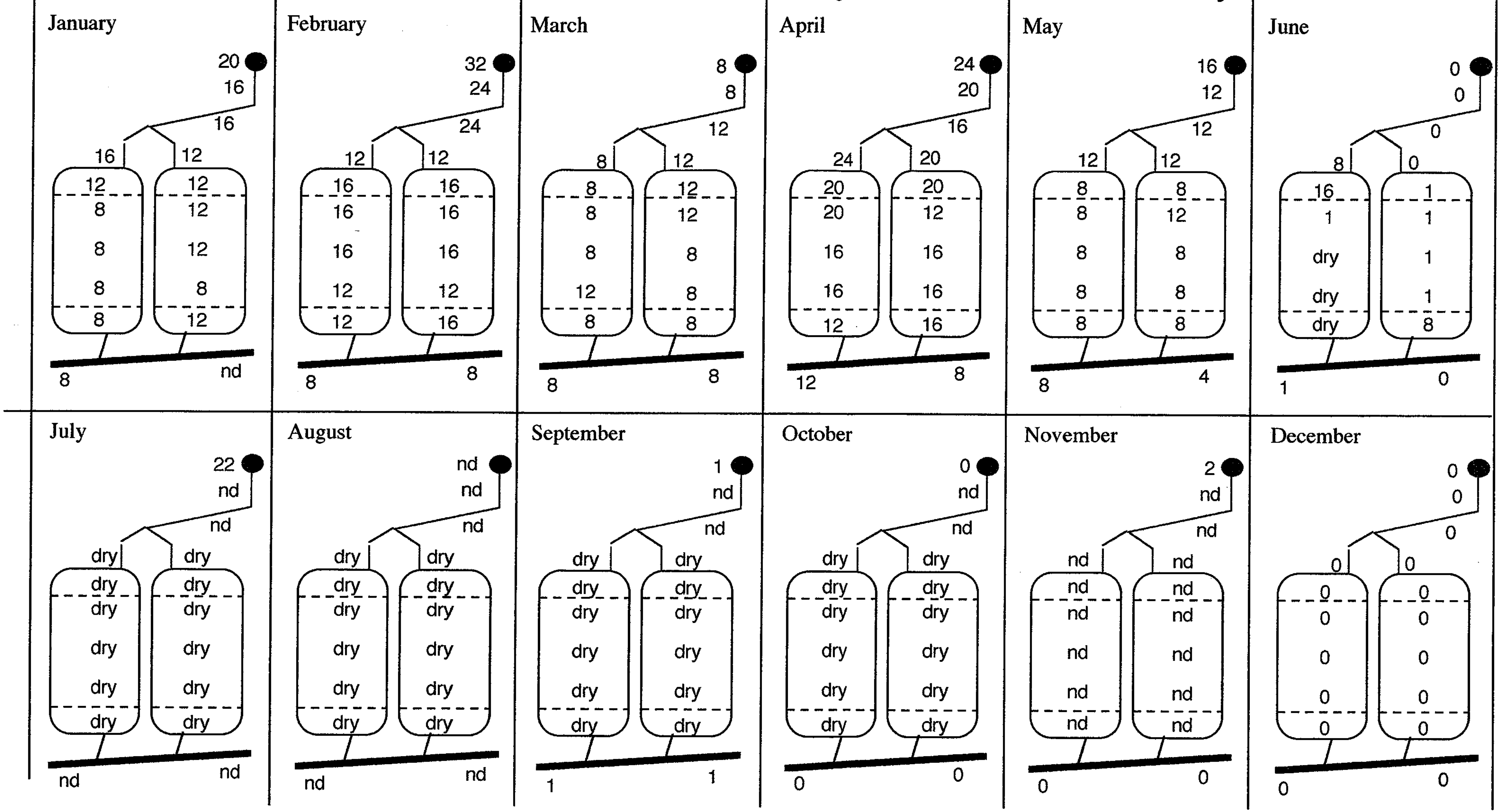
Figure A-14. Performance Statistics for Earth Conservancy Phase I Wetland for alkalinity in 2002



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

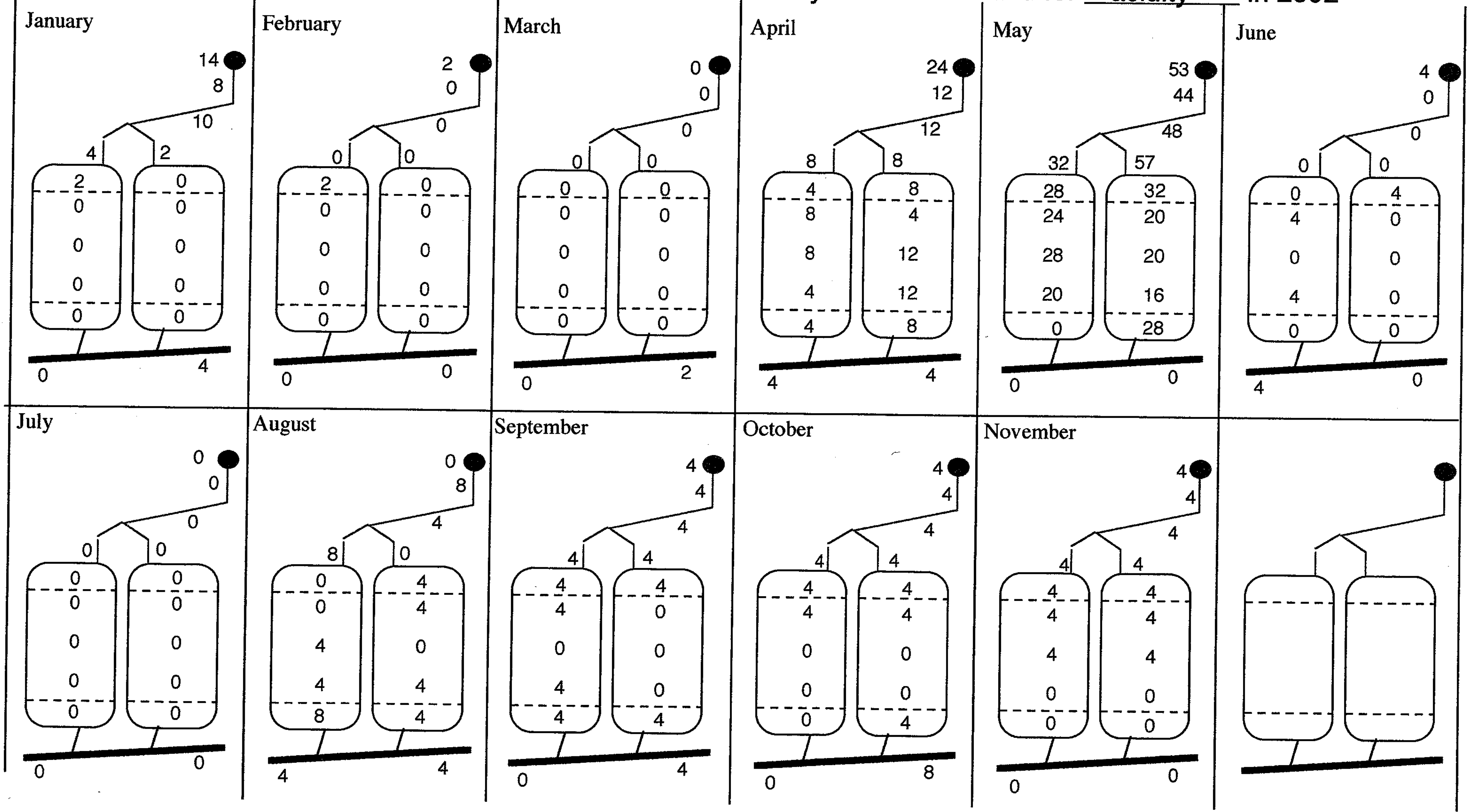
Figure A-15. Performance Statistics for Earth Conservancy Phase I Wetland for acidity in 2001



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 I Wetland for acidity in 2002



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