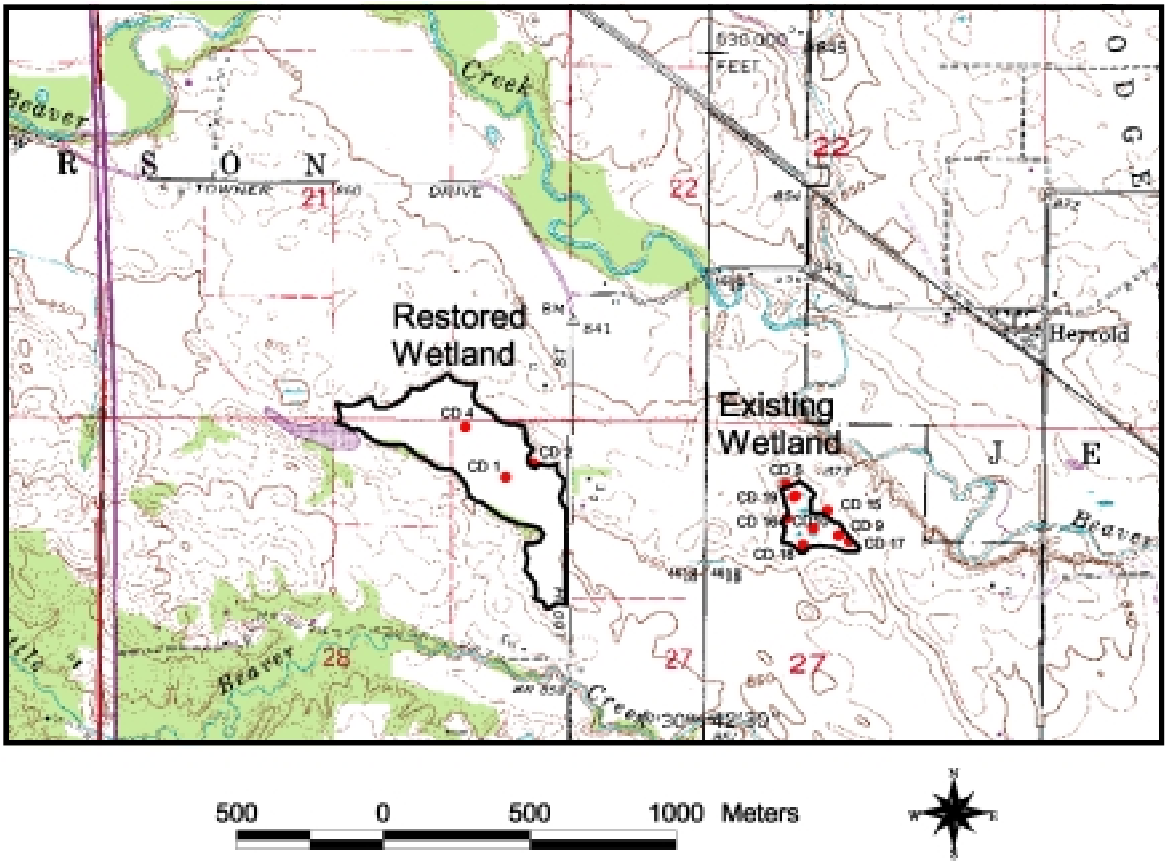
# WATER LEVEL MONITORING OF AN EXISTING WETLAND AND A RESTORED WETLAND AT CAMP DODGE 1996 - 1999

## A Summary Review

**Geological Survey Bureau**
**Technical Information Series 43**



**Iowa Department of Natural Resources**
**Lyle W. Asell, Interim Director**
**September 2000**

# WATER LEVEL MONITORING OF AN EXISTING WETLAND AND A RESTORED WETLAND AT CAMP DODGE 1996 - 1999

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**Geological Survey Bureau**
**Technical Information Series 43**

A Report of the Camp Dodge Wetland/Upland Habitat Restoration and Monitoring, Phase II Project

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**Iowa Department of Natural Resources**
**Lyle W. Asell, Interim Director**
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## 1996-1999:
## A Summary Review

**Iowa Department of Natural Resources, Geological Survey Bureau**
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R.D. Rowden, C.A. Thompson, M.C. Jones

## ABSTRACT

Camp Dodge is a 4,400-acre National Guard training facility located in central Iowa on the southern terminus of the Wisconsinan Des Moines Lobe (DML) in an area previously containing numerous prairie pothole and riparian wetlands. The advance of the DML resulted in the development of a complex of linked depressions, which may act as a relatively permeable, shallow subsurface drainage system. Land acquisitions by the facility afforded the opportunity to conduct an integrated wetland restoration with the emphasis of the study on restoring the sedge edge associated with prairie pothole wetlands. In 1995, researchers from several universities and state and federal agencies began studying the hydrology, water quality and flora and fauna of an existing prairie pothole and a previously drained wetland located within the facility. The existing wetland is located in an upland, semi-closed depression and the restoration site is located 0.5-mile northwest in an abandoned glacial outwash channel. The restoration site had been artificially drained by a tile system, which was cut at several locations in June 1996. Monitoring wells were installed at both sites, and the existing wetland served as a reference site for the restoration. This report summarizes the results of water-level monitoring at the two sites during water years (WYs) 1996-1999.

Coring was done to better understand the geomorphology and history of the sites. The restored site was dated to 9,970 ± 70 RCYBP and appears to have been active until recent times. No hiatuses were visible in the cores, although water level declines would have been expected in the middle Holocene, which was warm and dry in the study area and may have led to peat degradation. The stratigraphy is relatively continuous over the restoration site and from top to bottom consists of a dry to wet muck, a highly compressed fibric carbonate-rich peat, muck to peat with abundant shells, silty clay, highly organic muck grading to gyttja, all overlying outwash sands and gravel. The silt layer may correspond to the warm and dry period of the middle Holocene, however further dating is needed to better explain the observed sequence. The stratigraphy of the pothole from top to bottom consists of Holocene-age muck, till-derived colluvium, and then peat overlying late Wisconsinan glaciofluvial sand. The peat was dated to 11,540 ± 60 RCYBP.

Nested wells within both wetlands were instrumented with data-loggers and pressure transducers to continuously monitor changes in hydrology as the restoration progressed. Water levels at the restoration site remained below the land surface through WY 1996 and early WY 1997, then following a wet late summer-early fall, water levels rose and have remained above the land surface since February 1997. At the restoration site, surface water

levels have been essentially coincident with groundwater levels, suggesting a greater reliance on groundwater inputs. This is also indicated by few sharp increases in well water levels corresponding to precipitation events. The upland well has shown the most variation, and indicates that during most of the year groundwater is generally moving into the wetland. In the fall, during drier conditions, groundwater movement has been from the wetland into bank storage

Water-level data for the existing wetland showed less variability than the restored site during WY 1996 and early WY 1997, but greater short-term variability than the restored site during WYs 1997-1999. This is consistent with the ephemeral nature of the pothole. Sharp responses of water levels within the wetland corresponding to precipitation events suggest a greater dependence on precipitation and/or overland flow than groundwater inflows. A water budget previously developed corroborates this and shows that precipitation supplies in excess of 80% of the overall wetland budget, followed by groundwater inflow and runoff. Groundwater levels were often below the land surface during late summer and early fall when surface water was normally 2-3 feet deep in the wetland indicating net seepage out of the wetland. Well levels in both wetlands showed that local groundwater flow is generally directed from the northwest to the southeast. Water level data from upland wells near the study area also suggest that the groundwater flow in the area is from northwest to southeast.

The increasing similarity of longer-term water level responses of the upland wells in the restoration and existing sites suggests that hydrologic conditions at the restoration site are approaching a more natural balance. The more stable water levels within the restoration site during the latter half of the monitoring period suggest that the restoration site may be less ephemeral than the existing site.

The water quality of both wetlands was similar to historical water quality data and is representative of groundwater flowing through unconsolidated materials in this area of the DML. The concentrations of most ions were greater in the groundwater than in the surface water of the wetlands and generally increased toward the end of summer due to evaporative effects and decreased in the fall due to dilution from increased precipitation. The concentrations of pesticides, nitrates and phosphates were relatively low in both wetlands, probably due to the effects of dilution, volatilization and/or consumption by microorganisms within the wetlands.

The overall flow direction of groundwater in both wetlands appears to parallel Beaver Creek and may support the hypothesis of a linked-depression system. Horizontal gradients suggest that groundwater may be flowing through a shallow sand channel approximately 2-3 feet below the land surface. There may also be deeper sand channels located below the bottom of the wetlands connecting the wetlands to the larger Beaver Creek drainage system. Further study might employ a combination of ground-penetrating radar and a geographic information system to map shallow sub-surface sand bodies. Drilling transects across some of the sand bodies would confirm their structure. Data currently being collected by the Iowa Department of Natural Resources Geological Survey Bureau from monitoring wells located throughout Camp Dodge will be used to create a regional water table map, which should assist in future investigations.

## INTRODUCTION

Camp Dodge is a 4,400 acre National Guard training facility located in Johnston in central Iowa (Figure 1). With recent land acquisitions at Camp Dodge, the Environmental Planning staff at the base was interested in restoring several wetland sites as well as better managing the existing wetlands. This afforded the opportunity to conduct an integrated wetland restoration study. In 1995, researchers from the Iowa Department of Natural Resources Geological Survey Bureau (IDNR GSB) along with several universities and state and federal agencies began studying the hydrology, water quality and flora and fauna of an existing prairie pothole and a previously drained wetland, both located within the facility. The existing wetland covers approximately 5 acres and is located in an upland, semi-closed depression (Figure 2). The restoration site has a drainage area of 183 acres, with a natural storage area of about 33 acres. The site is located 0.5-mile northwest of the existing wetland in an abandoned glacial outwash channel. The drainage area to pool area ratio is 6:1, which is very low for this type of wetland. The recommended ratio would be 15 to 30 acres of drainage area to 1 acre of pool area. The area naturally has about 4 feet of storage so no additional embankment was required for the restoration.

The restoration site had been artificially drained by a tile system. A twelve-inch tile running through the central part of the basin was cut at several locations in June 1996. The end of the tile below the cuts was plugged with concrete to maintain the integrity of the tile system down gradient from the site. Tiles from terraces to the south of the wetland were also cut and allowed to outlet to the land surface up gradient of the basin. Because of the low drainage area to pool area ratio, the water table was expected to fluctuate,

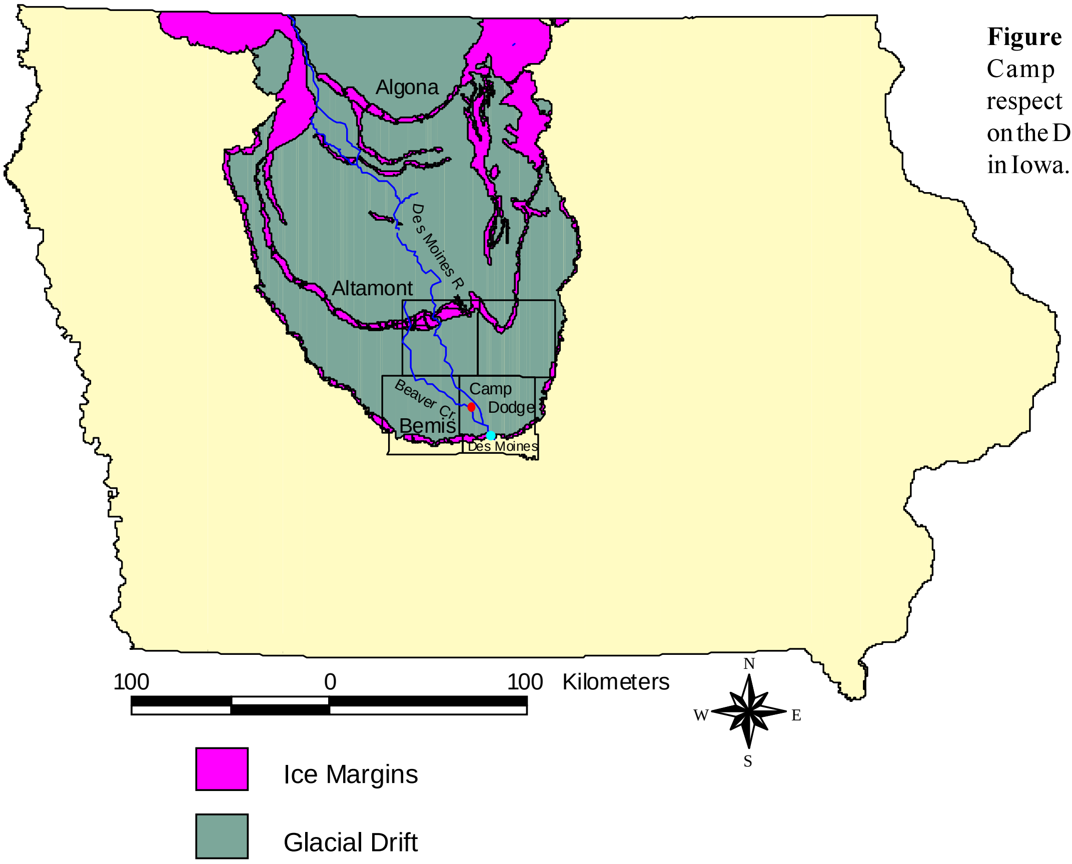

**Figure 1.** Location of Camp Dodge with respect to ice margins on the Des Moines Lobe in Iowa.

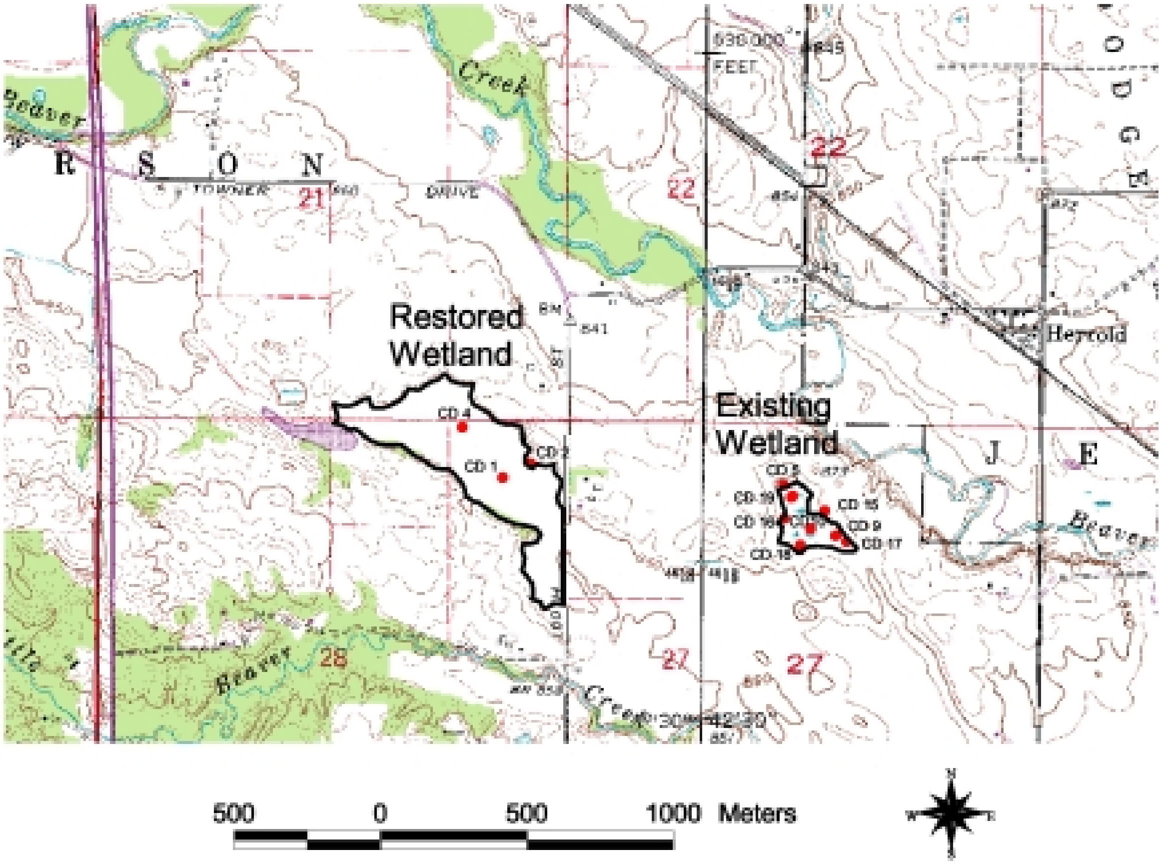

**Figure 2.** Portions of the Des Moines NW and Grimes 7.5' quadrangles showing the location of monitoring wells and well nests within the studied wetlands at Camp Dodge.

depending on the amount of precipitation the area received. Monitoring wells and instrumented well nests were installed at both sites, and the existing wetland served as a reference site for the restoration.

Wetlands are recognized as unique ecological systems, and are valued for numerous functions including surface water storage, sediment retention, water quality improvement, and local aquifer recharge as well as the classic functions of habitat for wetland-dependent species (Mitsch and Gosselink, 1993). The problem with many wetland restoration or creation projects is that, generally, they have failed to completely recreate the wetland ecosystem. Ideally wetland restorations should be measured by how well they recreate the functions of a natural wetland. In order to judge the success of a restoration project, it is necessary therefore to have a good understanding of basic functional processes. Most often, it is the hydrologic conditions that control wetland functions. Lack of a complete understanding of the basic hydrologic processes has historically limited wetland management practices and restoration efforts (Winter and Llamas, 1993).

The duration and frequency of flooding, or hydroperiod, is often used to capture the temporal dimension of "wetness". This emphasis on wetness often fails to account for non-flooded conditions in which the saturated zone moves vertically as the water table fluctuates. Small variations in topography and lithology can also affect groundwater interaction and wetland hydrology. Since the wetlands are within close proximity in the study area, these differences may be minimized, however, within a terminal moraine complex, significant changes in lithology often occur over very short distances. An understanding of wetland hydrology is important for successful restoration, yet few long-term hydrologic studies have been done on wetlands in the Midwest and Prairie States and even fewer studies have been done involving wetland restoration.

This report is a part of the Camp Dodge Wetland/Upland Restoration and Monitoring, Phase II, Project of the Iowa Army National Guard. It will focus on the hydrologic monitoring data from the existing prairie pothole and the restoration wetland during water years 1996-1999 (WYs; October 1 through September 30, designated by the calendar year in which it ends). This report will also briefly summarize the geomorphology and stratigraphy of the two wetland sites. Discussion of the flora and fauna of the wetlands and a discussion of the geomorphology and stratigraphy of the entire Camp Dodge facility will be addressed in subsequent reports. The hydrogeology and geochemistry of the existing pothole wetland are in Jones (1997).

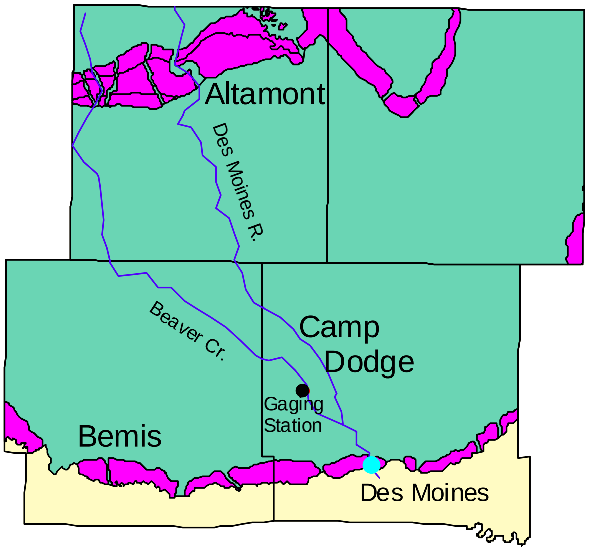

**Figure 3.** Location map of the area surrounding Camp Dodge showing the Altamont and Bemis ice margins. Also shown is the location of the U.S. Geological Survey, W.R.D. stream gaging station at Beaver Creek near Grimes, Iowa.

## WETLAND GEOMORPHOLOGY AND STRATIGRAPHY

The study area is located 9 miles north of the southern terminus of the Des Moines Lobe (DML; the name for the area in Iowa covered by the most recent glacial advance) in an area previously containing numerous prairie pothole and riparian wetlands. The Camp Dodge facility is located in the Beaver Creek watershed (Figure 3). Beaver Creek, now a tributary to the Des Moines River, was formerly a main drainageway for glacial meltwater. By 13.5ka the Des Moines Lobe glacier had retreated north of this area to the position marked by the Altamont Moraine. At this time Beaver Creek Valley served as an outwash channel carrying water and sediment from the ice margin to the pre-Wisconsin Des Moines Valley south of the DML terminus (Bettis and Hoyer, 1986).

The glacial deposits of the Dows Formation and post-glacial deposits of the DeForest Formation comprise the majority of surficial sediment in the study area (Bettis, et al., 1996). The Dows Formation is subdivided into four members, two of which are present in the uplands surrounding the wetlands: the Alden, a basal till and the Morgan, consisting of superglacial till, diamictons and associated meltwater deposits. The DeForest Formation includes the Woden Member, fine-grained colluvium and organic sediment located in semiclosed and closed depressions and the Flack Member, colluvium commonly marked by a stoneline that is discontinuous on upper slopes and becomes more continuous downslope. The Noah Creek Formation includes sand and gravel deposits found in present and abandoned stream valleys and on outwash plains. The Noah Creek may conformably or unconformably overly the Dows Formation and is unconformably buried by the DeForest Formation. Stratified diamictons of the Morgan Member are relatively thick and continuous across the uplands and sideslopes, and interfinger with the glaciofluvial sediments of the Noah Creek Formation along the outwash channel margins.

Previous geologic studies on the DML have identified a complex sequence of sediment that is the product of a stagnant, wasting glacier (Kemmis,

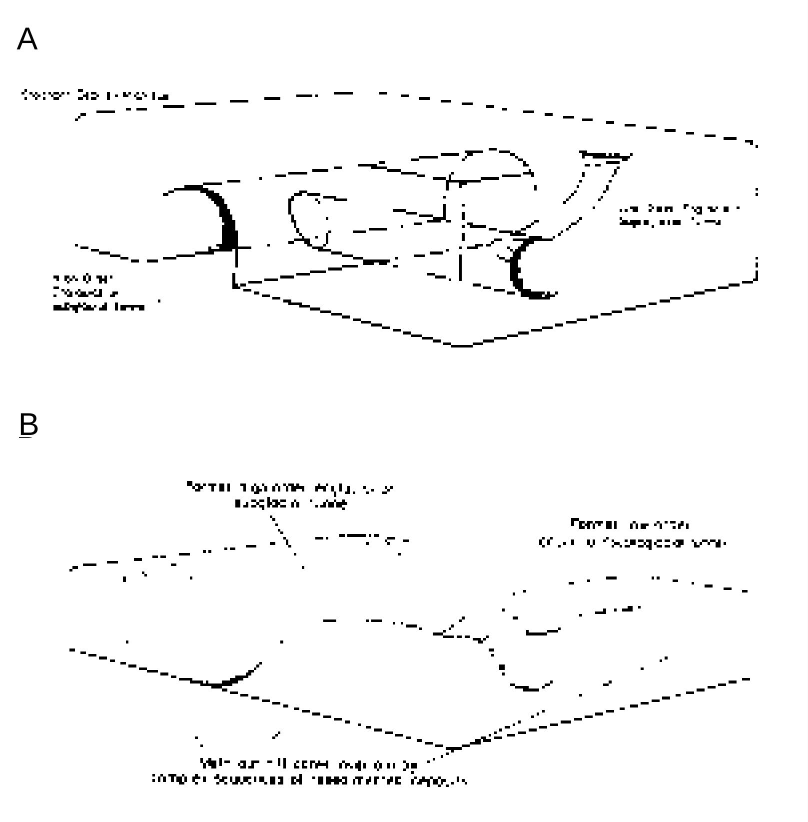

**Figure 4.** Kemmis' model for the development of linked depressions on the Des Moines Lobe showing A) the development of a glacial karst system during stagnation and B) formation of linked-depressions following tunnel collapse (from Bettis et al., 1996).

1991; Bettis et al., 1996). As the ice slowly melted, tunnels within the stagnant ice functioned as an internal drainage network. Eventually, these tunnels became clogged with stratified deposits of silt, sand and gravel, and then were covered with less sorted sediments. Shallow, porous sand and gravel bodies now occupy the former glacial tunnels and function as subsurface links between modern-day, semi-closed depressions on the land surface and successively larger surface-drainage routes. These conditions are common on the Des Moines Lobe and are referred to as linked-depression systems (Kemmis, 1991). The "linkage" generally is not visible from the land surface, but is present in the subsurface and may have important hydrologic implications. A model of a linked-depression system with three orders of drainage is shown in Figure 4. The existing wetland is located in an upland, semi-closed depression, interpreted as a former low-order tunnel. The restored wetland is in an abandoned glacial valley, interpreted as a second-order or higher drainage tunnel. Previous studies suggest that Beaver Creek was the principle drainage for central Iowa during the Bemis and Altamont glacial advances (Bettis and Hoyer, 1986). It is likely that, in the past, the existing wetland and Beaver Creek were hydrologically connected as part of a complex glacial drainage network (Jones, 1997). If the wetlands are part of a linked depression system, the linkage could significantly influence the hydrology and associated vegetative characteristics of both sites.

The general stratigraphy of the wetland study area was investigated as part of a larger, ongoing stratigraphic investigation of the entire Camp

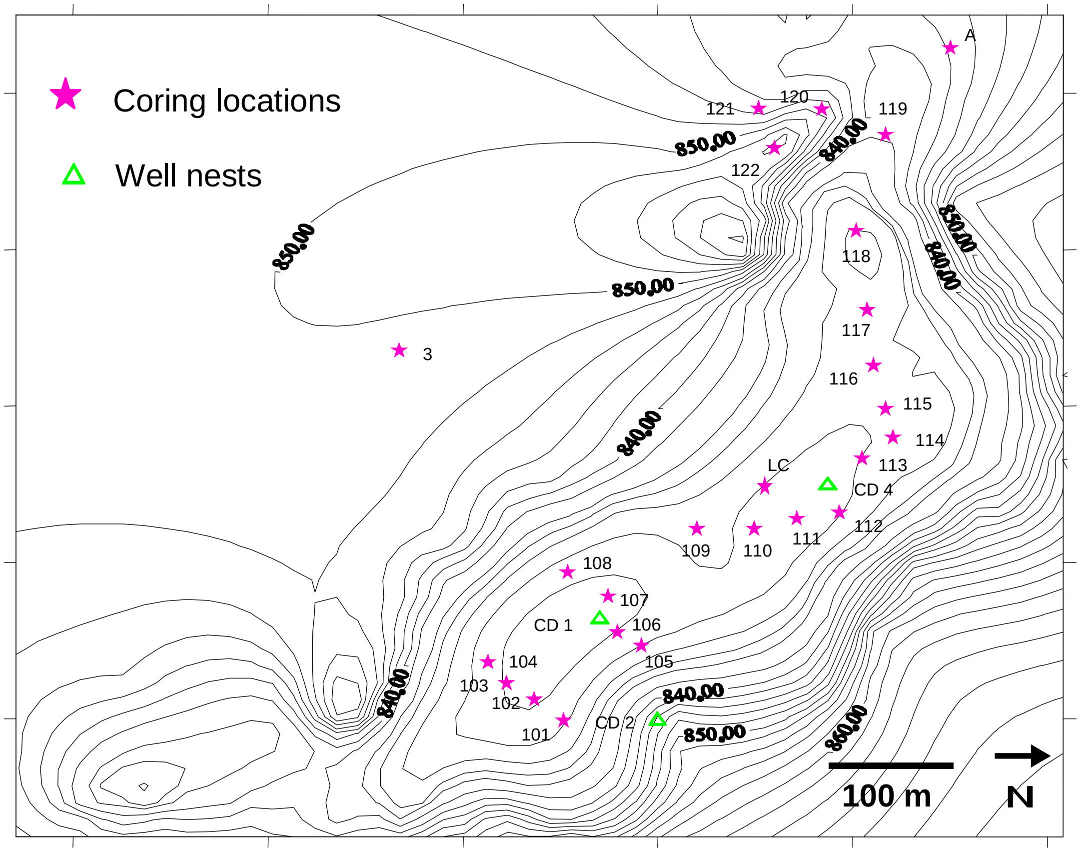

**Figure 5.** Location of core samples and well nests in the restored wetland basin with respect to topography.

Dodge facility. Information relating to the soils and unconsolidated geologic materials was reviewed from existing databases at the IDNR GSB. At the restoration site, seven core samples were collected using a Giddings hydraulic drill rig, and twenty-two core samples were collected using various hand probes (Figure 5). At the existing wetland, four Giddings core samples and twenty-seven hand probe core samples were collected (Figure 6). Radiocarbon dating was performed on one sample from the restoration site (site CD4, depth 15.4-16.7') and one sample from the existing wetland site (CD9C, depth 10.5-12.5'). More than one hundred additional core samples were taken throughout the Camp Dodge facility as part of the larger, ongoing stratigraphic study. All cores were described using modified US Department of Agriculture Natural Resources Conservation Service terminology (Soil Survey Staff, 1981). Boring logs for the existing wetland site are in Jones (1997) and boring logs for the restoration site are described in the appendix.

The upland deposits of the study area generally contain 2-25 feet of Morgan Member till, overlying 30-60 feet of Alden Member till (Bettis et al., 1996). One hilltop at the northeastern end of the existing wetland contained a very thin loess cap overlying Morgan Member till (Jones, 1997). The actual thickness of the till and depth to bedrock in the study area have not been determined.

## Restoration Site Stratigraphy

The restoration site consists of a fairly thick package of wetland sediments indicating a long period of infilling of the original basin. The site

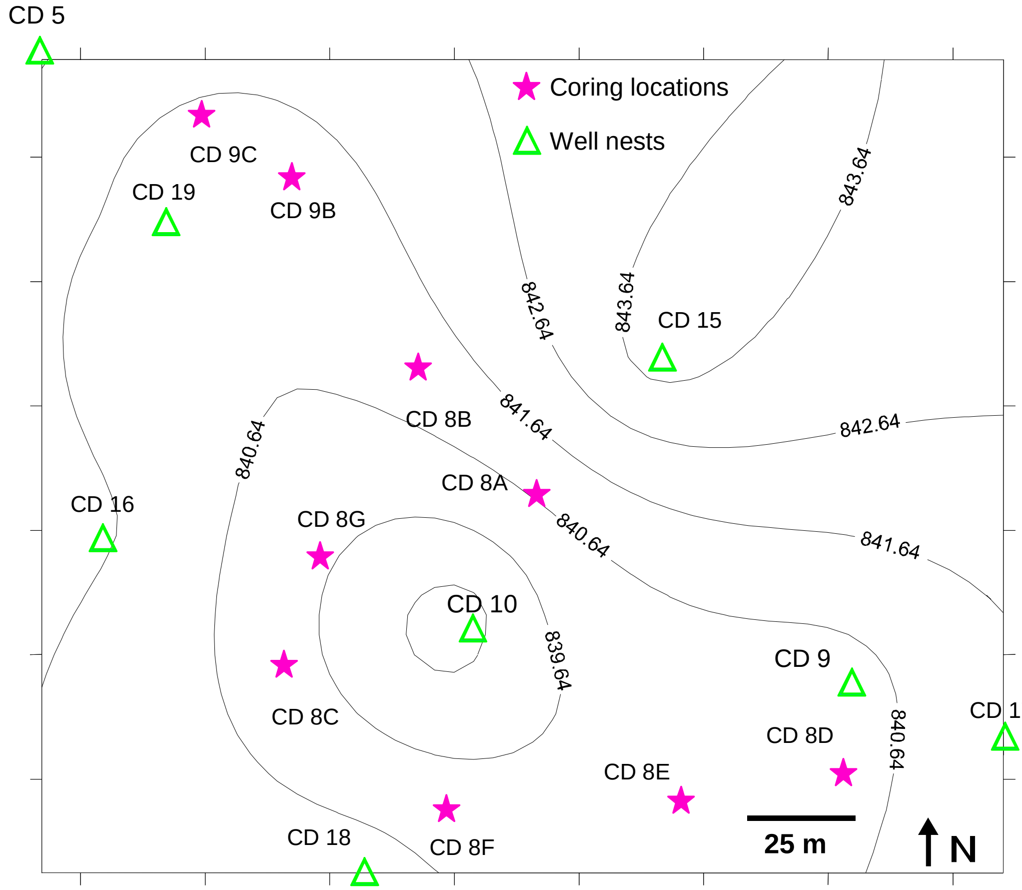

**Figure 6.** Location of core samples, wells and well nests in the existing wetland basin with respect to topography (modified from Jones, 1997).

was dated to 9,970 ± 70 RCYBP and appears to have been active until recent times. The top 10-15 inches of the site is often a dry organic soil probably reflecting the effects of drainage. This thickens to the west or in the up-gradient direction of the site. Overall, the stratigraphy is fairly consistent throughout the site, and from top to bottom consists of: dry to wet muck-soil; highly compressed fibric carbonate-rich peat; muck to peat with abundant shells; silty clay; and highly organic muck grading to gyttja-like, organic ooze, overlying outwash sands and gravel (Figure 7). In some cores, the lower muck unit may be separated into two units by another silt layer. At least one of the silt layers probably corresponds to the middle Holocene warm and dry period, however further dating is necessary to better explain the observed sequence. Similar stratigraphy has been seen in other wetlands located on the Des Moines Lobe (Baker et al., 1992). In a few cores there is evidence of a charcoal layer separating the lower ooze from the lower silt unit, again perhaps an indication of the onset of dry conditions as fire may have been likely in the prairies during an extended drought. The silt was deposited during the dry interval during brief periods of wetting or blown in from the surrounding hillsides. The compressed layer of plant debris may be related to drying of the top unit leading to dehydration and compaction of the lower unit.

The ooze layer at the bottom of the cores suggests that the site might have been a deep-water wetland during its early history. After the deposition of the silt, exchange with the underlying groundwater system may have been more limited and the character of the wetland seems to have

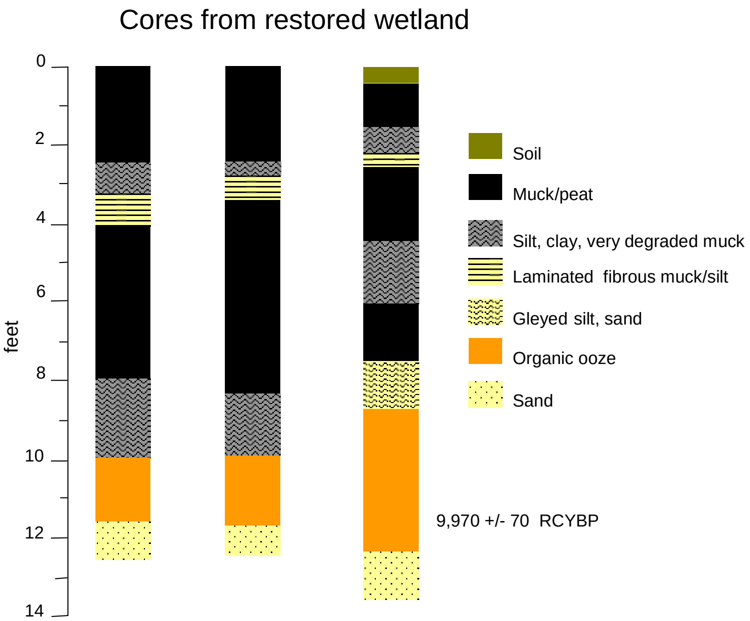

**Figure 7.** Selected cores from the restoration site (from Thompson, 1998).

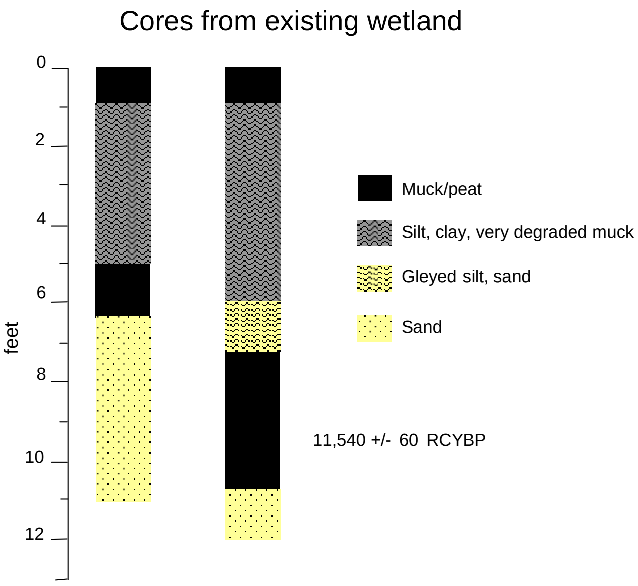

**Figure 8.** Selected cores from the existing wetland (from Thompson, 1998).

changed to a more semi-permanent to permanent shallow wetland. The muck units toward the middle of the core are somewhat fibrous indicating fairly saturated conditions. The upper muck tends to be very degraded and may reflect the reduced influence of groundwater caused by the filling of the basin and the increased reliance on precipitation, which would have led to seasonal wetting and drying cycles. Alternately, the degradation may be more recent and indicate the influence of the drainage tile.

## Existing Wetland Stratigraphy

The stratigraphy at the existing wetland consists of Holocene deposits overlying late Wisconsinan glacio-fluvial sand. Within the basin, slope-derived sediments or sapric muck overlie a clay or silt layer, which is underlain by sand and silt, then fibric muck, and finally peat over till (Figure 8). The uppermost sediments range from black soil to mucky organic rich soil, depending on the location of the core within the wetland.

Radiocarbon dating of the basal peat suggests that around 11,540±60 RCYBP the wetland contained an abundance of water which supported aquatic plant life that eventually promoted peat development (Jones, 1997). The well-sorted sand unit above the lower muck indicates that a period of significant drying occurred, perhaps coinciding with the drying period during the middle Holocene. The sand is a clean, well-sorted deposit, suggesting that during this time, the wetland was likely impacted more by wind-blown sediment, and organic accumulation was at a minimum. This conclusion seems reasonable since the thin sand layer is found throughout the wetland basin bottom at approximately the same depth (Jones, 1997). The uppermost silt and muck units indicate that there have been Holocene climatic fluctuations, causing the wetland to be ephemeral, impacting the organic accumulation within the basin and accelerating organic decomposition.

## Stratigraphic Implications

The basin stratigraphy of the existing and restoration sites can be explained in the context of the regional paleoclimate setting. Previous investigations using plant macro fossils, pollen, and stalagmites all indicate that there was a significant drying period in the middle Holocene in eastern Iowa from approximately 7,000 to 3,000 YBP (Baker et al., 1992, Dorale et al., 1992). The core samples from both study areas contain intervals that appear to coincide with the middle Holocene drying period. Cores from other wetlands (Colo Marsh and Jewell Bog) also show two distinct muck units with the younger starting to form about 4000 YBP. The change in climate appears to have impacted organic accumulation and accelerated organic decomposition in both basins.

The stratigraphic setting and character of sediments in and around the two wetlands may reveal information about the factors that control the hydroperiod of the wetlands. The sediment in the existing and restored wetlands shows that in the recent past both were seasonal to semi-permanent wetlands. The uppermost layer in both sites consists of sapric muck. This sediment may act as a sealing layer during wet conditions when groundwater is at or near the land surface and the sediment pore spaces are saturated (Jones, 1997). As the wetland dries out, mud cracks develop and the upper seal is broken, allowing water to percolate down into the lower sand unit at an accelerated rate. Mud cracks may persist even after rains resume. At the existing wetland, mud cracks which developed at the beginning of September 1996 were still apparent in late October, following seven days of light to moderate rainfall, totaling about 3 inches (Jones, 1997). Since evaporation and evapotranspiration are limited during late autumn, it is probable that the precipitation seeped into the ground through the cracks rather than causing re-wetting of the muck. When the uppermost muck becomes saturated again, the mud cracks close, the seal reforms, and the wetland holds water.

## HYDROLOGIC MONITORING

The quantity of groundwater and surface-water recharge that moves into the wetland sites is primarily controlled by the amount, timing, and intensity of precipitation and snowmelt that falls within the basin areas. The volume of groundwater and surface-water leaving the wetlands is a function of the amount of evaporation, evapotranspiration and seepage out of the basin areas. Climatic variations, along with antecedent conditions, exert a major control on the water budgets of the restoration and existing sites.

### Precipitation

Monthly precipitation and departure from normal for WYs 1996-1999 are shown in Figure 9. Precipitation data for WYs 1996-1999 were calculated using data from the Iowa Department of Agriculture and Land Stewardship, State Climatology Office (IDALS, SCO) Camp Dodge weather station, located 2.5 miles north of the northern edge of Camp Dodge. The Camp Dodge station began collecting precipitation data in August 1993. Since there is no long-term record, monthly departures from normal were calculated using precipitation totals from the Camp Dodge weather station and the 30 year long-term averages from the IDALS-SCO Ankeny weather station located at the Ankeny waste treatment plant a few miles southeast of the base.

Following a dry WY 1994 and a near normal WY 1995, WY 1996 was relatively dry. The annual precipitation total for the Camp Dodge study area was 26.97 inches, or 84% of the long-term average precipitation of 33.12 inches for the Ankeny weather station. The annual precipitation for WY 1997 was 31.72 inches, or 99% of the long-term average and the annual precipitation for WY 1998 was 42.26 inches, or 131% of the long-term average. Water Year 1999 had 34.19 inches of precipitation, or 106% of the long-term annual average.

Table 1 shows monthly precipitation totals and departure from normal for WYs 1996-1999 for the Camp Dodge area. The monthly totals showed large deviations from normal. During WY 1996,

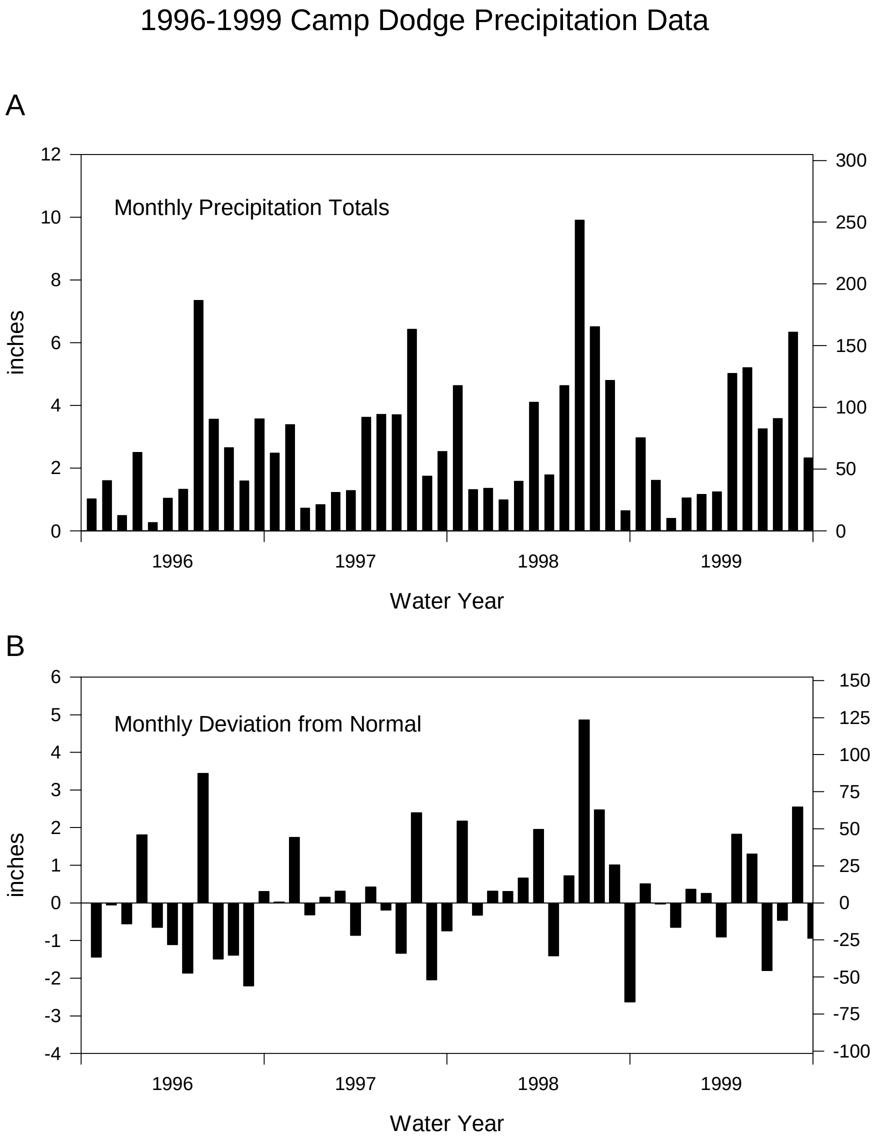

**Figure 9.** A) Monthly precipitation totals and B) departure from normal for the Camp Dodge study area, WYs 1996-1999 (Iowa Dept. of Ag. and Land Stewardship, State Climatology Office).

the totals for January and May were considerably greater than normal and the totals for October, December, February, March, April, and August were considerably smaller than normal. The wettest January and the driest February during the four-year monitoring period occurred in WY 1996. In WY 1997, the precipitation totals for November, January, February, April and July were greater than normal and the totals for December, March, May, June, August, and September were smaller than normal. The wettest month of the water year was November and the driest month was August. During WY 1998, all months, except for November, April and September, had greater than normal precipitation. June was the wettest month of the water year and September was the driest. In WY 1999, precipitation was below normal in November, December, March, June, July, and September. The driest month of the water year was December and the wettest month was August. This was the

**Table 1.** Monthly precipitation, departure from normal and percentage of normal for Camp Dodge for Water Years 1996-1999.

| Water Year 1996 | Camp D. precip inches | Departure from normal inches* | % of normal* | Water Year 1997 | Camp D. precip inches | Departure from normal inches* | % of normal* |
|---|---|---|---|---|---|---|---|
| Oct-95 | 1.02 | -1.44 | 41% | Oct-96 | 2.48 | 0.02 | 101% |
| Nov-95 | 1.60 | -0.05 | 97% | Nov-96 | 3.39 | 1.74 | 205% |
| Dec-95 | 0.49 | -0.56 | 47% | Dec-96 | 0.73 | -0.32 | 70% |
| Jan-96 | 2.50 | 1.81 | 362% | Jan-97 | 0.84 | 0.15 | 122% |
| Feb-96 | 0.27 | -0.65 | 29% | Feb-97 | 1.23 | 0.31 | 134% |
| Mar-96 | 1.04 | -1.11 | 48% | Mar-97 | 1.29 | -0.86 | 60% |
| Apr-96 | 1.33 | -1.87 | 42% | Apr-97 | 3.62 | 0.42 | 113% |
| May-96 | 7.35 | 3.44 | 188% | May-97 | 3.72 | -0.19 | 95% |
| Jun-96 | 3.56 | -1.49 | 70% | Jun-97 | 3.71 | -1.34 | 73% |
| Jul-96 | 2.65 | -1.39 | 66% | Jul-97 | 6.43 | 2.39 | 159% |
| Aug-96 | 1.59 | -2.20 | 42% | Aug-97 | 1.75 | -2.04 | 46% |
| Sep-96 | 3.57 | 0.30 | 109% | Sep-97 | 2.53 | -0.74 | 77% |
| TOTAL | 26.97 | -5.21 | 84% | TOTAL | 31.72 | -0.46 | 99% |

| Water Year 1998 | Camp D. precip inches | Departure from normal inches* | % of normal* | Water Year 1999 | Camp D. precip inches | Departure from normal inches* | % of normal* |
|---|---|---|---|---|---|---|---|
| Oct-97 | 4.63 | 2.17 | 188% | Oct-98 | 2.97 | 0.51 | 121% |
| Nov-97 | 1.32 | -0.33 | 80% | Nov-98 | 1.62 | -0.03 | 98% |
| Dec-97 | 1.36 | 0.31 | 130% | Dec-98 | 0.40 | -0.65 | 38% |
| Jan-98 | 0.99 | 0.30 | 143% | Jan-99 | 1.05 | 0.36 | 152% |
| Feb-98 | 1.58 | 0.66 | 172% | Feb-99 | 1.17 | 0.25 | 127% |
| Mar-98 | 4.10 | 1.95 | 191% | Mar-99 | 1.25 | -0.90 | 58% |
| Apr-98 | 1.79 | -1.41 | 56% | Apr-99 | 5.02 | 1.82 | 157% |
| May-98 | 4.63 | 0.72 | 118% | May-99 | 5.21 | 1.30 | 133% |
| Jun-98 | 9.91 | 4.86 | 196% | Jun-99 | 3.25 | -1.80 | 64% |
| Jul-98 | 6.51 | 2.47 | 161% | Jul-99 | 3.58 | -0.46 | 89% |
| Aug-98 | 4.80 | 1.01 | 127% | Aug-99 | 6.34 | 2.55 | 167% |
| Sep-98 | 0.64 | -2.63 | 20% | Sep-99 | 2.33 | -0.94 | 71% |
| TOTAL | 42.26 | 10.08 | 131% | TOTAL | 34.19 | 2.01 | 106% |

* Departure from normal and % of normal were calculated using precipitation totals from the Camp Dodge station and long-term monthly averages from the Ankeny station.

wettest August during the four-year monitoring period.

June, with an average precipitation of 5.05 inches for 1968-1998, has typically been the wettest month in the Camp Dodge area. The precipitation totals for June were 70% of normal in WY 1996, 73% of normal in WY 1997, 196% of normal in WY 1998 and 64% of normal in WY 1999.

The March through June period is typically marked by low evapotranspiration and wet antecedent conditions, and is important for groundwater recharge. The precipitation totals for the March through June period were 83% of normal in WY 1996, 85% of normal in WY 1997, 140% of normal in WY 1998 and 103% of normal in WY 1999.

## Methods

In June 1995, the IDNR GSB installed three

**Table 2.** Well depth, depth to the top of the screened interval, stratigraphic unit of the screened interval, and in situ hydraulic conductivity of wells in the restored and existing wetlands.

| Well Name | Total Well Depth (feet) | Depth to Top of Screened Interval (feet) | Stratigraphic Unit of Screened Interval | In situ Hydraulic Conductivity | |
|---|---|---|---|---|---|
| | | | | (ft/sec) | (cm/sec) |
| <u>Restoration site</u> | | | | | |
| CD 1A | 20.52 | 18.52 | medium to fine sand | n/a | n/a |
| CD 1B | 9.73 | 7.73 | sandy muck | n/a | n/a |
| CD 1C | 5.28 | 3.28 | compressed muck | n/a | n/a |
| CD 2A | 33.55 | 31.55 | medium to fine sand | n/a | n/a |
| CD 2B | 20.70 | 15.70 | bedded pebbly loam | n/a | n/a |
| CD 4A | 20.52 | 18.52 | fine sand | n/a | n/a |
| CD 4B | 9.73 | 7.73 | silty clay | n/a | n/a |
| <u>Existing site</u> | | | | | |
| CD 5A | 12.76 | 7.76 | muck | $32.48*10^{-9}$ | $(9.9*10^{-7})$ |
| CD 5B | 6.64 | 1.65 | muck | $3.60*10^{-8}$ | $(1.1*10^{-6})$ |
| CD 9A | 12.26 | 7.26 | sand | $13.45*10^{-8}$ | $(4.1*10^{-6})$ |
| CD 9B | 7.30 | 2.30 | muck | n/a | n/a |
| CD 10A | 21.06 | 16.06 | peat | n/a | n/a |
| CD 10B | 8.10 | 3.10 | muck | n/a | n/a |
| CD 15 | 8.88 | 7.70 | fine sand | $6.89*10^{-8}$ | $(2.4*10^{-6})$ |
| CD 16A | 10.99 | 9.82 | medium sand | $3.94*10^{-7}$ | $(1.2*10^{-5})$ |
| CD 16B | 5.10 | 4.10 | sand with black muck | n/a | n/a |
| CD 17A | 7.62 | 6.45 | gleyed clay | n/a | n/a |
| CD 17B | 4.87 | 3.87 | muck | n/a | n/a |
| CD 18A | 6.70 | 5.53 | medium sand | $8.86*10^{-7}$ | $(2.7*10^{-5})$ |
| CD 18B | 5.14 | 4.14 | gray/tan clay w/ CaCO3 nodules | $8.86*10^{-7}$ | $(2.7*10^{-5})$ |
| CD 19A | 12.70 | 11.53 | peaty/gyttia | n/a | n/a |
| CD 19B | 6.55 | 5.39 | muck/silt interface | n/a | n/a |
| CD 19C | 16.03 | 14.87 | medium sand | n/a | n/a |

monitoring well nests at the restoration site and two well nests at the existing wetland, using a Giddings drill rig (figures 5 and 6). At the restoration site, well nest CD 1 includes three wells, and well nests CD 2 and CD 4 include two wells at each site (Table 2). At the existing wetland, well nests CD 5 and CD 9 include two wells at each site. In the spring of 1996, five additional well nests, CD 10, CD 16, CD 17 and CD 18, which include two wells at each site, and CD 19 which includes three

**Figure 10.** Well platform at site CD 4 within the restoration site. Shown are the data logger enclosure, surface water stilling well and solar panel (photo by Carol Thompson).

**Figure 11.** Well platform at site CD 9 within the existing wetland. Wells CD 17A and 17B are visible in the background towards the right (photo by Carol Thompson).

**Figure 12.** Well site CD 2 within the restoration site. Shown are the data logger enclosure and solar panel with well CD 2B at left and well CD 2A at right (photo by Carol Thompson).

wells, and an individual well, CD 15, were installed at the existing wetland using hand soil probes. The monitoring wells that were installed around the edge of the pond were back filled to approximately one foot above the screened interval with sand, and sealed with approximately two feet of medium bentonite chips. The wells that were installed below the water surface within the existing wetland were not back filled with sand or capped with bentonite. Instead, hand probes with diameters of 0.5 inches less than the well casing diameters were used and the well casings were then driven into the boreholes, creating a natural seal. Total well depth, depth to the top of the screened interval, and the stratigraphic unit into which the wells are screened, are shown in Table 2. All wells were developed shortly after installation by pumping or bailing the wells dry and allowing them to recharge.

Selected well nests were instrumented with Campbell Scientific CR10X data loggers housed in fiberglass enclosures with KPSI isolated diaphragm pressure transducers installed in each monitoring well. Wooden platforms were used at well nests CD 1, CD 4, CD 9 and CD 10 to hold the equipment enclosures and allow servicing of the wells above the water surface (figures 10 and 11). At well nests CD 2 and CD 5, which were up gradient and normally out of the water, the monitoring enclosures were mounted on metal fence posts (Figure 12). Hourly data on wind speed and air temperature was recorded at site CD 9 using a Campbell Scientific 014 wind-speed anemometer and a 107/107B temperature probe. Lengths of 5 inch diameter well screen were driven into the muck and attached to the well nest platform at site CD 9 within the existing wetland in June 1996, and at sites CD 1 and CD 4 within the restoration site in June 1997. The well screens were used as stilling wells and instrumented with Stevens float and tape recorders to monitor surface water levels. On 07/31/97, the recorder at CD 4 was replaced with a Geokon vibrating wire pressure transducer and the recorder at CD 1 was discontinued.

In late April 1998, a grass fire at the restoration site melted the top five-foot section of well CD 2B. The top section of the well was replaced, and the enclosure and transducers were removed and relocated to well nest CD 10 in the existing wetland on 05/11/98. Following the removal of the instrumentation, the groundwater levels of wells CD 2A and CD 2B were measured monthly. The Stevens recorder at CD 10 was replaced with an Instrumentation Northwest pressure transducer on 06/30/98. On 05/13/98, the CD 9 platform blew over during the worst windstorm in Iowa’s recorded history and well CD 9A broke off at ground level. The instrumentation was removed and repaired, and then replaced on 07/21/98. Monitoring well CD 9A was replaced on 08/07/98.

Topographic surveying at both sites was done by stadia rod, using a theodolite loaned from the Geography department at the University of Iowa. All monitoring wells within the restoration and existing sites were surveyed by the IDNR Construction Services Bureau using a SOKKIA total station laser theodolite. Monitoring well elevations were taken from the top of the PVC well casings and referenced to an arbitrary on-site datum. Field water levels were measured with a hand held e-line (depth to water level meter) from the top of the well casings and recorded as negative numbers. At the instrumented sites, data loggers measured groundwater levels every minute and recorded the data every hour. The recorded water level measurements were corrected to true elevation by subtracting the depth to groundwater measurement from the elevation of the top of the casing. Groundwater levels recorded by the data loggers were corrected to the field measurements on a monthly basis. Transducer drift over extended periods of time was corrected by using incremental datum corrections between the monthly field verified measurements. At the existing wetland, groundwater levels of uninstrumented wells were measured weekly to biweekly from April 1996 to October 1996 and again from February 1997 to June 1997 (Jones, 1997). After June 1997, groundwater levels at the uninstrumented wells were measured monthly. It was sometimes not possible to obtain measurements during November, December, and January due to the presence of ice in the wells. All groundwater measurements, as well as slug and/or bail tests within the existing

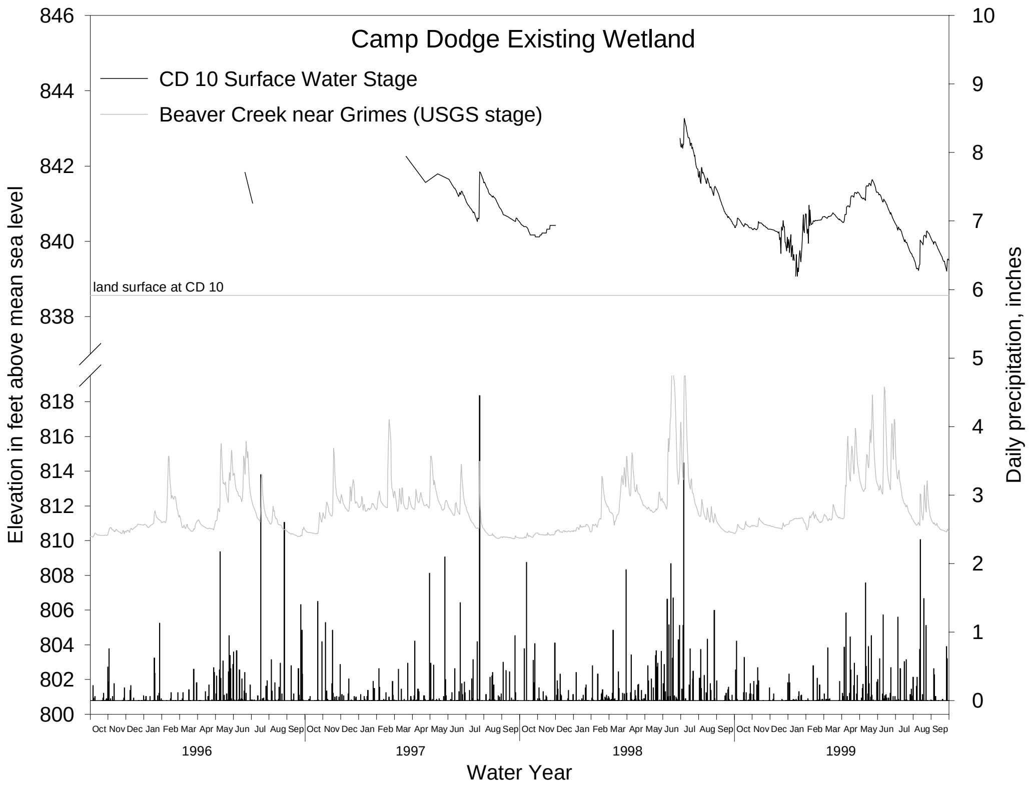

**Figure 13.** Surface water stage relative to land surface elevation of the existing wetland at site CD 10, WYs 1996-1999. Also shown is the stage of Beaver Creek near Grimes, Iowa and daily precipitation totals for the Camp Dodge study area, WYs 1996-1999 (Beaver Creek stage data are from the U.S. Geological Survey, W.R.D., IA Dist and precipitation data are from the Iowa Dept. of Ag. and Land Stewardship, State Climatology Office).

wetland through June 1997, including plots over time are in Jones (1997).

## MONITORING RESULTS

Slug tests were performed on all wells within the existing wetland during July 1996. Pump test data was also collected at sites CD 9 and CD 5 when the wells were bailed for chemical sampling, using results from the data loggers. The in-situ hydraulic conductivity values that were calculated using the Bouwer and Rice method (1976) are shown in Table 2, and described in Jones (1997). The values ranged from $10^{-5}$ cm/sec for medium sized well-sorted sand, $10^{-6}$ cm/sec for dirty sand and $10^{-7}$ cm/sec for deep muck and peat. The calculated values for the medium sized well-sorted sand do not match values published for similar stratigraphic units. Wells CD 16A and CD 18A, which are completed in sand, did not recover as quickly as well CD 19C which is screened in a thick deposit of sorted, medium sand. This may be accounted for in several ways. During completion, the well screens were driven into the ground beyond the bottom of the boreholes. This may have clogged the screened intervals or the screens may have partially or fully penetrated the silt layer commonly found below the shallow sand unit at the wetland site. Slug tests were not conducted on wells within the restoration site.

### Surface Water

Figures 13 and 14 show surface-water elevation within the existing wetland at site CD 10 and surface-water elevation within the restored

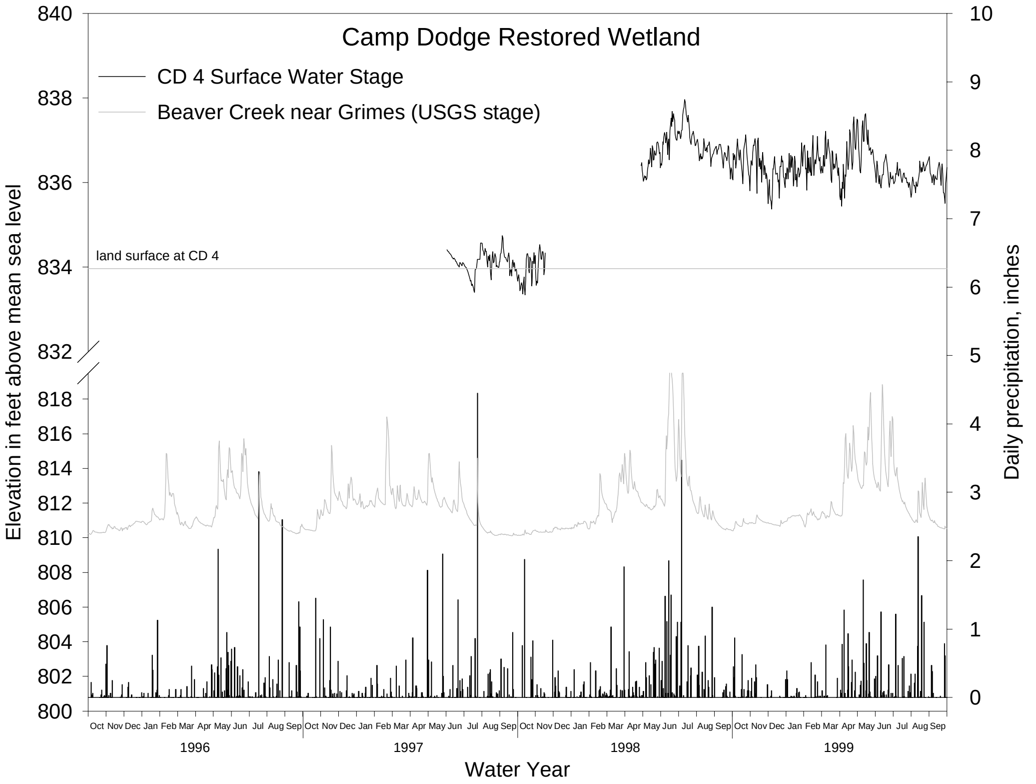

**Figure 14.** Surface water stage relative to land surface elevation of the restored wetland at site CD 4, WYs 1996-1999. Also shown is the stage of Beaver Creek near Grimes, Iowa and daily precipitation totals for the Camp Dodge study area, WYs 1996-1999 (Beaver Creek stage data are from the U.S. Geological Survey, W.R.D., IA Dist and precipitation data are from the Iowa Dept. of Ag. and Land Stewardship, State Climatology Office).

wetland at site CD 4 during WYs 1996-1999. The figures also show land surface elevation at both sites, as well as daily precipitation totals for the study area and the stage of Beaver Creek at a USGS gaging station located approximately two miles southeast. There was little or no surface water present at the restoration site prior to cutting the tile system that drained the area. After the tile lines were cut in June 1996 and following late summer-early fall rainfall events, groundwater levels rose above the land surface in late February 1997 and remained above the land surface except for brief periods in late WY 1997 and early WY 1998. Since May of WY 1998 water levels have fluctuated between about two to three feet above the land surface in the restoration site, while water levels within the existing site have generally declined from about four to less than one foot above the land surface. The restoration surface-water levels have generally increased and decreased along with groundwater levels, which may imply a greater reliance on groundwater inputs, rather than overland runoff. This is also suggested by the lack of sharp increases in monitoring well levels corresponding to precipitation events. Within the existing wetland, sharp increases and decreases in both monitoring well and surface-water levels corresponding to precipitation events, suggest a greater dependence on precipitation and/or overland runoff than groundwater inflow. A water budget previously developed corroborates this and shows that precipitation supplies over 80% of the overall existing wetland budget, followed by groundwater inflow and runoff (Jones, 1997). No water budget has been calculated for the restoration site.

Within both wetlands, surface-water elevations generally increase during late winter and spring runoff and generally decrease during the July through August period when evaporation and evapotranspiration increase. Following summer, surface-water levels increase again due to lower evaporation and evapotranspiration rates and increased precipitation. Comparison of daily precipitation totals, Beaver Creek stage, and surface water and groundwater levels in both wetlands show that antecedent conditions and the timing and intensity of precipitation affect runoff and recharge to the surface-water and soil-groundwater system. Following the relatively dry WY 1996, precipitation events in early WY 1997 had very little effect on the declining stage of Beaver Creek. The precipitation replenished soil moisture that was previously depleted rather than running off into the stream. This is corroborated by significant increases in monitoring well levels within both wetlands during early WY 1997. Precipitation events in late winter and early spring are important for groundwater recharge because this period is usually characterized by low evapotranspiration and wet antecedent conditions. Relatively small amounts of precipitation and snowmelt during late winter and early spring often generate larger runoff events than major precipitation events that occur in late spring and early summer when evaporation and evapotranspiration rates are greater. The minor rainfall events in late May and June of WY 1996 generated significant increases in the groundwater levels of both wetlands and in the stage of Beaver Creek, while a 3.30 inch rainfall on 07/17/96 had very little effect on the receding water levels of the wetlands and the stream. In WY 1997, a 4.45 inch rainfall on 07/24/97 had very little long-term effect on the receding stream stage, but did generate a 1.25 foot increase in the surface-water elevation of the existing wetland, and a 0.15 foot increase in the surface-water level of the restoration site. The highest mean daily surface-water elevation within the existing wetland during the monitoring period, 843.26 feet above sea level, was recorded on 07/07/98 following 3.47 inches of precipitation on 07/06/98. The highest mean daily surface-water elevation within the restoration site, 837.96 feet above sea level, occurred on 07/11/98. The lowest mean daily surface-water elevation recorded in the existing wetland, 839.07 feet, was recorded on 01/12/99 and 01/15/99. The lowest mean daily stage within the restoration site following the July peak, 835.37 feet, was recorded on 12/06/98. Surface-water levels within both wetlands were approaching previously recorded lows near the end of WY 1999.

The maximum surface area of the existing wetland was determined by measuring the height of the surface water against the outside of the well casings of monitoring wells located at the edge of the wetland (Jones, 1997). During the monitoring period, the area inundated by the existing wetland has extended to, and sometimes beyond, the edge monitoring wells (CD-16, 17, 18 and 19). Surface-water levels at these wells have ranged from 0 to more than 1 foot above the land surface. During the first half of the monitoring period, the average water surface extended to just inside the edge monitoring wells. The depth of ponding at site CD 10, near or at the deepest part of the existing wetland, has varied from about 0.5 to 4 feet during the monitoring period. The water surface has rarely extended to monitoring site CD 5 and has not extended to well CD 15 during the monitoring period. The area surrounding well nest CD 9 has been dry during much of WY 1999.

The surface-water elevations in both wetlands have generally correlated with depth to groundwater measurements. During periods when surface-water levels were higher, in the spring and early summer, the elevation of the groundwater surface in monitoring wells was generally higher. When surface-water levels were generally lower, near the end of August, September, and October, the depth to groundwater in the wells was greater. Within the existing wetland, the surface-water elevation at site CD 10 was usually slightly higher than the groundwater elevations of CD 10A and CD 10B showing a downward flux of water. Within the restored wetland, the surface water elevation at site CD 4 remained lower than the groundwater elevations of CD 4A and CD 4B during the latter part of WY 1997 and early WY 1998 as the area became inundated. Later, in WY 1998 and during WY 1999, the surface water elevation of the restored wetland was generally higher than the groundwater elevations of CD 4A and CD 4B during wetter periods, and lower than the groundwater elevations of the wells during drier periods. This probably reflects a lag in response time between the interaction of the groundwater and the surface water. The depth of the pond at site CD 4 has varied from about 0 to 4 feet during the monitoring period. The upland wells within both wetlands have shown the greatest variation in depth to groundwater measurements, and the greatest differences from the surface-water elevations.

## Horizontal Hydraulic Gradients

Water table maps for the existing wetland were constructed using the shallowest well from each well cluster and plotted for all sampling events, from June 20, 1996 to May 5, 1997 using SURFER™ (Golden Software) software (Jones, 1997). Selected maps showing major changes in the elevation of the groundwater table at the existing wetland are in Jones (1997). The water table maps suggest that groundwater flow is generally toward the southeast corner of the wetland. The water table elevation was relatively constant throughout the existing wetland, ranging from approximately 843 to 839 feet above mean sea level during the monitoring period. Within the restoration site, the water table elevation ranged from about 838 to 835 feet above mean sea level during the period.

Hydraulic gradients were calculated for the existing wetland between well CD 5B and wells CD 17B and CD 18B (Table 3). At the restoration site gradients were calculated between well CD 4B and wells CD 1C and CD 2B (Table 4). For the existing wetland, the gradients were calculated by subtracting the groundwater elevation of well 5B from the groundwater elevations of wells 17B and 18B and dividing by the distance between the wells. For the restoration site, the gradients were calculated by subtracting the groundwater elevation of well 4B from the groundwater elevations of wells 1C and 2B and dividing by the distance between the wells. Gradients were on the order of $10^{-3}$ to $10^{-4}$ ft/ft for wells within the existing wetland and $10^{-3}$ to $10^{-5}$ ft/ft for wells within the restoration site. Within the existing wetland, the gradients suggest that groundwater is generally moving from the northwest to the southeast. Gradients between CD 5B and CD 17B ranged from $-2.8 \times 10^{-3}$ to $1.7 \times 10^{-3}$ and averaged $-1.0 \times 10^{-3}$. Gradients between CD 5B and CD 18B ranged from $-4.1 \times 10^{-3}$ to $5.2 \times 10^{-3}$ and averaged $-1.3 \times 10^{-3}$.

Within the restoration site, the gradients between CD 4B and CD 1C also suggested that groundwater flow was generally toward the southeast during the monitoring period. The hydraulic gradients from CD 4B to CD 2B reversed from June 1996 to June 1997, and again from November 1998 to June 1999, indicating that during these periods groundwater flow was stagnant or very limited. Gradients from CD 4B to CD 1C ranged from $-2.6 \times 10^{-3}$ to $1.3 \times 10^{-3}$ and averaged $-3.3 \times 10^{-4}$. The gradients from CD 4B to CD 2B ranged from $-7.0 \times 10^{-3}$ to $6.7 \times 10^{-3}$ and averaged $3.4 \times 10^{-5}$. The differing lithologies of the screened intervals of the wells within the restoration site probably make the computed horizontal gradients less meaningful than the gradients for the wells in the existing wetland, where the lithologies of the screened intervals are more similar.

## Vertical Gradients

Vertical gradients for wells in the existing and restoration wetlands were calculated by subtracting the groundwater elevation of the deep well within each well nest from the groundwater elevation of the shallow well and dividing by the number of feet separating the well screens (tables 5 and 6, and figures 15-18). A negative number indicates an upward gradient (note the difference in scale between Figure 15 and figures 16-18). Comparison of vertical gradients from both wetlands with daily precipitation totals during the monitoring period shows little direct correlation.

In the restoration wetland, vertical gradients at CD 4 were very small. Gradients at CD 1 were also very small except from late 1995 through early 1996 when moderate upward and large downward gradients were observed. These large reversals occurred prior to the tile lines being cut

**Table 3.** Horizontal gradients of wells in the existing wetland calculated by subtracting the groundwater elevation of the inlet well (CD 5B) from the groundwater elevation of the outlet wells (CD 17B and CD 18B) and dividing by the distance between wells.

| Date | Groundwater Elevation CD5B (feet) | Groundwater Elevation CD17B (feet) | Horizontal Gradient | Date | Groundwater Elevation CD5B (feet) | Groundwater Elevation CD18B (feet) | Horizontal Gradient |
|---|---|---|---|---|---|---|---|
| 7/18/96 | 840.56 | 837.84 | -0.0027 | 7/18/96 | 840.56 | 837.97 | -0.0035 |
| 7/25/96 | 839.83 | 837.84 | -0.0020 | 7/25/96 | 839.83 | 838.38 | -0.0020 |
| 8/1/96 | 839.53 | 837.70 | -0.0018 | 8/1/96 | 839.53 | 838.42 | -0.0015 |
| 8/8/96 | 839.23 | 837.71 | -0.0015 | 8/8/96 | 839.23 | 838.06 | -0.0016 |
| 8/23/97 | 838.64 | 838.11 | -0.0005 | 8/23/97 | 838.64 | 838.33 | -0.0004 |
| 9/8/97 | 838.12 | 837.73 | -0.0004 | 9/8/97 | 838.12 | 837.63 | -0.0007 |
| 9/24/97 | 837.78 | 837.28 | -0.0005 | 9/24/97 | 837.78 | 837.04 | -0.0010 |
| 10/6/97 | 838.40 | 837.81 | -0.0006 | 10/6/97 | 838.40 | 837.94 | -0.0006 |
| 10/31/97 | 839.46 | 838.22 | -0.0012 | 10/31/97 | 839.46 | 838.59 | -0.0012 |
| 2/14/97 | 840.48 | 838.45 | -0.0020 | 2/14/97 | 840.48 | 839.40 | -0.0015 |
| 2/18/97 | 841.94 | 840.53 | -0.0014 | 2/18/97 | 841.94 | 839.57 | -0.0032 |
| 3/4/97 | 841.38 | 840.93 | -0.0005 | 3/4/97 | 841.38 | 840.69 | -0.0009 |
| 3/12/97 | 839.33 | 841.07 | 0.0017 | 3/12/97 | n/a | n/a | n/a |
| 4/14/97 | 841.56 | 841.31 | -0.0003 | 4/14/97 | 841.56 | 841.25 | -0.0004 |
| 4/23/97 | 841.42 | 841.23 | -0.0002 | 4/23/97 | 841.42 | 841.28 | -0.0002 |
| 4/30/97 | 841.87 | n/a | n/a | 4/30/97 | 841.87 | 841.21 | -0.0009 |
| 5/5/97 | 841.62 | 841.48 | -0.0001 | 5/5/97 | 841.62 | 841.39 | -0.0003 |
| 5/14/97 | 841.53 | 841.34 | -0.0002 | 5/14/97 | 841.53 | 841.52 | 0.0000 |
| 6/19/97 | 841.52 | 840.96 | -0.0006 | 6/19/97 | 841.52 | 841.31 | -0.0003 |
| 7/10/97 | 840.48 | 840.37 | -0.0001 | 7/10/97 | 840.48 | 840.86 | 0.0005 |
| 7/31/97 | 841.52 | 841.35 | -0.0002 | 7/31/97 | 841.52 | 841.30 | -0.0003 |
| 9/4/97 | 840.44 | 840.13 | -0.0003 | 9/4/97 | 840.44 | 840.46 | 0.0000 |
| 10/7/97 | 839.38 | 839.06 | -0.0003 | 10/7/97 | 839.38 | 838.91 | -0.0006 |
| 11/18/97 | 840.45 | 839.84 | -0.0006 | 11/18/97 | 840.45 | 839.76 | -0.0009 |
| 4/27/98 | 841.86 | 841.30 | -0.0006 | 4/27/98 | 841.86 | 840.63 | -0.0017 |
| 5/11/98 | 841.34 | 841.04 | -0.0003 | 5/11/98 | 841.34 | 841.45 | 0.0001 |
| 6/30/98 | 842.30 | 841.73 | -0.0006 | 6/30/98 | 842.30 | n/a | n/a |
| 8/7/98 | 841.62 | 840.38 | -0.0012 | 8/7/98 | 841.62 | 841.27 | -0.0005 |
| 9/14/98 | 840.64 | 838.96 | -0.0017 | 9/14/98 | 840.64 | 839.72 | -0.0012 |
| 10/5/98 | 841.32 | 839.69 | -0.0016 | 10/5/98 | 841.32 | 839.20 | -0.0029 |
| 11/16/98 | 840.97 | 839.00 | -0.0020 | 11/16/98 | 840.97 | 839.17 | -0.0024 |
| 12/14/98 | 840.50 | 838.71 | -0.0018 | 12/14/98 | 840.50 | 838.92 | -0.0021 |
| 1/12/99 | 839.77 | 839.77 | 0.0000 | 1/12/99 | 839.77 | 836.73 | -0.0041 |
| 2/8/99 | 841.71 | 838.89 | -0.0028 | 2/8/99 | 841.71 | 839.08 | -0.0036 |
| 3/22/99 | 841.44 | 839.24 | -0.0022 | 3/22/99 | 841.44 | 839.52 | -0.0026 |
| 4/19/99 | 841.88 | 839.55 | -0.0023 | 4/19/99 | 841.88 | 840.05 | -0.0025 |
| 5/11/99 | 841.72 | 839.49 | -0.0022 | 5/11/99 | 841.72 | 840.31 | -0.0019 |
| 6/14/99 | 841.33 | 839.42 | -0.0019 | 6/14/99 | 841.33 | 840.36 | -0.0013 |
| 7/27/99 | 838.70 | 836.28 | -0.0024 | 7/27/99 | 838.70 | 838.28 | -0.0006 |
| 8/12/99 | 840.11 | 839.98 | -0.0001 | 8/12/99 | 840.11 | 838.28 | -0.0025 |
| 9/30/99 | 838.68 | 838.47 | -0.0002 | 9/30/99 | 838.68 | 838.33 | -0.0005 |

A minus sign indicates groundwater flow is from CD5B towards CD17B or CD18B.

and may indicate the effect of the tile on the system. Since restoration, only very small vertical gradients have been noted, again with most being upward, and in the same range as the horizontal gradients. Site CD 2 showed primarily small upward gradients. Given the nature of the low permeability sediments that the wells are completed in, this may be simply due to the pressure head. Two prominent reversals occurred at CD 2 in the spring and summer of 1997.

In the existing wetland many of the wells showed frequent reversals particularly in the small diameter wells. Site CD 5 near the hypothesized inlet occasionally showed moderate to large

**Table 4.** Horizontal gradients of wells in the restoration wetland calculated by subtracting the groundwater elevation of the inlet well (CD 4B) from the groundwater elevation of the outlet wells (CD 1C and CD 2B) and dividing by the distance between wells.

| Date | Groundwater Elevation CD4B (feet) | Groundwater Elevation CD1C (feet) | Horizontal Gradient | Date | Groundwater Elevation CD4B (feet) | Groundwater Elevation CD2B (feet) | Horizontal Gradient |
|---|---|---|---|---|---|---|---|
| 8/10/95 | 835.75 | 834.03 | -0.0024 | 8/10/95 | 835.75 | 833.59 | -0.0025 |
| 11/21/95 | 833.79 | 832.25 | -0.0021 | 11/21/95 | 833.79 | 827.73 | -0.0070 |
| 12/10/95 | 836.12 | 834.25 | -0.0026 | 12/10/95 | 836.12 | 834.35 | -0.0021 |
| 1/10/96 | 829.23 | n/a | n/a | 1/10/96 | 829.23 | 828.53 | -0.0008 |
| 4/4/96 | 831.91 | 831.66 | -0.0003 | 4/4/96 | 831.91 | 829.60 | -0.0027 |
| 6/6/96 | 833.79 | 832.78 | -0.0014 | 6/6/96 | 833.79 | 839.56 | 0.0067 |
| 7/11/96 | n/a | 831.09 | n/a | 7/11/96 | n/a | 835.19 | n/a |
| 8/8/96 | 830.50 | 830.18 | -0.0004 | 8/8/96 | 830.50 | 832.42 | 0.0022 |
| 9/12/96 | n/a | 827.92 | n/a | 9/12/96 | n/a | 829.25 | n/a |
| 10/31/96 | 828.63 | 828.12 | -0.0007 | 10/31/96 | 828.63 | 825.81 | -0.0033 |
| 12/23/96 | 831.65 | 831.40 | -0.0003 | 12/23/96 | 831.65 | 833.51 | 0.0022 |
| 1/3/97 | 831.55 | 831.26 | -0.0004 | 1/3/97 | 831.55 | 833.38 | 0.0021 |
| 2/18/97 | 831.78 | 831.73 | -0.0001 | 2/18/97 | 831.78 | 832.87 | 0.0013 |
| 4/13/97 | 834.48 | 833.51 | -0.0013 | 4/13/97 | 834.48 | 837.71 | 0.0038 |
| 5/14/97 | 834.99 | 834.95 | -0.0001 | 5/14/97 | 834.99 | 838.49 | 0.0041 |
| 6/19/97 | 834.99 | 834.86 | -0.0002 | 6/19/97 | 834.99 | 835.71 | 0.0008 |
| 7/10/97 | 834.68 | 834.54 | -0.0002 | 7/10/97 | 834.68 | 833.05 | -0.0019 |
| 7/31/97 | 835.07 | 835.27 | 0.0003 | 7/31/97 | 835.07 | 833.38 | -0.0020 |
| 9/4/97 | 834.71 | 834.61 | -0.0001 | 9/4/97 | 834.71 | 830.08 | -0.0054 |
| 10/7/97 | 834.20 | 833.97 | -0.0003 | 10/7/97 | 834.20 | 828.69 | -0.0064 |
| 11/18/97 | 834.51 | 834.47 | -0.0001 | 11/18/97 | 834.51 | 832.49 | -0.0023 |
| 5/11/98 | 836.45 | 836.42 | 0.0000 | 5/11/98 | 836.45 | 838.21 | 0.0020 |
| 6/30/98 | 836.26 | 837.21 | 0.0013 | 6/30/98 | 836.26 | 839.40 | 0.0036 |
| 8/7/98 | 836.63 | 836.57 | -0.0001 | 8/7/98 | 836.63 | 836.12 | -0.0006 |
| 9/14/98 | 836.48 | 836.39 | -0.0001 | 9/14/98 | 836.48 | 835.29 | -0.0014 |
| 10/5/98 | 836.31 | 836.36 | 0.0001 | 10/5/98 | 836.31 | 834.78 | -0.0018 |
| 11/16/98 | 836.34 | 836.34 | 0.0000 | 11/16/98 | 836.34 | 837.44 | 0.0013 |
| 12/14/98 | 836.31 | 836.27 | -0.0001 | 12/14/98 | 836.31 | 836.59 | 0.0003 |
| 1/12/99 | 836.22 | 836.21 | 0.0000 | 1/12/99 | 836.22 | 836.05 | -0.0002 |
| 2/8/99 | 835.84 | 836.20 | 0.0005 | 2/8/99 | 835.84 | 838.17 | 0.0027 |
| 3/22/99 | 836.41 | 836.40 | 0.0000 | 3/22/99 | 836.41 | 838.85 | 0.0028 |
| 4/19/99 | 836.86 | 836.86 | 0.0000 | 4/19/99 | 836.86 | 840.14 | 0.0038 |
| 5/11/99 | 837.00 | 836.99 | 0.0000 | 5/11/99 | 837.00 | 838.27 | 0.0015 |
| 6/14/99 | 836.52 | 836.54 | 0.0000 | 6/14/99 | 836.52 | 838.46 | 0.0023 |
| 7/27/99 | 836.12 | 836.03 | -0.0001 | 7/27/99 | 836.12 | 835.30 | -0.0010 |
| 8/12/99 | 835.90 | 835.97 | 0.0001 | 8/12/99 | 835.90 | 835.66 | -0.0003 |
| 9/30/99 | 836.06 | 836.06 | 0.0000 | 9/30/99 | 836.06 | 835.37 | -0.0008 |

A minus sign indicates groundwater flow is from CD4B towards CD1C or CD2B.

downward gradients, surprising in that recharge usually occurs near the edges of wetlands. CD 9 near the hypothesized outlet displayed small gradients throughout the monitoring period, generally downward in 1996 and early 1997 and upward the rest of the time. This may be related to the timing and intensity of precipitation as 1996 was dry, with a return to normal rainfall in 1997. Since this trend was not observed at other sites, the influence of precipitation may be overshadowed by other factors. The range of gradients suggests that if a tile or natural outlet does exist, it is not particularly effective at this location. Upward gradients are expected at the edge of most wetlands. Site CD 10 in the middle of the wetland showed very small gradients as would be expected in this part of the wetland. At CD 16, gradients were small with upward gradients generally greater

**Table 5.** Vertical gradients of wells in the existing wetland calculated by subtracting the groundwater elevation of the deep well of each well nest from the groundwater elevation of the shallow well and dividing by the number of feet separating the well screens.

| Well Name | CD5 | CD9 | CD10 | CD16 | CD17 | CD18 | CD19 |
|---|---|---|---|---|---|---|---|
| Difference in Well Depths in feet | 6.12 | 4.96 | 12.96 | 5.89 | 2.75 | 1.56 | 9.48 |
| Date | Vertical Gradient | | | | | | |
| 1/10/96 | -0.0131 | 0.0101 | n/a | n/a | n/a | n/a | n/a |
| 3/7/96 | -0.0049 | 0.0464 | n/a | n/a | n/a | n/a | n/a |
| 4/4/96 | 0.0016 | 0.0444 | n/a | n/a | n/a | n/a | n/a |
| 5/22/96 | n/a | n/a | -0.0139 | n/a | n/a | n/a | n/a |
| 5/29/96 | n/a | n/a | -0.0216 | n/a | n/a | n/a | n/a |
| 6/6/96 | 0.0000 | 0.0202 | 0.0108 | n/a | n/a | n/a | n/a |
| 6/20/96 | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| 6/24/96 | -0.0147 | n/a | -0.0147 | n/a | n/a | n/a | n/a |
| 6/27/96 | 0.0049 | n/a | -0.0139 | n/a | n/a | n/a | n/a |
| 7/3/96 | -0.0033 | 0.0343 | -0.0131 | n/a | n/a | n/a | n/a |
| 7/11/96 | 0.4861 | 0.0363 | n/a | n/a | n/a | n/a | n/a |
| 7/18/96 | -0.0065 | 0.0121 | -0.0054 | -0.0475 | n/a | -0.6154 | 0.1551 |
| 7/25/96 | -0.0033 | 0.0484 | 0.1003 | 0.0102 | -0.5400 | -0.5321 | 0.1213 |
| 8/1/96 | -0.0082 | 0.0544 | 0.0262 | 0.0068 | -0.4873 | -0.3077 | 0.0570 |
| 8/8/96 | -0.0229 | n/a | n/a | 0.0119 | -0.4127 | -0.4167 | 0.0591 |
| 8/10/96 | -0.0310 | 0.1472 | -0.0015 | n/a | n/a | n/a | n/a |
| 8/23/96 | 0.0065 | 0.0060 | n/a | -0.0170 | -0.9709 | 0.0833 | 0.0559 |
| 9/8/96 | -0.0082 | 0.0262 | -0.0193 | -0.0968 | -0.1309 | 0.0577 | 0.0570 |
| 9/12/96 | -0.0065 | 0.0040 | n/a | n/a | n/a | n/a | n/a |
| 9/24/96 | -0.0065 | 0.0343 | 0.0008 | -0.0458 | -0.1636 | -0.0385 | 0.0601 |
| 10/6/96 | -0.0016 | 0.0222 | -0.0177 | 0.0051 | n/a | 0.0064 | n/a |
| 10/31/96 | 0.0082 | 0.0060 | -0.0108 | -0.0119 | -0.2691 | 0.0192 | 0.0686 |
| 11/21/96 | -0.0114 | -0.0282 | n/a | n/a | n/a | n/a | n/a |
| 12/20/96 | 0.2484 | 0.0181 | n/a | n/a | n/a | n/a | n/a |
| 12/23/96 | 0.0131 | 0.0081 | n/a | n/a | n/a | n/a | n/a |
| 1/3/97 | 0.0033 | 0.0423 | -0.0556 | n/a | n/a | n/a | n/a |
| 2/14/97 | -0.0082 | -0.0907 | n/a | -0.0153 | -0.5491 | -0.0641 | -0.0084 |
| 2/18/97 | 0.0572 | -0.1129 | 0.0008 | -0.1290 | 0.0182 | -0.6474 | 0.0295 |
| 3/4/97 | -0.0016 | n/a | n/a | -0.0374 | -0.0255 | -0.2051 | 0.0084 |
| 3/12/97 | n/a | -0.0141 | -0.0108 | -0.0068 | -0.0582 | 0.0000 | 0.0158 |
| 3/21/97 | -0.0016 | -0.0060 | n/a | -0.0170 | -0.0327 | -0.0513 | 0.0021 |
| 4/14/97 | 0.0082 | 0.0423 | n/a | -0.0204 | -0.0327 | -0.0513 | 0.0105 |
| 4/23/97 | 0.0016 | -0.2036 | n/a | -0.0051 | -0.0255 | 0.0064 | 0.0021 |
| 4/30/97 | 0.0507 | n/a | n/a | -0.0543 | n/a | -0.1154 | 0.0000 |
| 5/5/97 | -0.0049 | -0.0081 | n/a | -0.0068 | -0.0327 | -0.1090 | 0.0074 |
| 5/14/97 | -0.0033 | -0.0121 | n/a | 0.0187 | -0.0655 | 0.0064 | 0.0021 |
| 6/18/97 | -0.0082 | -0.0141 | -0.0039 | 0.0085 | -0.0345 | 0.1410 | n/a |
| 7/10/97 | -0.0065 | -0.0181 | -0.0031 | 0.0034 | -0.0691 | 0.8462 | 0.0095 |
| 7/31/97 | -0.0114 | -0.0181 | -0.0031 | 0.0068 | -0.0436 | -0.1795 | 0.0116 |
| 8/23/97 | 0.0074 | 0.0060 | -0.0185 | -0.0170 | -0.1709 | 0.0833 | 0.0559 |
| 9/4/97 | -0.0098 | -0.0403 | -0.0023 | 0.0102 | -0.0655 | 0.1154 | n/a |
| 9/8/97 | -0.0082 | 0.0262 | -0.0193 | -0.0968 | -0.1309 | 0.0577 | 0.0570 |
| 9/12/97 | -0.0049 | 0.0040 | n/a | n/a | n/a | n/a | n/a |
| 9/24/97 | -0.0065 | 0.0353 | 0.0008 | -0.0458 | -0.1636 | -0.0385 | 0.0601 |

A minus sign indicates an upward vertical gradient.

than downward gradients. Moderate to large upward gradients at CD 17 support observations from CD 9 suggesting that if a tile or natural outlet does exist, it is not particularly effective. Both CD 18 and CD 19 showed frequent reversals, however gradients were generally small at CD 19 while large at CD 18. It is possible that the wells at CD 18 may not have been sealed properly allowing for

**Table 5.** Continued.

| Well Name | CD5 | CD9 | CD10 | CD16 | CD17 | CD18 | CD19 |
|---|---|---|---|---|---|---|---|
| Difference in Well Depths in feet | 6.12 | 4.96 | 12.96 | 5.89 | 2.75 | 1.56 | 9.48 |
| Date | Vertical Gradient | | | | | | |
| 10/6/97 | -0.0016 | 0.0222 | -0.0181 | 0.0051 | -0.2255 | 0.0064 | 0.0633 |
| 10/7/97 | 0.1585 | -0.0766 | 0.0000 | 0.0136 | -0.0109 | 0.0321 | n/a |
| 10/31/97 | 0.0082 | 0.0060 | -0.0108 | -0.0119 | -0.2691 | 0.0192 | 0.0686 |
| 11/18/97 | -0.0016 | -0.0040 | n/a | 0.0017 | -0.0218 | 0.0128 | -0.0717 |
| 4/27/98 | 0.0441 | -0.0060 | -0.0031 | 0.0051 | -0.0473 | -0.7821 | -0.0749 |
| 5/11/98 | -0.0033 | -0.0161 | -0.0023 | 0.0136 | -0.0364 | 0.0769 | -0.0527 |
| 6/30/98 | -0.0147 | n/a | -0.0046 | -0.0017 | -0.0218 | n/a | -0.0854 |
| 7/21/98 | 0.0000 | n/a | -0.0015 | n/a | n/a | n/a | n/a |
| 8/7/98 | -0.0114 | n/a | -0.0023 | 0.0136 | 0.0400 | 0.0705 | 0.0559 |
| 9/14/98 | 0.3366 | -0.0544 | -0.0008 | -0.0051 | -0.1491 | 0.2628 | 0.1044 |
| 10/5/98 | 0.3252 | 0.0060 | -0.0015 | -0.0560 | 0.1164 | -0.1795 | 0.0454 |
| 11/16/98 | 0.0033 | -0.0101 | -0.0015 | 0.0017 | -0.1127 | -0.2372 | -0.0949 |
| 12/14/98 | 0.0082 | -0.0242 | 0.0000 | -0.0017 | -0.0945 | 0.0641 | 0.1192 |
| 1/12/99 | 0.0000 | -0.0605 | -0.0455 | 0.0136 | -0.7964 | 0.1987 | -0.0432 |
| 2/8/99 | -0.0033 | -0.0605 | -0.0008 | 0.0017 | -0.0436 | -0.1282 | 0.0074 |
| 3/22/99 | 0.0049 | -0.0181 | 0.0000 | 0.0153 | -0.0436 | 0.0385 | -0.0285 |
| 4/19/99 | -0.0033 | -0.0403 | -0.0015 | 0.0017 | -0.0764 | -0.0897 | -0.0295 |
| 5/11/99 | 0.0082 | -0.0202 | 0.0000 | -0.0119 | -0.1127 | 0.1474 | -0.0222 |
| 6/14/99 | -0.0082 | -0.0403 | 0.0000 | 0.0221 | -0.0545 | 0.3333 | -0.0211 |
| 7/27/99 | -0.0065 | -0.0605 | 0.0000 | 0.0221 | -0.8764 | 1.4103 | 0.2141 |
| 8/12/99 | 0.0359 | -0.0323 | 0.0031 | -0.2241 | 0.3200 | -0.8077 | -0.0380 |
| 9/30/99 | 0.0131 | -0.1008 | 0.0008 | -0.0136 | 0.0218 | 1.9487 | 0.0907 |
| Average | 0.025 | -0.008 | -0.004 | -0.017 | -0.160 | 0.010 | 0.026 |
| Average Upward | -0.008 | -0.043 | -0.011 | -0.040 | -0.191 | -0.280 | -0.048 |
| Average Downward | 0.077 | 0.028 | 0.018 | 0.010 | 0.103 | 0.242 | 0.056 |

A minus sign indicates an upward vertical gradient.

these frequent large reversals. Mud cracks, as discussed below, may also affect vertical gradients within the existing wetland.

## Groundwater Flow

The data from the existing wetland are consistent with the ephemeral nature of the basin (figures 19-22). Groundwater levels are often below the surface during late summer, suggesting net seepage out of the wetland. Surface water is often 2-3 feet deep in the wetland during this time, suggesting that the surface water and groundwater are not directly linked. The slow rate of seepage out of the basin may support the hypothesis of a linked-depression wetland. The underlying sand layer may act as a drain on the wetland, consistent with lake-groundwater interactions as shown by Winter (1976). However, this is not consistently supported by vertical gradients, particularly for wells CD 17 and CD 18.

Groundwater flow appears to be directed toward a subsurface drainage outlet at the southeast edge of the wetland. Drilling in this area does show a sand layer extending out from the wetland as would be consistent with a linked drainage system hypothesis. The hypothesized outlet for the existing wetland is near well nest CD 17 (Jones, 1997). This area is also the location of an abandoned collapsed clay tile line that a previous

**Table 6.** Vertical gradients of wells in the restoration wetland calculated by subtracting the groundwater elevation of the deep well of each well nest from the groundwater elevation of the shallow well and dividing by the number of feet separating the well screens.

| Well Name | CD1 | CD2 | CD4 |
|---|---|---|---|
| Difference in Well Depths in feet | 15.24 | 12.85 | 10.79 |
| Date | Vertical Gradient | | |
| 8/10/95 | -0.1148 | -0.0249 | 0.0213 |
| 11/21/95 | -0.1148 | -0.0342 | -0.0074 |
| 12/10/95 | -0.1148 | -0.0187 | 0.0195 |
| 1/10/96 | 0.2848 | -0.0903 | -0.0389 |
| 3/17/96 | n/a | -0.0350 | 0.0093 |
| 4/4/96 | 0.8904 | -0.0296 | 0.0009 |
| 6/6/96 | -0.0026 | -0.0125 | 0.0334 |
| 7/11/96 | -0.0039 | -0.0265 | n/a |
| 7/18/96 | -0.0072 | n/a | 0.0176 |
| 8/8/96 | -0.0016 | -0.0156 | 0.0222 |
| 9/12/96 | 0.0046 | -0.0553 | n/a |
| 10/31/96 | -0.0085 | -0.1027 | 0.0704 |
| 12/23/96 | -0.0039 | 0.0016 | 0.1019 |
| 1/3/97 | 0.0020 | -0.0078 | 0.0120 |
| 2/18/97 | -0.0138 | -0.0047 | -0.0056 |
| 4/13/97 | -0.0690 | 0.1323 | 0.0019 |
| 5/14/97 | -0.0030 | -0.0187 | -0.0019 |
| 6/19/97 | -0.0022 | -0.0327 | 0.0046 |
| 7/10/97 | -0.0016 | 0.1852 | 0.0056 |
| 7/31/97 | 0.0000 | -0.0257 | -0.0083 |
| 9/4/97 | -0.0020 | -0.0389 | -0.0009 |
| 10/7/97 | -0.0020 | -0.0366 | 0.0074 |
| 11/18/97 | -0.0026 | -0.0319 | -0.0037 |
| 4/27/98 | -0.0026 | n/a | 0.0176 |
| 5/11/98 | -0.0020 | -0.0047 | -0.0019 |
| 6/30/98 | 0.0833 | -0.0257 | -0.0399 |
| 8/7/98 | 0.0000 | -0.0350 | 0.0046 |
| 9/14/98 | -0.0295 | -0.0475 | -0.0880 |
| 10/5/98 | -0.0029 | -0.0327 | -0.0074 |
| 11/16/98 | -0.0023 | -0.0031 | -0.0046 |
| 12/14/98 | -0.0007 | -0.0125 | 0.0000 |
| 1/12/99 | 0.0013 | -0.0171 | 0.0056 |
| 2/8/99 | -0.0026 | 0.0319 | -0.0380 |
| 3/22/99 | -0.0013 | 0.0023 | -0.0028 |
| 4/19/99 | -0.0020 | -0.0428 | -0.0019 |
| 5/11/99 | -0.0014 | -0.0342 | -0.0037 |
| 6/14/99 | 0.0000 | -0.0156 | -0.0037 |
| 7/27/99 | -0.0013 | -0.0436 | 0.0056 |
| 8/12/99 | -0.0125 | 0.0521 | 0.0176 |
| 9/30/99 | 0.0000 | -0.0187 | -0.0037 |
| Average | 0.019 | -0.015 | 0.003 |
| Average Upward | -0.018 | -0.030 | -0.015 |
| Average Downward | 0.211 | 0.068 | 0.020 |

A minus sign indicates an upward vertical gradient.

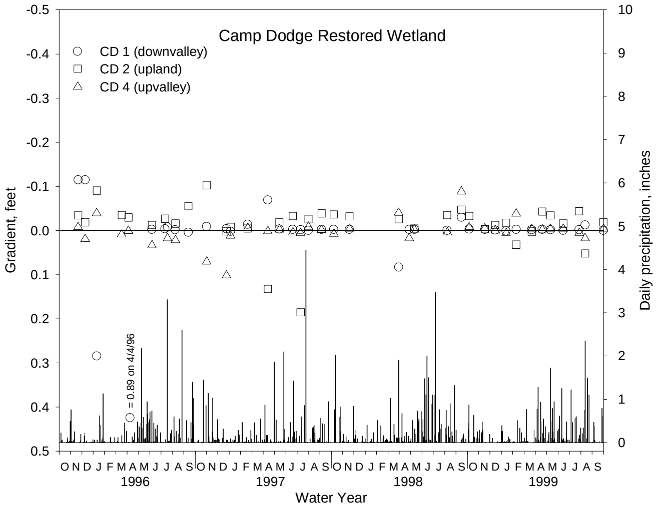

**Figure 15.** Vertical gradients for well sites CD 1, CD 2 and CD 4 within the restored wetland, WYs 1996-1999 (Precipitation data are from the Iowa Dept. of Ag. and Land Stewardship, State Climatology Office).

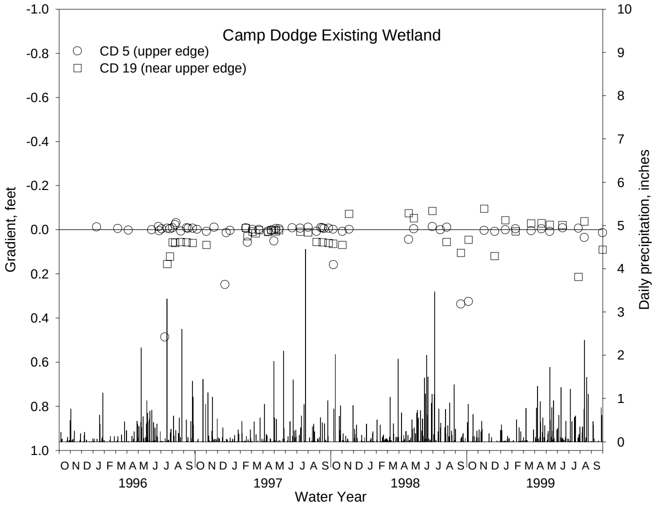

**Figure 16.** Vertical gradients for well sites CD 5 and CD 19 within the existing wetland, WYs 1996-1999 (Precipitation data are from the Iowa Dept. of Ag. and Land Stewardship, State Climatology Office).

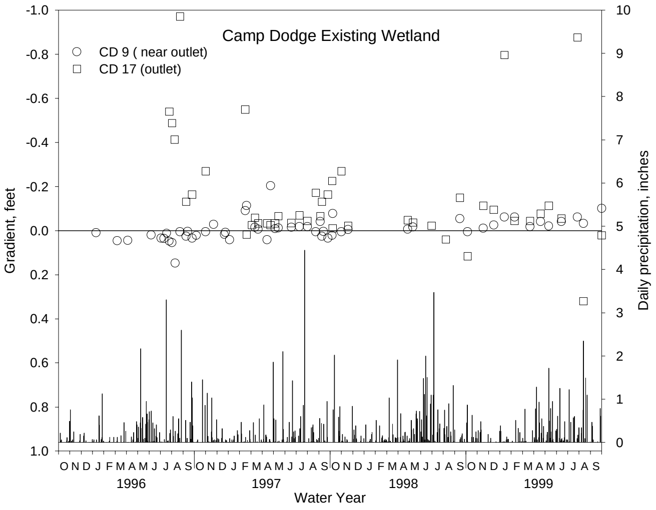

**Figure 17.** Vertical gradients for well sites CD 9 and CD 17 within the existing wetland, WYs 1996-1999 (Precipitation data are from the Iowa Dept. of Ag. and Land Stewardship, State Climatology Office).

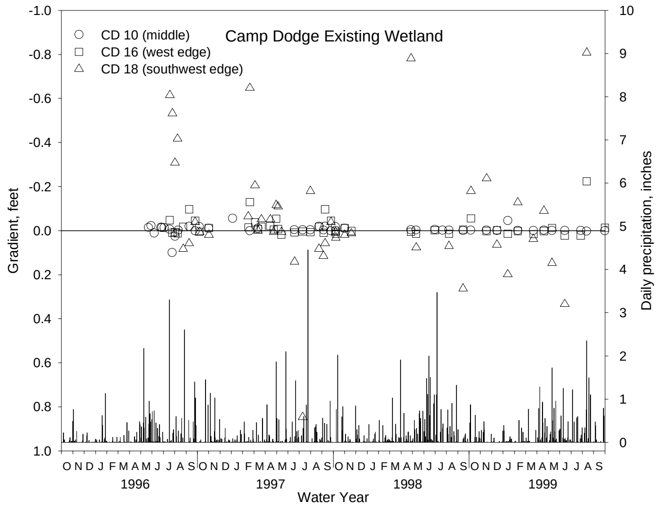

**Figure 18.** Vertical gradients for well sites CD 10, CD 16 and CD 18 within the existing wetland, WYs 1996-1999 (Precipitation data are from the Iowa Dept. of Ag. and Land Stewardship, State Climatology Office).

landowner installed during the 1950's (Diane Anderson [previous landowner's daughter], personal communication, 1995). The tile line is presently filled with silt and clay, but may still be partially functioning. Field observations by Jones (1997) of a collapse feature associated with the tile indicated that the collapse increased in size during WYs 1996 and 1997. It has not been determined to what extent the tile line affects the groundwater system. During various periods, the collapse feature has held water at approximately the same elevation as the wetland, bringing into question the effectiveness of the tile.

Well sites CD 9 and CD 17 near the tile collapse feature did not indicate a strong downward gradient, as would be expected if the tile were functioning properly. Instead, observations from the wells indicated an upward gradient, suggesting that the tile has minimal effect on the groundwater system. It is possible that tile effects are seasonally related to water levels. During dry periods, the water table may already be below the tile, and during very wet periods the capacity of the tile may be too small to have much affect. In order to verify the amount of water that the tile system may still remove, it would require more intensive examination of vertical gradients adjacent to the tile.

Observations by Winter (1976) and others have shown that in semi-enclosed basins, as shallow groundwater flows downslope, hydraulic pressure builds up. This pressure allows the groundwater to move upward, toward the toe of the slope, creating upward gradients around the edges of semi-closed basins or ponds. In general, this is shown to be true for the existing wetland with the notable exception of CD 5 which shows moderate to large downward gradients and CD 18 which shows very large upward and downward gradients.

The gradient reversals within the existing wetland during the monitoring period suggest that during drier periods, groundwater moves downward from the bottom of the wetland basin near sites CD 19 and CD 9 into a shallow sand layer located below the muck. Core samples from a well installed near the southeast end of the wetland as part of the basin-wide monitoring well network showed a layer of medium sand from 6 to 9 feet below the land surface. During wetter periods, groundwater probably moves up into the wetland from the sand layer. At sites CD 16 and CD 18, which are farther out from the edge of the average water surface of the wetland, the gradients suggest that groundwater was moving upward during drier periods and downward during wetter periods. A possible explanation for the gradients observed at sites CD 16 and CD 18 might be related to the formation of mud cracks near the sites. As the area around the pond dries out, mud cracks develop and the uppermost layer of sediment that acts as a seal is broken. This may allow water to move upward from the sand layer below at an accelerated rate. The direction of groundwater movement through the mud cracks could also be downward during periods when the hydrostatic pressure within the sand layer is lower than the hydrostatic pressure within the overlying materials. During wetter periods, as the muck layer becomes saturated to supersaturated again, the seal reforms, and the added pressure of the shallower groundwater exerts enough force to cause the vertical gradient to become downward. The average downward gradient at CD 5, the proposed inlet, and the average upward gradient at CD 17, the proposed outlet, suggest that groundwater might generally be flowing into the shallow sand lens near CD 5 and out of the sand lens near CD 17. Since vertical gradients are generally greater than horizontal gradients, by one to two orders of magnitude, the wetland might be classified as a recharge-discharge system.

Water-level data for the restoration site showed trends similar to those observed in the existing wetland during the monitoring period (figures 23-26). Groundwater levels increased significantly from January through May 1996 then declined to the lowest levels monitored near the end of WY 1996. Levels increased significantly through May 1997 then declined again through the end of WY 1997. Groundwater levels, then increased through June 1998, decreased to January 1999, increased again into May 1999, and then generally decreased to the end of the monitoring period. Groundwater levels at CD 2, the upland well nest, have shown the greatest variation of all wells monitored, and have remained at least 3 feet below the land

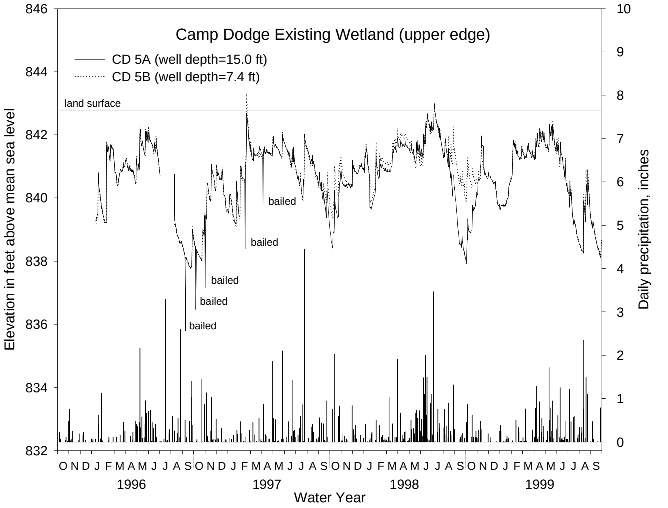

**Figure 19.** Groundwater levels for wells CD 5A and CD 5B relative to land surface elevation of the existing wetland at site CD 5, WYs 1996-1999 (Precipitation data are from the Iowa Dept. of Ag. and Land Stewardship, State Climatology Office).

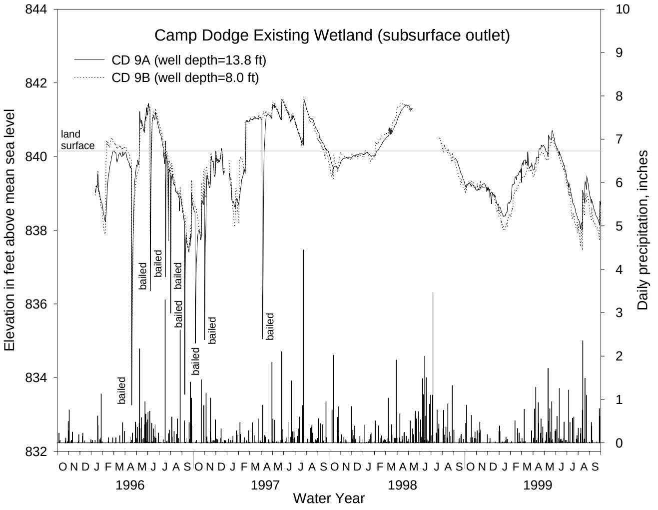

**Figure 20.** Groundwater levels for wells CD 9A and CD 9B relative to land surface elevation of the existing wetland at site CD 9, WYs 1996-1999 (Precipitation data are from the Iowa Dept. of Ag. and Land Stewardship, State Climatology Office).

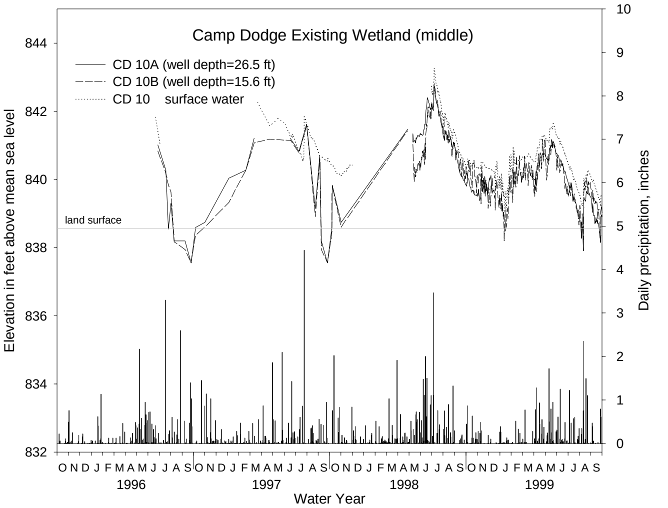

**Figure 21.** Groundwater levels for wells CD 10A and CD 10B and surface water stage relative to land surface elevation of the existing wetland at site CD 10, WYs 1996-1999 (Precipitation data are from the Iowa Dept. of Ag. and Land Stewardship, State Climatology Office).

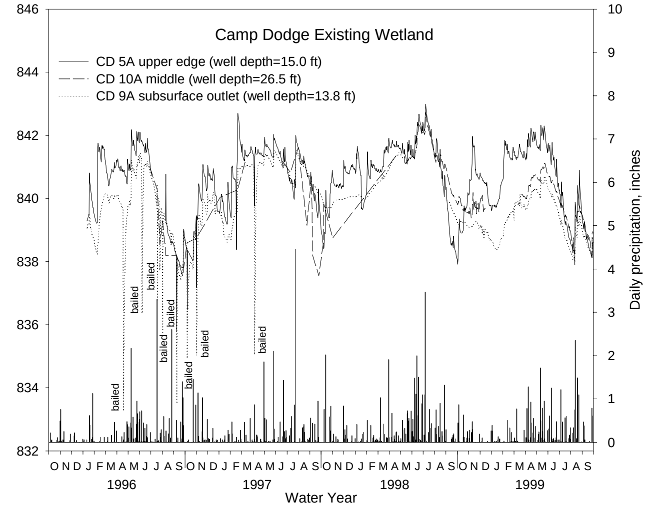

**Figure 22.** Groundwater levels for wells CD 5A, CD 10A and CD 9A within the existing wetland, WYs 1996-1999 (Precipitation data are from the Iowa Dept. of Ag. and Land Stewardship, State Climatology Office).

surface during the monitoring period. At well nests CD 1 and CD 4, groundwater levels have for the most part remained above the land surface since emerging in late February 1997. The water level of well CD lC declined below the land surface briefly in late March and early April of 1997. Surface water has remained 3-4 feet deep within the wetland during even the driest periods in the latter half of the monitoring period, suggesting a slow rate of seepage out of the basin.

With the limited number of wells in the restoration wetland, it is difficult to determine the distribution of recharge and discharge points. The strongly layered lithology within the restoration site probably promotes horizontal gradients. Differences in the magnitude of gradients between wells CD 1 and CD 4 may be caused by the wells being completed in differing lithologies.

It is reasonable to suggest that the general flow direction in the area immediately surrounding the wetland is downslope into the wetland. The overall flow direction of groundwater in the study area surrounding both wetlands probably parallels the Beaver Creek Valley. Comparison of water levels in the restoration monitoring wells shows that during the spring, levels in CD 2A become significantly higher than levels in CD 1A and CD 4A, and during the fall, water levels in CD 2A decline below levels in wells CD 1A and CD 4A. This suggests that during wetter periods, groundwater flow is from the upland sediments into the underlying sediments. During drier periods, the head of the ponded surface water probably causes groundwater to flow from beneath the pond into bank storage. Comparison of well levels shows that these periods have been short lived in comparison to periods of recharge into the wetland. Although vertical gradients are generally greater than horizontal gradients, by one to two orders of magnitude, the layered lithology of the site probably promotes lateral flow. In addition, the setting of the site as a second order subsurface drainage tunnel also promotes flow out of the wetland so the restoration wetland might be classified as a flow through system.

## Wetland Comparisons

Comparison of water levels from the up slope wells within both wetlands shows that well nest CD 2 in the restoration site displayed much greater variability than nest CD 5 in the existing site during WY 1996 through January of WY 1998. From January 1998 through the end of the monitoring period, the magnitude of water level fluctuations at sites CD 2 and CD 5 were more similar. This may suggest that hydrologic conditions within the restoration wetland are reaching a more natural state, following an initial period of adjustment after the tile system was cut. Following the emergence of groundwater in the restoration site, groundwater levels at sites CD 1 and CD 4 have shown less variation than groundwater levels at CD 5, CD 9 and CD 10. During the latter half of the monitoring period, well levels at CD 9 and CD 10 showed significant increases and decreases, falling below the land surface for various periods, while water levels at CD 1 and CD 4 have shown relatively little variation, remaining two to three feet above the land surface. These differences suggest that the restoration site may be less ephemeral than the existing site. Factors contributing to the more stable water levels within the restoration site may include the larger basin area and the generally lower land surface elevation. The lack of sharp increases in surface water and groundwater levels corresponding to precipitation events suggests that the restoration site has been less dependant on precipitation and runoff recharge than the existing site, at least since the tile system has been cut.

Jones (1997) proposed that in the deepest part of the existing wetland, groundwater may be leaking into the shallow sand layer (located four to five feet below the pond surface) or to a deeper sand channel, located deeper than current borings have penetrated. An alternative hypothesis by Jones (1997) suggests that the shallow sand channel and the presumed deeper sand channel may connect near the “outlet” end of the existing wetland. Currently, there is not enough data to prove either hypothesis at either wetland. It is possible that the hydrogeology of the study area is influenced by a linked depression system, but the sand conduits (or links) may be located 25 to 35 feet below the

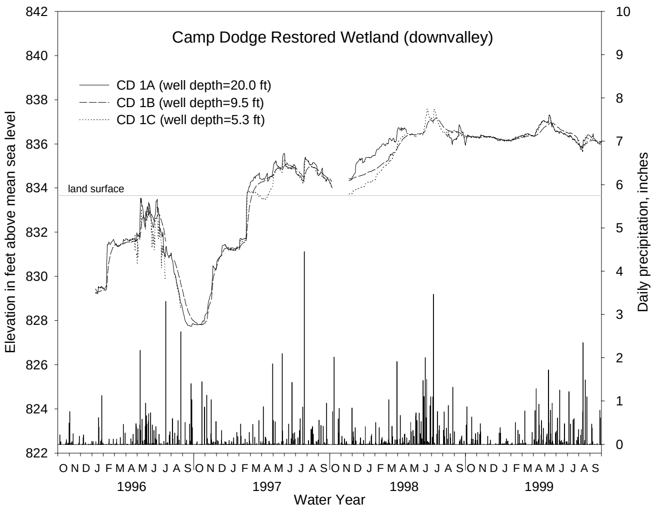

**Figure 23.** Groundwater levels for wells CD 1A, CD 1B and CD 1C relative to land surface elevation of the restored wetland at site CD 1, WYs 1996-1999 (Precipitation data are from the Iowa Dept. of Ag. and Land Stewardship, State Climatology Office).

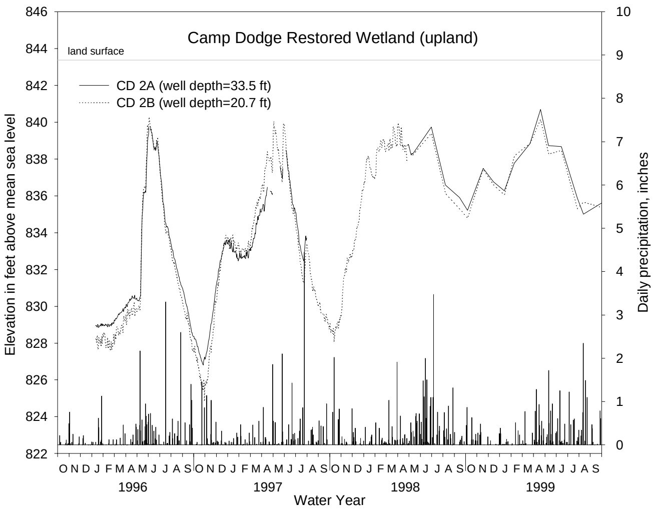

**Figure 24.** Groundwater levels for wells CD 2A and CD 2B relative to land surface elevation of the restored wetland at site CD 2, WYs 1996-1999 (Precipitation data are from the Iowa Dept. of Ag. and Land Stewardship, State Climatology Office).

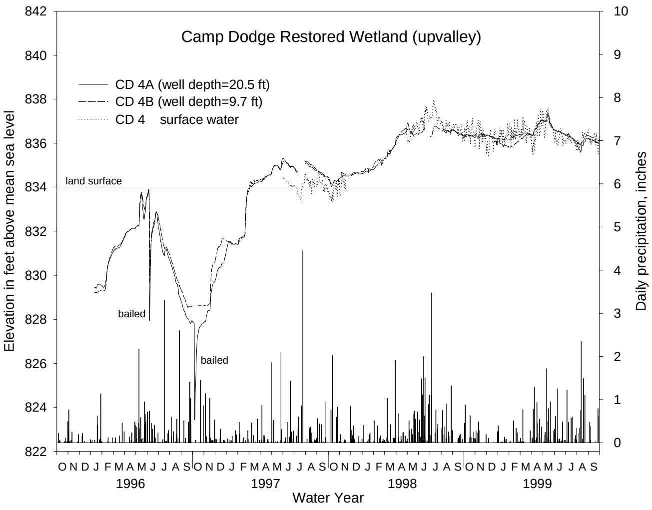

**Figure 25.** Groundwater levels for wells CD 4A and CD 4B and surface water stage relative to land surface elevation of the restored wetland at site CD 4, WYs 1996-1999 (Precipitation data are from the Iowa Dept. of Ag. and Land Stewardship, State Climatology Office).

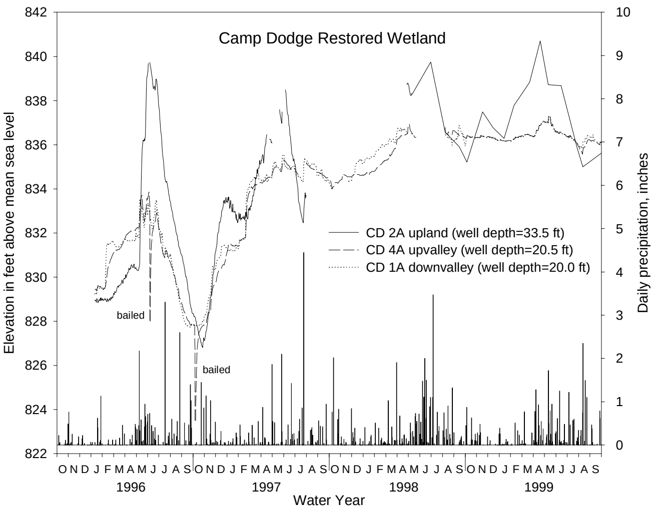

**Figure 26.** Groundwater levels for wells CD 2A, CD 4A and CD 1A within the restored wetland, WYs 1996-1999 (Precipitation data are from the Iowa Dept. of Ag. and Land Stewardship, State Climatology Office).

bottom of the basins. In order to ascertain whether or not the study area is located within a linked depression system, and whether or not the wetlands are connected by the system, additional subsurface information is needed. One method of investigation might be to use a combination of ground-penetrating radar and a geographic information system to map shallow sub-surface sand bodies, then drill transects across a few of the sand bodies to confirm their structure. A regional water table map has not yet been published for this area of the Des Moines Lobe, but data is currently being collected by the IDNR GSB from about 70 monitoring wells (at an average depth of 20-25 feet), located throughout the Camp Dodge National Guard Base. This data will be used to create a regional water table map, which should assist in future investigations.

There are significant hydrologic differences between the two wetlands based on the thickness of the wetland sediments. The existing wetland generally has a thinner sediment package, and is more subject to drying, allowing for deep mud cracks. The restored wetland sediments are much thicker, providing a better sealing layer. The sand below the existing wetland is probably directly related to the existence of the basin and could easily act as a drain. The sand below the restored wetland is probably much thicker with greater continuity and extent.

## WATER QUALITY

Since the wetlands are located in an area previously dominated by agriculture, the Environmental Planning group at Camp Dodge were concerned about the impacts of agricultural contaminants, especially nitrates and pesticides, upon the surface water and groundwater quality of the wetlands. The restoration site had been actively farmed in the years just prior to restoration. The area surrounding the existing wetland had been in hay for many years prior to acquisition by the National Guard. Groundwater and surface water quality of the wetlands are a function of recharge within the wetland drainage basins, and are controlled by the amount, timing, and intensity of precipitation and snowmelt. Climatic variations and antecedent conditions exert a major control on the transport and concentrations of agriculturally related contaminants, as well as on the concentrations of naturally occurring constituents.

The wetlands receive both infiltration and runoff recharge, which have unique chemical signatures. Infiltration recharge is often enriched in nitrate and other chemicals that are mobile in soil, relative to runoff recharge, particularly runoff derived from snow melt. Runoff recharge usually has lower concentrations of such compounds, but is enriched in herbicides and other chemicals with low soil mobility. As runoff recharge moves through the hydrologic system relatively low nitrate and high herbicide concentrations often occur during peak flow periods. The runoff recharge is typically followed by higher nitrate and lower herbicide concentrations as the associated infiltration recharge moves through the groundwater system.

Previous groundwater studies in Iowa have shown that during prolonged dry periods, nitrate and herbicide (particularly atrazine) concentrations generally show a slow, steady decline. This decline likely occurs as an increasing percentage of recharge to tile lines and surface waters is relatively older groundwater from less transmissive parts of the hydrologic system. In general, low recharge periods are accompanied by low contaminant concentrations. Contaminant concentrations are generally higher during periods of higher recharge.

A geochemical investigation of the existing wetland was conducted during the summer and fall of 1996 (Jones, 1997). This report will discuss results from the initial sampling of both the existing and restored wetlands that occurred on June 6, 1996 and two additional samplings that occurred on October 6, 1996 and April 3, 1997. All analyses from these samplings were performed by the University of Iowa Hygienic Laboratory using USEPA approved methods. Analytical methods and sampling procedures are reviewed in Jones (1997).

### Sampling Locations

Sampling sites reviewed in Jones (1997) included eight monitoring well clusters containing 16 wells and four surface water sites. The sites were sampled weekly during the summer and biweekly to monthly during the fall of 1996. During September and October of 1996, surface water samples were not collected because the pond was dry. The sampling sites for the three samplings discussed below include monitoring well nest CD 4 in the restoration site, and well nests CD 5 and CD 9 within the existing wetland (Figure 2). Additional sampling sites include four surface water sites, CDRP1, CDEM, CDND1, CDND3, and one groundwater seep, CDOX. Site CDRP1 was located about 1,300 feet west of CD 4 in the restoration wetland. Within the existing wetland, site CDEM was just west of CD 10, and sites CDND1, CDND2 and CDND3 were midway between CD 15 and CD 16. Sites CDND1-3 were at essentially the same location, but were sampled at varied depths, with CDND1 being 1 inch deep, CDND2 being 6 inches deep and CDND3 being 12-15 inches deep. The physical location of these samplings changed somewhat as the wetland's surface water area changed, but the depth of water that the samples were taken from did not change. Site CDOX was a groundwater seep located just over 2 miles southeast of the existing wetland in an abandoned oxbow.

## Results

No samples had been collected in these wetlands prior to this study. Historical data was obtained from Geological Survey Bureau Municipal Water Supply records which contain data collected in 1938, 1963, 1965, and 1967 from two shallow wells (40 and 60 feet deep) at Camp Dodge and a neighboring well located two miles from Camp Dodge at Pioneer Corporation's Johnston location (Jones, 1997). The wells were completed in sand lenses, which are presumably part of the Beaver Creek alluvial aquifer. Sampling results indicate that total dissolved solids (TDS) of the groundwater had ranged from 383 to 460 mg/L and pH ranged from 7.0 to 7.8 standard units (SU). Calcium and bicarbonate were the major ions found, with minor concentrations of sulfate and sodium. The nitrate values from the historical results ranged from 0 to 27 mg/L, which are lower than concentrations currently found in both surface water and groundwater in most areas on the Des Moines Lobe.

Both wetlands were initially sampled on June 6, 1996. The Camp Dodge weather station recorded 0.23 inches of precipitation during the day, but daily discharge at Beaver Creek continued to recede, suggesting that the precipitation had little effect on recharge in the area. No precipitation occurred during the other two sampling days. Samples were analyzed for common herbicides and insecticides, nitrogen series including ammonia-nitrogen, organic-nitrogen and nitrate-nitrogen, total phosphorous, major ions, and some common metals (tables 7-11). It was proposed that if nitrates and phosphates reached the existing wetland, the effects of dilution and/ or consumption by micro-organisms would be so great that concentrations of nitrates and phosphates would be relatively low (Jones, 1997). The results from both wetlands generally supported this hypothesis. It was also assumed that if pesticides were present in either wetland they would be detected in the surface water, so monitoring wells were not sampled for pesticides. Sampling site CDOX was chosen to be representative of groundwater in the Camp Dodge area. Herbicide analyses included acetochlor, alachlor, atrazine, butylate, cyanazine, desethylatrazine, deisopropylatrazine, metolachlor, metribuzin, and trifluralin, and acid herbicide analyses included 2,4 - D, silvex, dicamba, and bentazon (Table 7). Insecticide analyses included carbofuran, chlorpyrifos, ethoprop, fonofos, phorate, terbufos (Table 8). Atrazine was the only pesticide that was detected at any site. It was detected at a concentration of 0.14 µg/L on June 6, 1996, at CDND3 in the existing wetland. The detection was probably related to runoff, since it had rained on the day the sample was collected.

Surface and groundwater samples showed generally low concentrations of nitrogen and phosphorous (Table 9). Concentrations of ammonia nitrogen as N ranged from 30.0 to <0.1 mg/L and were greatest in the restoration site wells. Within the existing wetland, ammonia nitrogen concentrations from the monitoring wells were generally greater than concentrations from the surface water, and also generally greater than concentrations from site CDOX. Concentrations of organic nitrogen as N ranged from 8.3 mg/L at CD 4B to 1.6 mg/L at CDOX. Within the existing

**Table 7.** Summary of pesticide analyses collected from the restored and existing wetlands on June 6, 1996.

| Site | Date | acetochlor | alachlor | atrazine | butylate | cyanazine | desethyl-atrazine | deisopropyl-atrazine | metalochlor |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | concentration, µg/L | | | | |
| Restoration Wetland | | | | | | | | | |
| Surface Water sites | | | | | | | | | |
| CDRP1 | 6/6/96 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Existing Wetland | | | | | | | | | |
| Surface Water sites | | | | | | | | | |
| CDEM | 6/6/96 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| CDND3 | 6/6/96 | <0.10 | <0.10 | 0.14 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Groundwater seep | | | | | | | | | |
| CDOX | 6/6/96 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |

< - below the stated detection limit

The following componds were not detected: bentazon, dicamba, metribuzin, silvex, trifuralin, and 2, 4-d

wetland, the organic nitrogen concentration from the surface water site was greater than the concentrations from the monitoring wells. Nitrite nitrogen as N was not analyzed for within the restoration wetland, and was below detectable levels in the surface water and wells within the existing wetland. Concentrations of nitrate nitrogen as N ranged from 4.2 mg/L at CDOX to below detectable concentrations in a number of monitoring wells in both wetlands. Nitrate nitrogen as N was not detected in surface water at either wetland. Concentrations of total phosphorous ranged from 2.1 mg/L at CD 4A to 0.2 mg/L at CD 9A, and were above detection limits at all sampling sites. As mentioned, nitrate concentrations were expected to be low in both surface and groundwater because of nutrient cycling within the wetlands. In wetlands, nitrate is reduced to nitrogen, which then volatilizes into the air (Arndt and Richardson, 1993). Jones (1997) suggested that within the existing wetland, changes in phosphate values corresponded to biogeochemical cycles. When plants are alive in the wetland, phosphate values remain low, and as plant matter begins to decompose and form a litter layer, the litter releases phosphorous back into the soil and eventually into the shallow groundwater.

Major ion analyses included bromide, calcium, chloride, fluoride, magnesium, potassium, sodium and sulfate (Table 10). Calcium, magnesium, sulfate and chloride were the most abundant ions detected in both wetlands. Bromide and fluoride were not detected in the existing wetland, and not analyzed for in the restoration site. The results are similar to historical water quality data previously discussed, and representative of groundwater flowing through unconsolidated materials in this area of the Des Moines Lobe. As would be expected, the concentrations of most ions were greater in the groundwater than in the surface water of the wetlands. Calcium concentrations in groundwater ranged from 280 mg/L at CD 4B, to

**Table 8.** Summary of insecticide analyses collected from the restored and existing wetlands on June 6, 1996.

| Site | Date | carbofuran | chlorpyrifos | ethoprop | fonofos | phorate | terbofos |
|---|---|---|---|---|---|---|---|
| | | | | concentration, µg/L | | | |
| Restoration wetland | | | | | | | |
| Surface Water sites | | | | | | | |
| CDRP1 | 6/6/96 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Existing wetland | | | | | | | |
| Surface Water sites | | | | | | | |
| CDEM | 6/6/96 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| CDND3 | 6/6/96 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |
| Groundwater seep | | | | | | | |
| CDOX | 6/6/96 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |

< - below the stated detection limit

62 mg/L at CD 9B. Concentrations of calcium in surface water ranged from 71 mg/L at CDND1 to 44 mg/L at CDEM. Chloride concentrations in groundwater ranged from 3.0 mg/L at CDOX to 20.0 mg/L at CD 5A. In surface water, chloride concentrations ranged from 4.9 to 11.0 mg/L at CDEM. Magnesium concentrations in groundwater ranged from 71 mg/L at CD 4A to 12 mg/L at CDOX, and in surface water concentrations ranged from 15 mg/L at CDND1 to 12 mg/L at CDRP1. Potassium concentrations in groundwater ranged from 8.5 mg/L at CDND1 to 1.3 mg/L at sites CD 4B and CD 9A. Within surface water, potassium concentrations ranged from 8.5 mg/L at CDND1 to 4.1 mg/L at sites CDRP1 and CDND3. Sodium concentrations in groundwater ranged from 16.0 mg/L at CD 4A to 3.4 mg/L at CDOX, and in surface water concentrations ranged from 3.1 mg/L at CDRP1 to 2.0 mg/L at CDEM and CDND3. Sulfate concentrations in groundwater ranged from 100 mg/L at CD 5A, to 1.0 mg/L at CD 9B. Concentrations of sulfate in surface water ranged from 880 mg/L at CDEM to 6.9 mg/L at CDND3. The concentration reported from CDEM on 10/06/99, 880 mg/L, appears unreasonably great in comparison to the rest of the data.

Metals analyses included total cadmium, total iron, total lead and total zinc (Table 11). Total cadmium and total lead were not detected at any monitoring site. Total iron concentrations were generally greater in groundwater than in surface water within both wetlands. Total zinc concentrations did not show an appreciable difference from groundwater to surface water. Iron concentrations in surface water ranged from 0.71 mg/L at CDEM to 0.30 mg/L at CDND3. In groundwater, iron concentrations ranged from 2.6 mg/L at CD 9A to 0.87 mg/L at CD 9B. Total zinc concentrations ranged from 0.03 mg/L at CD 4B and CD 9A to < 0.02 mg/L at CDRP1, CD 4A, CDEM, CDND3, and CDOX.

**Table 9.** Summary of nitrogen-series analyses collected from the restored and existing wetlands.

| | Site | Date | ammonia nitrogen as N | organic nitrogen as N | nitrite nitrogen as N | nitrate nitrogen as N | total phosphorous |
|---|---|---|---|---|---|---|---|
| | | | | concentration, mg/L | | | |
| Restoration wetland | | | | | | | |
| Surface Water sites | | | | | | | |
| | CDRP1 | 6/6/96 | <0.10 | | | <0.10 | 0.4 |
| Monitoring wells | | | | | | | |
| | CD4A | 6/6/96 | 30.0 | | | <0.10 | 2.1 |
| | CD4B | 6/6/96 | 0.1 | | | 0.6 | 0.3 |
| | CD4B | 10/6/96 | 22.0 | 8.3 | | 0.5 | |
| Existing wetland | | | | | | | |
| Surface Water sites | | | | | | | |
| | CDEM | 6/6/96 | <0.10 | | | <0.10 | 0.4 |
| | CDEM | 10/6/96 | 0.1 | 4.3 | | <0.10 | |
| | CDND1 | 4/3/97 | | | <0.50 | <0.50 | |
| | CDND3 | 6/6/96 | <0.10 | | | <0.10 | 0.4 |
| Monitoring wells | | | | | | | |
| | CD5A | 4/3/97 | | | <0.50 | <0.50 | |
| | CD5B | 4/3/97 | | | <0.50 | <0.50 | |
| | CD9A | 6/6/96 | 1.1 | | | <0.10 | 0.2 |
| | CD9A | 10/6/96 | 1.0 | 1.8 | | 0.2 | |
| | CD9A | 4/3/97 | | | <0.50 | 0.7 | |
| | CD9B | 6/6/96 | 0.4 | | | 0.4 | 1.5 |
| | CD9B | 10/6/96 | 0.7 | 2.9 | | 0.2 | |
| | CD9B | 4/3/97 | | | <0.50 | 0.7 | |
| Groundwater seep | | | | | | | |
| | CDOX | 6/6/96 | <0.10 | | | <0.10 | 0.6 |
| | CDOX | 10/6/96 | 0.1 | 1.6 | | 4.2 | |

< - below the stated detection limit

The much greater calcium and magnesium concentrations from the wells in the restoration site compared with the concentrations from the wells in the existing wetland indicates a greater degree of leaching of the sediments at the existing wetland. The muck and sand deposits beneath the existing wetland are thinner, and have probably undergone more wetting and drying cycles than the sediments underlying the restoration site. This would allow increased leaching of calcium and magnesium. The sediments of both wetlands contain abundant snail remains and react violently with dilute hydrochloric acid.

Within the existing wetland, Jones (1997) identified seasonal trends in major ion concentrations. Most samples showed greater ion

**Table 10.** Summary of major ion analyses collected from the restored and existing wetlands.

| Site | Date | bromide | calcium | chloride | fluoride | magnesium | potassium | sodium | sulfate |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | concentration, mg/L | | | | |
| Restoration wetland | | | | | | | | | |
| Surface Water sites | | | | | | | | | |
| CDRP1 | 6/6/96 | | 49.0 | 6.9 | | 12.0 | 4.1 | 3.1 | 15.0 |
| Monitoring wells | | | | | | | | | |
| CD4A | 6/6/96 | | 200.0 | 5.9 | | 71.0 | 4.6 | 16.0 | 48.0 |
| CD4B | 6/6/96 | | 280.0 | | | 56.0 | 1.3 | 6.5 | |
| CD4B | 10/6/96 | | | 7.9 | | | | | 22.0 |
| Existing wetland | | | | | | | | | |
| Surface Water sites | | | | | | | | | |
| CDEM | 6/6/96 | | 44.0 | 4.9 | | 13.0 | 4.3 | 2.0 | 7.6 |
| CDEM | 10/6/96 | | | 11.0 | | | | | 880.0 |
| CDND1 | 4/3/97 | <0.50 | 71.0 | 8.0 | <0.50 | 15.0 | 8.5 | 2.8 | 38.0 |
| CDND3 | 6/6/96 | | 48.0 | 5.1 | | 14.0 | 4.1 | 2.0 | 6.9 |
| Monitoring wells | | | | | | | | | |
| CD5A | 4/3/97 | <0.50 | 120.0 | 20.0 | <0.50 | 36.0 | 1.6 | 8.0 | 100.0 |
| CD5B | 4/3/97 | <0.50 | 120.0 | 14.0 | <0.50 | 33.0 | 3.4 | 5.8 | 37.0 |
| CD9A | 6/6/96 | | 130.0 | 11.0 | | 33.0 | 1.3 | 4.1 | 9.4 |
| CD9A | 10/6/96 | | | 11.0 | | | | | 8.4 |
| CD9A | 4/3/97 | <0.50 | 120.0 | 9.8 | <0.50 | 35.0 | 2.1 | 4.6 | 21.0 |
| CD9B | 6/6/96 | | 62.0 | 12.0 | | 16.0 | 2.0 | 3.5 | 15.0 |
| CD9B | 10/6/96 | | | 7.7 | | | | | 1.0 |
| CD9B | 4/3/97 | <0.50 | 110.0 | 8.8 | <0.50 | 30.0 | 5.1 | 4.5 | 1.8 |
| Groundwater seep | | | | | | | | | |
| CDOX | 6/6/96 | | 42.0 | 3.0 | | 12.0 | 8.0 | 3.4 | 16.0 |
| CDOX | 10/6/96 | | | 5.3 | | | | | 23.0 |

< - below the stated detection limit

concentrations toward the end of July and beginning of August, and lower concentrations toward the end of August and the beginning of September. The variability was attributed to dilution from increased precipitation during wetter periods and evaporative effects during dryer periods. Elevated sulfate concentrations in some wells in the existing wetland corresponded to areas of upward hydraulic gradients, and also corresponded with high chloride concentrations. The higher concentrations generally occurred in samples taken a few days following significant precipitation events. Jones (1997) suggested that the oxidation of pyrite within the till substrate could produce increased sulfate concentrations and corresponding high chloride concentrations.

**Table 11.** Summary of metal analyses collected from the restored and existing wetlands.

| | Site | Date | total cadmium | total iron | total lead | total zinc |
|---|---|---|---|---|---|---|
| | | | concentration, mg/L | | | |
| Restoration wetland | | | | | | |
| Surface Water sites | | | | | | |
| | CDRP1 | 6/6/96 | <0.001 | 0.47 | <0.10 | <0.02 |
| Monitoring wells | | | | | | |
| | CD4A | 6/6/96 | <0.001 | 0.90 | <0.10 | <0.02 |
| | CD4B | 6/6/96 | <0.001 | 1.10 | <0.10 | 0.03 |
| Existing wetland | | | | | | |
| Surface Water sites | | | | | | |
| | CDEM | 6/6/96 | <0.001 | 0.71 | <0.10 | <0.02 |
| | CDND3 | 6/6/96 | <0.001 | 0.30 | <0.10 | <0.02 |
| Monitoring wells | | | | | | |
| | CD9A | 6/6/96 | <0.001 | 2.60 | <0.10 | 0.03 |
| | CD9B | 6/6/96 | <0.001 | 0.87 | <0.10 | 0.02 |
| Groundwater seep | | | | | | |
| | CDOX | 6/6/96 | <0.001 | 1.80 | <0.10 | <0.02 |

< - below the stated detection limit

Jones (1997) divided wells in the existing wetland into three groups based on depth, then divided these groups into two groups based on lithology (sand versus muck) and did not see any statistically significant differences in the groundwater geochemistry of the groups.

## SUMMARY

The objectives of this study were to describe the surficial geology of the existing and restoration wetlands, evaluate the hydrology of the two wetlands and disseminate hydrologic information to other project members to allow an integrated evaluation of the vegetation and habitat conditions through the restoration.

It is important to recognize that although wetlands are partially closed systems they are also connected to larger flow systems. Recognition of this may lead to an improved understanding of the wetlands as part of an integrated ecosystem. The advance of the Des Moines Lobe resulted in the development of a complex of linked depressions, which may function as relatively permeable, shallow subsurface drainage systems. The existing wetland is located in an upland, semi-closed depression, interpreted as a former low-order drainage tunnel. The restored wetland is in an abandoned glacial valley, interpreted as a second-order or higher drainage tunnel. The stratigraphy of the wetlands was consistent with these interpretations and showed that both wetlands date to the waning stages of the last Ice Age in this region. The restoration site has generally undergone infilling throughout the Holocene changing from a deep-water, to a shallow-water wetland. The thinner sediment package at the existing site shows that degradation of sediment has been common, implying a more ephemeral existence for the site.

There are significant hydrologic differences between the two wetlands based on the thickness of the wetland sediments. The existing wetland generally has a thinner sediment package, and is more subject to drying allowing for deep mud cracks. This may account for the occasional downward gradients. The restored wetland sediments are much thicker, providing a better sealing layer. Although no wells are present in the sand in the restoration wetland, the water there would presumably show an upward gradient from the confining effect of the thick, low permeability wetland sediments.

In general, recharge-discharge areas within the wetlands were in accordance with previous models. Some exceptions occurred and may be related to the formation of deep mud cracks in the system allowing for significant vertical leakage. The limited number of wells within the restoration site did not provide enough data to test the models. The variation of gradients within the existing wetland from the model might be expected, since the lithology of the site does not match the simplified lithology used in the models. The vertical gradients for most well nests within the existing wetland fluctuated between upward and downward during the monitoring period. Vertical gradients for wells in the restoration site showed fewer reversals. The distribution of average vertical gradients within the existing wetland showed the greatest downward gradients near the hypothesized inlet, and the greatest upward gradients near the hypothesized outlet.

Within both wetlands, surface-water elevations generally increase during late winter and spring runoff and generally decrease during the July through August period when evaporation and evapotranspiration increase. Surface-water elevations in both wetlands generally correlated well with depth to groundwater measurements. The upland wells within both wetlands have shown the greatest variation in depth to groundwater measurements, and the greatest differences from the surface-water elevations. A budget constructed for the existing wetland shows that most of the water in the wetland is from precipitation with minor groundwater inflow and that the major outflow from the site is via evapotranspiration. This may also be true for the restoration site, although because of the setting and the increased linear extent of the valley walls there is probably more groundwater inflow, resulting in greater water permanence, which has been exhibited since cutting the tiles. This increased groundwater inflow hypothesis is supported by referencing water levels in the upland well at the restoration site.

The data from the existing wetland are consistent with the ephemeral nature of the basin. Groundwater levels are often below the surface during late summer, indicating net seepage out of the wetland. Surface water was often 2-3 feet deep in the wetland during this time, indicating a slow rate of seepage out of the basin. The increasing similarity of longer-term water level responses of the upland wells in the restoration and existing sites suggests that hydrologic conditions at the restoration site are approaching a more natural balance. The more stable water levels within the restoration site during the last half of the monitoring period suggest that the restoration site may be less ephemeral than the existing site.

The water quality of both wetlands was similar to historical water quality data and representative of groundwater flowing through unconsolidated materials in this area of the Des Moines Lobe. The concentrations of most ions were greater in the groundwater than in the surface water of the wetlands and generally increased toward the end of summer due to evaporative effects and decreased in the fall due to dilution from increased precipitation. The concentrations of pesticides, nitrates and phosphates were relatively low, probably due to the effects of dilution, volatilization and/ or consumption by micro-organisms within the wetlands.

The overall flow direction of groundwater in both wetlands appears to parallel Beaver Creek and may support the hypothesis of a linked-depression system. Drilling near the southeast end of the existing wetland does show a sand layer extending out from the wetland as would be consistent with a linked drainage system hypothesis. Horizontal gradients suggest that groundwater may flow through a shallow sand channel approximately 2-3 feet below the land surface. There may also be deeper sand channels located below the bottom of the wetlands connecting the wetlands to the larger Beaver Creek drainage system. Additional subsurface information will be needed to ascertain whether or not the study area is located within a linked depression system. One method of investigation might employ a combination of ground-penetrating radar and a geographic information system to map shallow sub-surface sand bodies. Drilling transects across some of the sand bodies would confirm their structure. Data currently being collected by the IDNR GSB from monitoring wells located throughout Camp Dodge will be used to create a regional water table map, which should assist in future investigations.

In order to understand the wetlands as part of an integrated ecosystem, the larger flow system to which they belong must be understood. At larger scales, many landuse and management practices are integrated, and hydrologic responses are dampened and complicated by climatic variations, antecedent conditions, storage effects and biochemical processing in both surface-water and groundwater systems. Policy makers and planners must be aware of the potential time lags involved at these larger scales and make appropriate commitments to long-term support.

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A number of Geological Survey Bureau staff have been involved with this project at one time or another. Much of the information contained in this report is a result of their combined efforts. Carol Thompson was responsible for writing the proposal and obtaining the legacy grant. She was also responsible for the monitoring network design and wrote most of the core descriptions with assistance from Art Bettis, who is now with the University of Iowa Geoscience Department. Mary Clare Jones was responsible for most of the data collection and interpretation of data from the existing prairie pothole wetland. This report utilizes much information from her thesis. John Schmidt developed the programming used to operate and maintain the database that contains the water quality data. Thanks go to Huaibao Liu and Keith Schilling of the Hydrogeology and Environmental Studies Section staff for their assistance in constructing monitoring wells and well platforms. Thanks to Troy Duff from the IDNR Construction Services Bureau for surveying the well elevations and reference points in both wetlands. Deb Quade and Art Bettis offered insight concerning Des Moines Lobe stratigraphy, and continue to work on mapping the surficial geology within Camp Dodge and developing a regional water table map. Many thanks to Matt Goolsby for assisting with field work in a variety of climatic conditions. Pat Lohmann provided assistance with graphic arts and formatting of this report. Thanks also to Huaibao Liu for proofreading this report.

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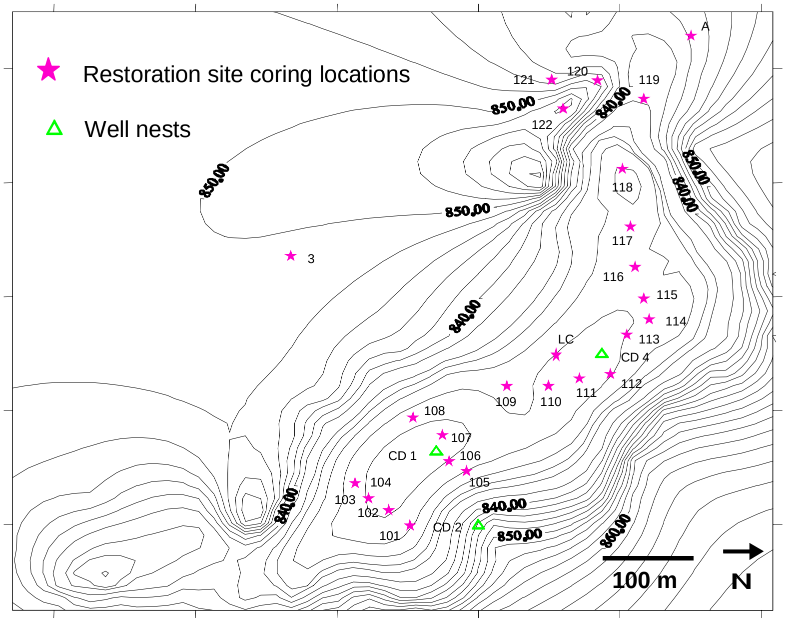
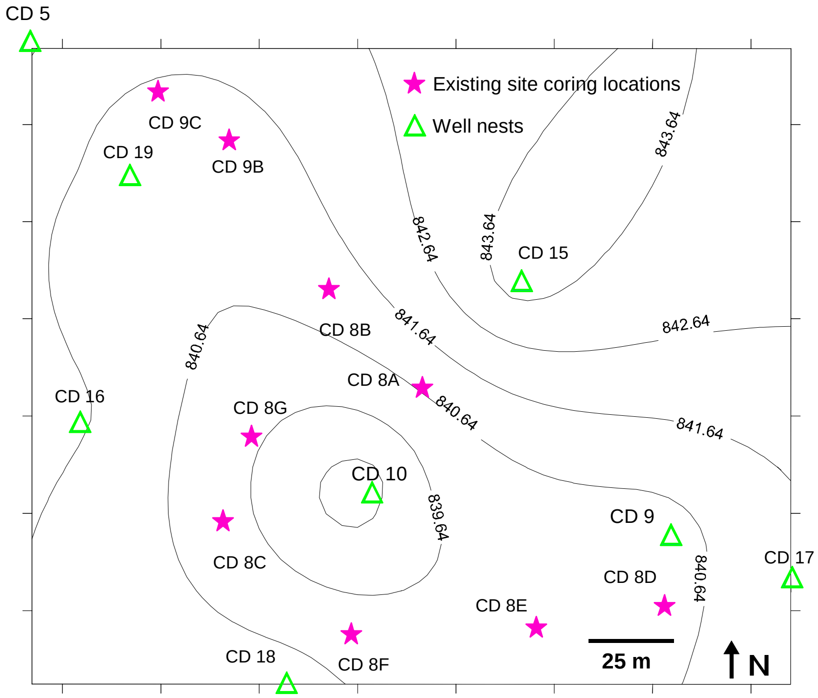
# APPENDIX

## Core Descriptions

# Location maps for core descriptions in Appendix





## Well cores – restoration wetland site

**CD 1**

| | |
|---|---|
| Location: | SE NW NE NE 28 T80N R25W |
| Landscape Position: | valley bottom |
| Altitude: | 834 feet above MSL |
| Slope: | 0-3% |
| Date drilled: | 6/29/95 |
| Coring methods: | 7.6 cm diameter core, Giddings piston corer |
| Remarks: | Considerable core loss and compression. |

| Depth (cm) | Description |
|---|---|
| 0-12.2 | Black (2.5YR 2.5/0), crumbly dry organic loam, clear boundary. |
| 12.2-30.5 | a.a., effervescent, snails and shell parts noted. |
| 30.5-64.0 | Dark brown to black (10YR2/1) organic muck, fine carbonate sand on surface, effervescent, gradual boundary, abundant snail remains, numerous root channels. |
| 64.0-94.5 | Very dark gray to black (10YR 3/1), silty muck, clear boundary, snail remains present. |
| 94.5-173.7 | Very dark brown (10YR 2/2) degraded muck, abundant snail remains which sometimes occur in distinct bands. |
| 173.7-179.8 | a.a., texture denser, siltier. |
| 179.8-198.1 | Very dark gray (2.5 YR 3/0) silty muck, effervescent, abundant snails. |
| 198.1-219.5 | a.a., but slightly more brown (5YR 3/1) silty muck. |
| 219.5-280.4 | Very dark gray (10YR 3/1) muck, some fibrous material in pockets, violent effervescence, few snails. |
| 280.4-304.8 | Gray (10YR 5/1) fine sand. |

*Field notes:*
*Sand encountered at 12.2 feet*
*Augered rest of hole*
*At 20 feet encountered pebbly sand, 1-2 inch diameter*

Well construction

| Well A | Well B | Well C |
|---|---|---|
| 1 1/4” PVC Schedule 40 | 1 1/4” PVC Schedule 40 | 1 1/4” PVC Schedule 40 |
| 2 10’ pipe, 1 2’ screen | 1 10’ pipe, 1 2’ screen | 1 5’ pipe, 1 2’ screen |
| MP 1.48’ above ground | MP 2.27’ above ground | MP 1.72’ above ground |

**CD 2**

| | |
|---|---|
| Location: | SW NE NE NE 28 T80N R25W |
| Landscape Position: | upper footslope |
| Altitude: | 843 feet above MSL |
| Slope: | 9-14% |
| Date drilled: | 6/28/95 |
| Coring methods: | 7.6 cm diam core, Giddings piston corer |
| Remarks: | |

| Depth (cm) | Soil Horizon (weathering zone) | Description |
|---|---|---|
| | | *Dows Formation, Morgan Member* |
| 0-20 | + | Brown (10YR4/3) pebbly loam, weak fine granular, friable, strong effervescence, abrupt boundary, abundant roots. |
| 20-43 | A | Dark brown to dark grayish brown (10YR3/3-4/2) loam, moderate medium subangular blocky, friable, strong effervescence, gradual boundary, abundant roots. |
| 43-70 | AC | Dark grayish brown to yellowish brown (10YR4/2-5/6) pebbly loam, weak medium subangular blocky, friable, strong effervescence, gradual boundary, abundant insect burrows. |
| 70-180 | C1<br>(MOU) | Brown to light olive brown (10YR5/3-2.5Y5/4) stratified pebbly loam and sandy loam, massive, friable, strong effervescence, gradual boundary, common to abundant medium to fine yellowish brown (10YR5/6-5/8) mottles and streaks, few thin discontinuous dark reddish brown (5YR3/2) coatings. |
| 180-244 | C2<br>(MOU) | As above with fewer mottles and streaks, pebbles larger (4-5cm diameter). |
| 244-475 | C3<br>(MOU) | Brown to light olive brown (10YR5/3-2.5Y5/4) stratified silt loam with 5+ cm diameter inclusions of rounded compact diamicton (till balls), few fine pebbles, lower 10cm has more pebbles, abrupt boundary. |
| 475-503 | C4<br>(UU) | Dark gray to gray (10YR4/1-5/1) bedded pebbly loam and sandy loam, contains several graded beds with abundant pebble content at base that become less pebbly upward, clear boundary. |
| 503-970 | C5<br>(UU) | Dark gray to gray (10YR4/1-5/1) loamy medium to fine sand with a few zones of coarse sand, few relatively thin graded pebbly loam beds. |

Well construction

| Well A | Well B |
|---|---|
| 1 1/4” PVC Schedule 40 | 1 1/2” PVC Schedule 40 |
| 3 10’ pipe, 1 5’ pipe, 1 2’ screen with sock | 4 5’ pipe, 1 5’ screen with sock |
| MP 3.45’ above ground | MP 4.3’ above ground |

**CD 4**

| | |
|---|---|
| Location: | NW NE NE 28 T80N R25W |
| Landscape Position: | valley bottom |
| Altitude: | 834 feet above MSL |
| Slope: | 0-3% |
| Date drilled: | 6/29/95 |
| Coring methods: | 5 cm diam core; hand corer |
| Remarks: | |

| Depth (cm) | Description |
|---|---|
| 0-30.5 | Black stiff muck over grayish-brown silty muck. |
| 30.5-213 | Grayish-brown silty muck with shell fragments, occasional zones of more fibric material but no peat, charcoal noted at approximately 152 cm, shell density increases near bottom. |
| 213-244 | a.a., density increases to bottom to an organic-rich silty clay with shells. |
| 244-335 | Organic silty clay. |
| 335-510 | Fibrous muck to peat. |

Well Construction

| Well A | Well B |
|---|---|
| 1 1/4” PVC Schedule 40 | 1 1/4” PVC Schedule 40 |
| 2 10’ pipe, 1 2’ screen | 1 10’ pipe, 1 2’ screen |
| MP 1.48’ above ground | MP 2.27’ above ground |

## Well cores – existing wetland site

**CD 5**

| | |
|---|---|
| Location: | SW NE NE NW 27 T80N R25W |
| Landscape Position: | edge of depression |
| Altitude: | 843 feet above MSL |
| Slope: | 0-3% |
| Date drilled: | 6/29/95 |
| Coring methods: | 7.6 cm diameter core, Giddings piston corer |
| Remarks: | Core described 5/6/98. |

| Depth (cm) | Description |
|---|---|
| 0-3 | Dark brown peaty muck, very fibrous litter layer. |
| 3-20 | Fine sandy overwash, 10YR 3.1, mixed with a small amount of organic debris. |
| 20-30 | Dark brown sandy muck, no reaction, few roots. |
| 30-61 | Dark gray silty muck, iron staining along roots, no reaction. |
| 61-91 | Dark gray 10YR 3/1 mucky silt, noticeable iron deposits along root holes, no reaction. |
| 91-100 | Black degraded muck, moist, some hint of blocky structure, few very thin sand layers (1-2 mm thick). |

| | |
|---|---|
| 100-105 | Brown peaty muck to peat, fibrous. |
| 105-122 | Black muck, few shells. |
| 122-152 | Black, grades from silty muck to silt, a few pebbles and sand stringers. |
| 152-228 | Black muck to silty muck, mild effervescence mostly associated with shell remains, matrix non-reactive, scattered shell and snail remains, more abundant below 167 cm. |
| 228-252 | Dark brown organic muck, 10YR 3/2 to 10YR 4/4 with gleyed inclusions 5G4/2. |
| 252-258 | Carbonate-rich muck to silt, violent effervescence. |
| 258-279 | Dark gray laminated silt, some wood. |
| 279-305 | Green silt, mildly effervescent. |
| 305-427 | Medium-coarse pebbly sand. |
| | *Dows Formation, Morgan Member* |
| 427-670 | Unoxidized, unleached till. |

Well construction

| Well A | Well B |
|---|---|
| 1 1/4” PVC Schedule 40 | 1 1/4” PVC Schedule 40 |
| 3 5’ pipe, 2 2’ screens | 2 5’ pipe, 1 2’ screen |
| MP 3.95’ above ground | MP 4.6’ above ground |

**CD 9**

Location: SE NW NE 27 T80N R25W
Landscape Position: depression
Altitude: 840 feet above MSL
Slope: 0-3%
Date drilled: 7/27/95
Coring methods: 2.5 cm diameter core
Remarks:

| Depth (cm) | Description |
|---|---|
| 0-274 | Black muck, some silty, some small fibrous zones, shells. |
| 274-350 | Very hard brown compressed peat with carbonate grains. |
| 350-411 | Medium sand. |

Well construction

| Well A | Well B |
|---|---|
| 1 1/4” PVC Schedule 40 | 1 1/4” PVC Schedule 40 |
| 1 10’ pipe, 1 5’ pipe, 1 2’ screen | 1 10’ pipe, 1 2’ screen |
| MP 3.65’ above ground | MP 3.95’ above ground |

## Selected core descriptions for restoration site

**A**

| | |
|---|---|
| Location: | SW SW SW SE 21 T80N R25W |
| Landscape Position: | footslope of saddle separating linked depressions |
| Altitude: | 840-850 feet above MSL |
| Slope: | 2-5% |
| Date drilled: | 6/29/95 |
| Coring methods: | 7.6 cm diameter core, Giddings piston corer |
| Remarks: | |

| Depth (cm) | Soil Horizon (weathering zone) | Description |
|---|---|---|
| | | *Dows Formation, Alden Member* |
| 0-22 | Ap | Very dark gray to very dark grayish brown (10YR3/1-3/2) pebbly loam, weak medium to fine granular, friable, noneffervescent, abrupt boundary, abundant roots. |
| 22-40 | AC | Dark brown (10YR3/3) pebbly loam, moderate medium to fine subangular blocky, friable, moderate effervescence, gradual boundary, common roots, common insect burrows. |
| 40-60 | CA | Yellowish brown (10YR5/4) pebbly loam, more pebbles than above, weak medium to fine subangular blocky, friable, strong effervescence, clear boundary. |
| 60-105 | C1k<br>(MJOU2) | Pale brown to light yellowish brown (10YR6/3-6/4) pebbly loam, weak coarse prismatic, friable, violent effervescence, gradual boundary, common coarse yellowish brown (10YR5/6) mottles, abundant thin discontinuous carbonate coatings. |
| 105-250 | C2<br>(MJOU) | Pale brown to light yellowish brown (10YR6/3-6/4) pebbly loam, massive, friable, violent effervescence, clear boundary, common coarse brown (7.5YR4/4) mottles with grayish brown (2.5Y5/2) interiors along root channels. |
| 250-340 | C3<br>(MJOU) | Yellowish brown to light yellowish brown (10YR5/4-6/4) pebbly loam, massive, firm, violent effervescence, gradual boundary, thin discontinuous brown (7.5YR4/4) coatings along subvertical joints, some joints have grayish brown (2.5Y5/2) faces. |
| 340-398 | C4<br>(MJOU-UJU) | Yellowish brown to gray (10YR5/4-5/1) pebbly loam, massive, firm, violent effervescence, clear boundary, thin almost continuous brown (7.5YR4/4) coatings along joints. |
| 398-671 | C5<br>(UU) | Dark gray (10YR4/1) pebbly loam, massive, firm, violent effervescence. |

**LC**

Location: NW NE NE 28 T80N R 25W
Landscape Position: valley bottom
Altitude: 830-840 feet above MSL
Slope: 0-3%
Date drilled: 10/30/97
Remarks: Livingston corer, core sampled for pollen and ash.

| Depth (cm) | Drive | Description |
|---|---|---|
| 0-13 | 1 | Black organic soil to muck, loose, friable dry, few fine-medium roots, plant debris near top, non-reactive, few shells, 54% ash, 4% carbonate. |
| 13-23 | 1 | Very dark grayish-brown 10YR 3/1 to 3/2 carbonate muck, abrupt boundary, oxidized rhizospheres, abundant shell debris, very reactive, 71% ash, 26% carbonate. |
| 23-35 | 1 | 10YR 3/2 carbonate muck, oxidized rhizospheres, less shell debris, very reactive, clear boundary, 80% ash, 27% carbonate. |
| 35-48 | 2 | 10YR 3/2 muck, some lighter color 10YR 4/3, wet, few shells, very reactive, clear boundary, 75% ash, 18% carbonate. |
| 48-70 | 2 | 10YR 2/2 silty muck, less organic rich, more silt than above, slightly plastic, clear boundary, 82% ash, 10% carbonate. |
| 70-73 | 3 | Very dark brown (10YR 3/2) to black (10YR 2/1) muck, loose, clear boundary, very reactive. |
| 73-75 | 3 | Very dark gray (10YR 3/1) muck, few shells, moist, very reactive. |
| 75-83 | 3 | Black (10YR 2/1) muck, moist, few shells, very reactive, 75% ash, 10% carbonate. |
| 83-89 | 3 | Very dark grayish brown (10YR 2/2) muck, slightly plastic, few shells, very reactive. |
| 89-94 | 3 | Very dark grayish brown muck (10YR 2/2) with abundant shells, very reactive. |
| 94-105 | 3 | Very dark grayish brown muck (10YR 2/2) peaty muck, very few scattered shells, violently reactive 68% ash, 20% carbonate. |
| 105-124 | 3 | Very dark grayish brown muck (10YR 2/2) peaty muck, shells increase with depth, very thin layer at 117 cm, very reactive, 66% ash, 10% carbonate. |
| 124-133 | 3 | Very dark grayish brown muck (10YR 2/2) muck, iron staining along roots, dense shell debris, some large shells, 78% ash, 22% carbonate. |
| 133-138 | 3 | Dark grayish brown 10YR 3/2 muck, moist, some shells-gastropods and shell fragments, common tabular macropores with iron oxide staining, abrupt boundary. |
| 138-142 | 3 | 5Y 4/1 dark gray gleyed silty muck to greenish silt, few shells, violently effervescent, 91% ash, 16% carbonate. |
| 142-145 | 4 | Very dark brown (10YR 2/2) to black muck, some shells, slight increase in silt with depth, also some carbonate-rich thin layers evident, 87% ash, 13% carbonate. |
| 145-154 | 4 | Very dark gray to black (2.5 Y 2/0-3/0) muck, slightly sticky, few shells, 85% ash, 7% carbonate. |
| 154-187 | 4 | Black very dark gray muck 2.5Y 2/0-3/0, several thin shell concentrations noted, 88% ash, 9% carbonate. |
| 187-194 | 4 | Black (2.5Y 2/0) silty muck, a hint of fine angular block structure noted, few shells, 88% ash, 9% carbonate. |
| 194-200 | 5 | Black to very dark gray (2.5y 2/0-3/0) silty muck, friable, moist, macropores, common shell debris, some very thin lenses of shells, 88% ash, 9% carbonate. |
| 200-211 | 5 | Black (10YR 2/1) silty muck, good structure, fine subangular blocky, ped surfaces are smooth and shiny may be highly compressed plant debris lens, common fine dark yellowish brown (10YR ¾-3/6) iron stains on ped surfaces, plastic, very dark gray cutans (2.5Y 3/0) lining macropores, some shell debris, also some thin lenses of shells, 87% ash, 4% carbonate. |

|  |  |  |
|---|---|---|
| 211-217 | 5 | Black (10YR 2/1) silty muck, firm, sticky, plastic, moderate shell debris, 85% ash, 7% carbonate. |
| 217-220 | 6 | Very dark gray brown (10YR 3/3) -black silty muck, breaks along zones of highly compressed, decomposed, smooth and shiny plant fragments, abundant shell debris, macropores which look like plant molds, violently reactive 88% ash, 5% carbonate. |
| 220-237 | 7 | Black (10YR 2/1) silty muck, shells increase with depth, 88% ash, 4% carbonate. |
| 237-256 | 7 | Black to very dark gray (10YR 3/1) silty muck, moist, abundant shells, two thin. Layers of concentrated shell debris, a few thin surfaces of compressed plant debris, 85% ash, 10% carbonate. |
| 256-270 | 7 | Black (5Y 2.5/1) featureless muck, slightly more organic than above, many matted plant fragments, almost no shells, a few sand granules near bottom, slightly reactive, strong sulfur odor, 76% ash, 4% carbonate. |
| 270-283 | 7 | Very finely laminated very dark grayish brown (2.5Y 4/2) muck or silt, nonstick, looks like ooze, abundant plant fragments and fibers, very reactive, this layer is lighter, has no structure, and is springy when first retrieved, 83% ash, 24% carbonate. |
| 283-290 | 8 | a.a., moister than above and darker (2.5Y 3/2-4/2), 81% ash, 12% carbonate. |
| 290-314 | 9a | a.a., sandier near bottom, a few pockets of fiber mixed in, 87% ash, 14% carbonate. |
| 314-330 | 9a-9b | Top laminated grading to a featureless ooze, dark grayish brown (2.5Y 4/2) mixed with sand , very reactive, sand layers increase in thickness and frequency to bottom, 94% ash, 7% carbonate. |
| 330-410 | 9b-10a | Finely laminated dark gray brown (2.5Y 4/2) to dark gray (5Y 4/1) silty mucky ooze, abundant organic fragments, very reactive, sulfur odor, 91-96% ash, 10-18% carbonate. |
| 410-427 | 10a-10b | Dark gray (5Y 4/1) to dark greenish gray (5GY 4/1) fine to medium loamy sand, abundant organic fragments including twigs and wood, few shells, very reactive, 97% ash, 5% carbonate, drive 10b begins at 411 cm. |
| 427-453 | 10b | Massive dark gray (5Y 4/1) sand, very reactive. |

**3**

| | |
|---|---|
| Location: | SE NW NE 28 T80N R25W |
| Landscape Position: | low upland ridge |
| Altitude: | 880-870 feet above MSL |
| Slope: | 2-5% |
| Date drilled: | 6/30/95 |
| Coring methods: | 7.6 cm diameter core, Giddings piston corer |
| Remarks: | |

| Depth (cm) | Soil Horizon (weathering zone) | Description |
|---|---|---|
|  |  | *Eolian Sand* |
| 0-28 | Ap | Very dark grayish brown (10YR3/2) loamy sand, very friable, noneffervescent, abrupt boundary, abundant roots. |
| 28-37 | A | Very dark grayish brown (10YR3/2) loamy sand, moderate fine granular, very friable, noneffevescent, clear boundary, abundant roots. |
| 37-60 | Bw | Dark brown to brown (10YR3/3-4/3) loamy sand, moderate medium subangular blocky, friable, noneffervescent, abrupt boundary, common roots. |
|  |  | *Dows Formation, Alden Member* |
| 60-88 | 2BC | Dark yellowish brown (10YR4/4) pebbly loam with thin stone zone at top, weak medium to coarse prismatic, friable, noneffervescent, clear boundary, few fine iron accumulations, few roots. |
| 88-246 | 2C1<br>(MJRU) | Grayish brown (2.5Y5/2) pebbly loam, massive, friable, strong effervescence, gradual boundary, abundant coarse olive brown (2.5Y4/4) mottles. |

|  |  |  |
|---|---|---|
| 246-442 | 2C2 (MJOU) | Brown (10YR5/3) pebbly loam, few thin seams of coarse sand, massive, firm, strong effervescence, clear boundary, abundant coarse brown and dark reddish brown (7.5YR4/4 and 5YR3/2)) mottles. |
| 442-484 | 2C3 (UJU) | Dark gray (10YR4/1) pebbly loam, few thin seams of coarse sand, massive, firm, strong effervescence, gradual boundary, common thin almost continuous brown (7.5YR4/4) accumulations along joints. |
| 484-632 | 2C4 (UU) | Dark gray (10YR4/4) pebbly loam, few thin seams of coarse sand, massive, firm, strong effervescence, abrupt boundary, wood at 570cm. |
|  |  | *Pennsylvanian System* |
| 632-840 | R | Gray to olive gray siltstone with 8cm thick coal at top, red mottles in lower meter, very dry and stiff. |

**101**
Location: NE NE NE 28 T80N R 25W
Landscape Position: valley bottom
Altitude: 830-840 feet above MSL
Slope: 0-3%
Date drilled: 3/27/96
Remarks: Approximately 30 feet from wetland edge.

| Depth (cm) | Description |
|---|---|
| 0-38 | Black dry muck. |
| 38-89 | Muck grading to fine to med grayish brown sand near bottom, becomes clayier. |
| 89-127 | Black pebbly (redeposited Morgan Member?) very sandy loam. |
| 127-152 | Grayish sand layer mixed with silt. |
|  | *Dows Formation, Morgan Member* |
| 152-160 | Brown oxidized very sandy and pebbly, loam. |

**102**
Location: SE NE NE 28 T80N R 25W
Landscape Position: valley bottom
Altitude: 830-840 feet above MSL
Slope: 0-3%
Date drilled: 3/27/96
Remarks: Approximately 90 feet from wetland edge, much core compression, top of core averages 60% ash, ash content increases down core.

| Depth (cm) | Description |
|---|---|
| 0-18 | Black highly organic loam (55% ash), some plant debris (2 in long, 1/8 in diameter), few snails population, reacts weakly with acid, abrupt boundary. |
| 18-41 | Gray brown sandy loam (fibric), abundant snail shells (3 mm), abundant root channels (1 mm diameter), oxidized rhizospheres, surfaces, strong reaction, gradual boundary. |
| 41-58 | a.a., shells more abundant to bottom (6 mm max diameter), strong reaction, gradual boundary. |
| 58-84 | Black clayey silt, reacts weakly with acid, some mottling, very poor recovery and distortion from removal from barrel. |
| 84-99 | Very dense compressed fibric layer, black to brown. |
| 99-175 | Brown to reddish brown peat, fibric, abundant snails, strong reaction, abrupt boundary with above, transitional to below. |

| | |
|---|---|
| 175-218 | Black silty clay but highly organic, few thin lenses of more fibric peat to peaty muck, strong reaction (sulfur odor), bivalve and gastropod shells. |
| 218-265 | Black silty clay, denser than above, non-reactive, thin (8 cm) sand lens present @ 256 cm, some pyrite crystals noted near bottom. |
| 265-300 | Very dense organic-rich silty clay, some lenses of brown peat. |
| 300-311 | Brown/gray fibric, compressed plant debris, large wood chip @ 300 cm (1 in long and 1 cm wide). |
| 311-326 | a.a., but sandier, some seeds and wood fragments present. |
| 326-357 | Abrupt boundary with above, grey/brown organic silt, lots of seeds present, but not a lot of plant debris, shells present (1-2 mm to 1-2 cm), @350 cm sand increases in abundance. |
| 357-420 | Grey/brown very organic-rich layer almost gyttya like, top is brown, stratified below gray brown grading into gray throughout. |

**103**

| | |
|---|---|
| Location: | SE NE NE 28 T80N R 25W |
| Landscape Position: | valley bottom |
| Altitude: | 830-840 feet above MSL |
| Slope: | 0-3% |
| Date drilled: | 3/27/96 |
| Remarks: | Drilled 20 feet, poor recovery 8-10 feet, hit sand at 16 feet description from upper core and field notes. |

| Depth (cm) | Description |
|---|---|
| 0-30.5 | Very dark brown-black silty muck, very few fine roots, slightly oxidized, abundant plant detritus, few shells, non-reactive matrix. |
| 30.5-61 | Very dark brown to black muck to silty muck, some gray, denser than above, few roots, some gastropod shell fragments, good oxidation in areas especially along roots, gray areas reactive, black areas non-reactive. |
| 61-91 | Grey/brown/red dense silt, abundant shells (1-2 mm), good oxidation along root zones, reacts readily with acid, root zones are <1mm, angular blocky structure. |
| 91-106 | Top is a thin layer of fibric peat (1-2 cm), then back to a gray silt with abundant compressed plant debris, reactive, still some structure, fewer shells than above, oxidation along root zones. |
| 106-122 | Black, highly organic, fibric, peaty-muck, abundant shells (grades from 1mm size at top to 3 mm size at bottom), prominent oxidation along root channels (1 mm in diameter), reactive. |
| 122-152 | Black muck, abundant shells (1 mm to 0.74 cm) and plant debris (1 in long, 2 mm wide), no visible root zones, reactive. |
| 152-233 | Black muck, shells are present in distinct layers, reaction related to shell occurrence, @185 cm some gleyed sediment, greenish-gray, below is a grayish-tan silt, mixed with compressed plant debris, denser to bottom. |
| 233-252 | Silty muck, much more silt and sand than above, large shell fragments, not as much plant debris as above, more woody debris (1/8 in wide) two distinct sand lenses @ 266 and 273 cm, reactive. |
| 252-480 | Organic gyttja-like sediment, brown. |
| 480-610 | Fine to coarse gray sand. |

**104**

| | |
|---|---|
| Location: | SE NE NE 28 T80N R 25W |
| Landscape Position: | valley bottom |
| Altitude: | 830-840 feet above MSL |
| Slope: | 0-3% |
| Date drilled: | 3/27/96 |
| Remarks: | Approximately 100 feet from south valley edge, core description from field notes. |

| Depth (cm) | Description |
|---|---|
| 0-46 | Loose black organic loam, frost layer just below litter. |
| 46-91 | Black muck with shells, there is a layer of very firm layered firmly packed fibers. |
| 91-137 | Brownish black silty muck. |
| 137-152 | Loose wet muck black to brown. |
| 152-183 | Dark gray silt with abundant shells, some sand grains noted. |
| 183-213 | Very firm dark gray clay grading to organic ooze. |
| 213-259 | Brown gyttja like organic layer, near bottom more mixed with fibers and carbonates. |
| 259-452 | Missing. |
| 452-579 | Top is a very dark brown peaty layer with fibers, large pieces of wood and shells, last 90 cm is dark gray, (possible Morgan Member) very fine grained loam. |

**105**

| | |
|---|---|
| Location: | NE NE NE 28 T80N R 25W |
| Landscape Position: | valley bottom |
| Altitude: | 830-840 feet above MSL |
| Slope: | 0-3% |
| Date drilled: | 4/8/96 |
| Remarks: | Core description from field notes. |

| Depth (cm) | Description |
|---|---|
| 0-20 | Black loamy, sandy muck. |
| 20-71 | Light tan, dry sand. |
| 71-122 | Gray sand mixed with some organic debris. |
| 122-244 | 1 tube = 4 feet missing. |
| 244-366 | Gray sand a.a., slightly browner @ bottom. |
| 366-498 | a.a., poor recovery. |

**106**

| | |
|---|---|
| Location: | SW NE NE NE 28 T80N R 25W |
| Landscape Position: | lower slope |
| Altitude: | 830-840 feet above MSL |
| Slope: | 0-3% |
| Date drilled: | 4/8/96 |
| Remarks: | Core description from field notes, poor recovery. |

| Depth (cm) | Description |
|---|---|
| 0-122 | Black loose dry muck. |
| 122-244 | Sand mixed with organics, last 30 cm is a brown to light tan silty clay loam, thin sand lenses throughout. |
| 244-488 | Sand. |

**107**

Location: SW NE NE 28 T80N R 25W
Landscape Position: lower slope
Altitude: 830-840 feet above MSL
Slope: 0-3%
Date drilled: 4/8/96
Remarks: Drilled 12 feet, recovered 8 feet, core description from recovered core.

| Depth (cm) | Description |
|---|---|
| 0-30 | Black silty loam, some plant debris and roots, reactive. |
| 30-42 | Gray-brown silty, sandy loam, abundant shells (1mm-3mm), oxidized root zones. |
| 42-78 | Black-brown silt, top has a planar arrangement of shells, shells gradually decrease to bottom, oxidized root zones (2 mm), reactive. |
| 78-91 | a.a., but increased clay content, shells and roots disappear, reactive layer of compressed plant debris near bottom. |
| 91-121 | Brown peaty muck to peat (70% ash), wood chips (2 cm long), some shells (2 mm). |
| 121-195 | Black peaty muck to muck, abundant shells (<1 mm to 0.5 cm), wood chunk at 142 cm, dense shells at 157and 182 cm, reactive (gives off a sulfur smell). |
| 195-203 | Light brown silt and sand, reactive. |
| 203-210 | Black muck (86-89% ash). |
| 210-259 | Gray sandy organic muck, abundant seeds, some gleyed lenses noted at 228-243, greenish sand. |
| 259-335 | Black to brown mucky peat, some fibric areas, also some thin sand lenses. |
| 335-365 | Gray medium to fine grained, well sorted sand with some silt. |

**108**

Location: SW NE NE 28 T80N R 25W
Landscape Position: valley bottom
Altitude: 830-840 feet above MSL
Slope: 0-3%
Date drilled: 4/8/96
Remarks:

| Depth (cm) | Description |
|---|---|
| 0-30 | Black, highly organic silty loam, fine roots. |
| 30-42 | a.a., small shells present (diameter is 1/8 in), root zones show oxidation, reacts weakly with acid. |
| 42-65 | Gray/black silty muck, abundant whole shells and shell debris, reacts strongly with acid, good oxidized root zones (1/8 in wide), some roots still present. |
| 65-75 | Gray silty muck, shells present (1/8 -1/16 in), some fine oxidized roots present, reacts well with acid. |
| 75-85 | Gray/black silty muck, red/orange oxidation coloring at top, reacts weakly with acid, lower part has abundant shells, root channels, faintly oxidized. |
| 85-106 | Black/gray silty muck, more dense than above, compressed plant debris zone, compressed plant debris looks like it was replaced to some extent by $CaCO_3$, reaction with acid is very strong. |
| 106-130 | Black silty muck, lower density than above, wood chips at 43 in, abundant oxidized root channels (1/8 - 1/16 in wide), reacts well with acid, abundant shell and shell debris (1/16 in diameter), there are a few thin lenses of fibric peat to peaty muck. |
| 130-175 | Black muck, reduced sulfur smell present, some small crystals of pyrite, reacts well with acid, some zones of concentrated shells. |

| | |
|---|---|
| 175-182 | Brown/gray silty clay, does not react with acid. |
| 182-243 | Brown silty clay, no reaction. |
| 243-365 | Very little recovery, loose black muck changing to firm silty muck from field notes. |
| 365-430 | Brown fibric peat. |
| 430-470 | Gyttja-like material, sponge like feeling, abundant seeds, large chunks of wood. |
| 470-487 | Gray green sand and gravel, range in size from 1/8 in to 1 in silt around the pebbles is calcareous. |

**109**

| | |
|---|---|
| Location: | SE NW NE NE 28 T80N R 25W |
| Landscape Position: | valley bottom |
| Altitude: | 830-840 feet above MSL |
| Slope: | 0-3% |
| Date drilled: | 4/8/96 |
| Remarks: | Core description from field notes. |

| Depth (cm) | Description |
|---|---|
| 0-30 | Loose black sandy muck. |
| 30-91 | Loose sand and gravel, light tan fine-medium sand and small pebbles. |
| 91-122 | Silty sand, more cohesive than above. |
| 122-175 | Silty sand grading to dark black silty sand over dark tan-gray sand over fine-medium brown sand, oxidized root channels. |
| 175-366 | Wet medium-coarse sand and pebbles, brown-orange large pebbles (up to 2 in), some silty layers, ended in coarse gravel. |

**110**

| | |
|---|---|
| Location: | SE NW NE NE 28 T80N R 25W |
| Landscape Position: | valley bottom |
| Altitude: | 830-840 feet above MSL |
| Slope: | 0-3% |
| Date drilled: | 4/8/96 |
| Remarks: | On the edge of circular cattail patch about 50' E of circular fresh cattail patch. |

| Depth (cm) | Description |
|---|---|
| 0-30 | 7.5 YR 2/0, very dark black silt, fine root channels (<1mm). |
| 30-61 | a.a., reacts with acid, shell and plant debris present. |
| 61-122 | 10YR 3/1, very dark gray, reacts violently with acid, shell debris present, some oxidation present along plant fragments and root zones. |
| 122-223 | 10YR 3/1 black to dark gray muck to mucky silt, grades to 10 YR 2/1 fibric peat, shell fragments increase to bottom, reacts with acid throughout (actual core measures 33.8 cm). |
| 223-365 | 10 YR 3/1 muck, shells are present, range in size (0.1-0.2 in), and increase to bottom, sand lenses present @ 22 cm, (actual core measures 53 cm). |
| 365-427 | Very firm black silty muck, shells become less abundant (actual core measures 39 cm). |
| 427-488 | 10 YR 2/2, very dark brown fibric peat, reacts with acid. |
| 488-549 | 10 YR 3/2, gray-brown, organic muck to ooze, some zones of compressed plant material and fibric peat, reacts well with acid, shells present, increase to bottom, range in size (0.1-1.5 in). |
| 549-610 | Dark reddish brown silty clay, reactive. |
| 610-700 | 5 Y 4/1, greenish-gray silty clay loam, reacts with acid. |
| 700-732 | Gray sand. |

**111**

| | |
|---|---|
| Location: | NW NW NE NE 28 T80N R 25W |
| Landscape Position: | valley bottom |
| Altitude: | 830-840 feet above MSL |
| Slope: | 0-3% |
| Date drilled: | 4/8/96 |
| Remarks: | On transect, about 75 feet S of CD-4 in triangular sedges, description from field notes. |

| Depth (cm) | Description |
|---|---|
| 0-150 | Black muck. |
| 150-182 | Firm gray-black silty clay. |
| 182-366 | Green sand grading to gray sand. |

**112**

| | |
|---|---|
| Location: | SW SE SE 21 T80N R 25W |
| Landscape Position: | valley bottom |
| Altitude: | 830-840 feet above MSL |
| Slope: | 0-3% |
| Date drilled: | 4/8/96 |
| Remarks: | Poor recovery especially upper half, water table appears to be at 3-4 feet. |

| Depth (cm) | Description |
|---|---|
| 0-61 | Loose black loamy silt. |
| 61-122 | Gray-black sandy silt (sand =10%), shells present (<0.01 in), good oxidation along root channels and planar surfaces, reacts well with acid. |
| 122-137 | Black –gray organic silt, few shells, little to no oxidation. |
| 137-183 | Very dark black muck, reacts readily with acid, abundant shells. |
| 183-244 | Dark black muck to silty muck, fewer shells than above, reacts readily with acid. |
| 244-290 | Greenish-gray silt, reacts readily with acid, few shells, several small pieces of wood (0.003 in wide), small grains of pyrite. |
| 290-305 | Thin layer of compressed plant debris. |
| 305-335 | Black-brown to green-gray organic silt, reacts readily with acid, med to small wood chips, plant debris present. |
| 335-366 | Black-brown organic muck with 30% gray sand toward bottom, reacts with acid, plant and wood debris present. |
| 366-487 | Gray sand, little recovery. |

**113**

| | |
|---|---|
| Location: | SW SE SE 21 T80N R 25W |
| Landscape Position: | valley bottom |
| Altitude: | 830-840 feet above MSL |
| Slope: | 0-3% |
| Date drilled: | 4/8/96 |
| Remarks: | Described 5/8/97. |

| Depth (cm) | Description |
|---|---|
| 0-61 | Top black-brown, organic loam, very reactive. |
| 61-122 | Black loam with iron staining dry, reactive. |
| 122-132 | Brown peaty muck lots of carbonate debris with shells, shells decrease down core. |
| 132-145 | Black-dark gray muck with few shells some good layers with shells at bottom, iron staining along roots, very reactive. |
| 145-158 | Dense silt layer. |
| 158-168 | Very dark brown muck, more shells than above. |
| 168-198 | Dark brown-very dark brown muck, some shells, some fibric peat lenses, very reactive. |
| 198-244 | Dark gray muck, high carbonate content, abundant shell debris, very reactive. |
| 244-366 | Black silt with abundant shell and shell debris, very reactive. |
| 366-389 | Black mucky silt with abundant shells, some peaty muck maybe along burrow or large root hole, grades to a muck with sand, some roots, some good rich peat inclusions. |
| 389-470 | Dark gray-gray, silt darkens downward, not reactive. |
| 470-487 | Peaty muck with wood, very reactive. |
| 487-610 | Organic ooze to silt, few shells, very dark gray-brown with some plant debris, laminated shell debris at bottom. |
| 610-732 | Charcoal near top, most of core is gray silt, very reactive, bottom is wood 2”. |
| 732-853 | Dark gray, 10 YR 3/1 silt grading to 10 YR 4/0 oxidized till, not many pebbles over a 10YR 3/2 till with pebble. |

**114**

| | |
|---|---|
| Location: | SE SW SE 21 T80N R 25W |
| Landscape Position: | valley bottom |
| Altitude: | 830-840 feet above MSL |
| Slope: | 0-3% |
| Date drilled: | 4/8/96 |
| Remarks: | Poor recovery, description from field notes. |

| Depth (cm) | Description |
|---|---|
| 0-122<br>~50% recovery | Loose black loamy muck, some sandy loam, grading to gray-brown muck, shells, oxidized roots, grades to dark brown to very dark brown muck, some fibric zones near bottom, good acid reaction. |
| 122-213<br>~50% recovery | Top 1/3, very dark brown muck, numerous shells, middle is similar but with more shells, stiffens at bottom to silty muck. |
| 213-243 | Soft black muck, large abundant shells, becoming firmer at bottom, grades to silty muck, whole section reactive. |
| 243-366<br>~58% recovery | Black silty muck to silt, some shells, grades to dark-brown to brownish yellow organic ooze, bottom 5 cm is gray sand. |
| 366-488 | Gray sand. |

**115**

| | |
|---|---|
| Location: | SE SW SE 21 T80N R 25W |
| Landscape Position: | valley bottom |
| Altitude: | 830-840 feet above MSL |
| Slope: | 0-3% |
| Date drilled: | 5/7/96 |
| Remarks: | |

| Depth (cm) | Description |
|---|---|
| 0-6 | Matted roots. |
| 6-25 | Loose, black soil, few shells, non-reactive. |
| 25-46 | Very dark gray calcareous muck, small bands of shells, also some scattered throughout, iron staining along roots. |
| 46-64 | Dark gray-brown-black muck, laminated shell layer, fine roots oxidized root channels. |
| 64-71 | Very dark gray-black muck, few shells, slightly siltier, than above, oxidized root channels. |
| 71-76 | a.a., more shells than above some burrows. |
| 76-89 | Somewhat featureless silty muck, few shells. |
| 89-107 | Laminated layers of packed cellulose plant debris, some shells, silty muck. |
| 107-121 | Muck, black-dark gray, few shells, more finer shells to bottom, lens of fibric peat at 114 cm, reactive throughout, some unoxidized root channels. |
| 121-167 | Dark gray-black muck scattered shells, reactive, oxidized root channels, some fibric zones especially at 155 cm. |
| 167-189 | Top black muck than grades to grayer with more snails with depth, good oxidized root channels. |
| 189-203 | Black-very dark gray, long oxidized root channels from 195-201 very abundant shells. |
| 203-213 | Very dark gray muck, slightly siltier than above, fewer shells decrease with depth, no noticeable root channels. |
| 213-243 | Dark gray muck, abundant shells, a tan precipitate has formed on bagged core. |
| 243-304 | No sample. |
| 304-320 | Dark gray brown-black muck, abundant shells to 315 cm, then dark black burrow, abrupt contact with below, very reactive. |
| 320-322 | Dark yellowish brown to dark grayish brown at bottom sandy loam, reactive, thin charcoal layer at bottom. |
| 322-341 | Dark brown-gray-black clay silt mixed with muck, some hint of laminated structure, slightly reactive. |
| 341-344 | Carbonate muck with laminate structure, grayish brown, few shells very reactive. |
| 344-350 | a.a., carbonate muck with mixed organic-rich burrows. |
| 350-367 | Very dark brown to dark gray-brown muck, scattered shells. |
| 367-374 | Carbonate muck, some pods of black muck, few snails. |
| 374-381 | Dark grayish brown muck, very reactive, few snails. |
| 381-396 | Gray carbonate mud mixed with organics, scattered shells, burrows, reactive. |
| 396-427 | a.a., muck mixed with sand. |
| 427-488 | Gray fine-medium sand. |

**116**

| | |
|---|---|
| Location: | SE SW SE 21 T80N R 25W |
| Landscape Position: | valley bottom |
| Altitude: | 830-840 feet above MSL |
| Slope: | 0-3% |
| Date drilled: | 5/7/96 |
| Remarks: | Described 5/7/98, very poor recovery below 8’, drilled to 28’. |

| Depth (cm) | Description |
|---|---|
| 0-45 | Black loam, non-reactive, some roots. |
| 45-168 | Black muck, reactive, some shells, some iron staining. |
| 168-213 | Silty muck, abundant pressed plant debris peat, iron staining along root casts, snails. |
| 213-244 | a.a., grayer. |
| 244-366 | Green-gray sand grading to gray silty sand. |

**117**

| | |
|---|---|
| Location: | SE SW SE 21 T80N R 25W |
| Landscape Position: | valley bottom |
| Altitude: | 830-840 feet above MSL |
| Slope: | 0-3% |
| Date drilled: | 5/7/96 |
| Remarks: | Drilled to 518 cm. |

| Depth (cm) | Description |
|---|---|
| 0-10 | Non calcareous black loamy soil, dry, roots are fine, abrupt boundary with below. |
| 10-20 | Slightly grayer mucky loam, abundant snails (effervesces with acid), oxidized root channels, moist. |
| 20-36 | Grey/brown silty muck; less snail debris, good oxidized root zone, wetter than above, compressed plant debris. |
| 36-51 | Gradational boundary with above, grades into a black, loamy, silty muck, fewer snails, good oxidized root channels, wetter than above. |
| 51-97 | Very dark gray to black, silt to silty muck, reactive, some shells near top of section, 82-97 cm layer of laminated plant debris. |
| 97-107 | Black to very dark brown muck (60% ash), fewer shells than above, some peaty inclusions, slightly reactive. |
| 107-119 | Very dark brown mucky peat with some shells. |
| 119-171 | Black muck with abundant shells, noticeable iron staining along root channel, reactive |
| 171-194 | Black silty loam, reacts weakly with acid, snail abundance decreases downward, iron staining along roots, abrupt contact with below. |
| 194-208 | Tan to greenish silt, no snails. |
| 208-259 | Dark grayish brown to grayish brown (more reduced colors in field, greener) very fine sand to silt, some sand pockets, sandier at top, noticeable iron staining near bottom, large wood chip near middle. |
| 259-305 | Dark brown-dark gray brown, fairly featureless silty-muck, more sand at top, very bottom picks up more shell debris and large shells, lots of dispersed sand on outside of core, from above?, reactive. |
| 305-335 | Dark gray-dark gray brown muck, few shells, middle is very laminated, fibric peat, thin layer of concentrated plant debris, bottom is sand mixed organic material. |
| 335-518 | Gray sand, poor recovery. |

**118**

| | |
|---|---|
| Location: | NE NW NE 28 T80N R 25W |
| Landscape Position: | valley bottom |
| Altitude: | 830-840 feet above MSL |
| Slope: | 0-3% |
| Date drilled: | 5/7/96 |
| Remarks: | |

| Depth (cm) | Description |
|---|---|
| 0-23 | Black firm muck to loamy soil, thicker than in other nearby cores. |
| 23-122 | Thin tan silt layer overlies hard black silt to silty muck, very few shells. |
| 122-140 | Firm black muck to silty muck (slightly reactive) over a layer of laminated plant debris (strong reaction) over a black-brown silty muck, very featureless (no reaction) then a thin shell layer. |
| 140-229 | Gray-yellow brown silt to silty sand (more reduced in field, greener), sandier to bottom, very reactive. |
| 229-335 | Sand to 259 cm, then grayish brown sandy silt, lots of thin sand lenses. |

| | |
|---|---|
| 335-396 | Sand at top grading to grayish to dark brown silt, featureless (non-reactive or very slight), iron staining on wrap. |
| 396-488 | Poor recovery, sand or sandy loam. |

**119**

| | |
|---|---|
| Location: | SW SW SE 21 T80N R 25W |
| Landscape Position: | valley bottom |
| Altitude: | 830-840 feet above MSL |
| Slope: | 0-3% |
| Date drilled: | 5/7/96 |
| Remarks: | Very uniform core, unlike others in area. |

| Depth (cm) | Description |
|---|---|
| 0-61 | Black loose loam grades to stiffer black muck, shell abundance varies through section, very reactive except extreme top. |
| 61-122 | Black muck with shells over brown silt grading to black silt with shells, reactive decreasing to bottom. |
| 122-203 | Dark silty muck to black muck, shells increase to bottom, still very firm. |
| 203-244 | Tan silt, darker gray with depth, iron staining along roots. |
| 244-366 | Silty sand grades to sand, pebbly at bottom (reduced green in field). |
| 366-488 | Pebbly sand. |

**120**

| | |
|---|---|
| Location: | NW NW NE 28 T80N R 25W |
| Landscape Position: | valley bottom |
| Altitude: | 840-850 feet above MSL |
| Slope: | 0-3% |
| Date drilled: | 5/7/96 |
| Remarks: | |

| Depth (cm) | Description |
|---|---|
| 0-91 | 0-2 plant debris, 2-15 sand, rest is black silty muck, slight to non-reactive, no shells. |
| 91-122 | Black silt, no shells, non-reactive, very firm. |
| 122-183 | Very dark brown (10YR2/2) silty muck to silt, few shell fragments, gradually gets grayer with depth, non-reactive. |
| 183-244 | Black-dark gray silt, no pebbles, no shells. |
| 244-366 | Black silt, near middle begins to pick up pebbles, bottom is gray-brown sandy loam with pebble (Morgan Mill till?). |
| 366-457 | Blue-gray silt over soft silty loam. |
| 457-579 | Coarse sand, poor recovery. |

**121**

Location: NW NW NE 28 T80N R 25W
Landscape Position: valley bottom
Altitude: 840-850 feet above MSL
Slope: 0-3%
Date drilled: 5/7/96
Remarks:

| Depth (cm) | Description |
|---|---|
| 0-122<br>50% recovery | 0-5 Black loam to loamy muck with roots, 5-25 black silty muck non-reactive, 25-38 black to brown sandy muck, 38-46 very sandy muck, 46-58 black silt. |
| 122-244<br>50% recovery | Black silt, featureless, non-reactive. |
| 244-335<br>55% recovery | Black silt grades to loamy tan sand or a sandy loam. |
| 335-366 | Darker gray than above loamy sand or sandy loam. |
| 366-488 | Sand, lots of iron staining, poor recovery. |

**122**

Location: NW NW NE 28 T80N R 25W
Landscape Position: valley bottom
Altitude: 840-850 feet above MSL
Slope: 0-3%
Date drilled: 5/7/96
Remarks: Very uniform core, unlike others in area.

| Depth (cm) | Description |
|---|---|
| 0-61 | 0-20 very dark gray-brown loam, dry, very reactive, 20-30.5 some large pebbles, dark brown loam, dry, very reactive, 30.5-61 1ight yellow brown (10YR6/4) loam very, reactive some pebbles. |
| 61-122 | a.a., yellow-brown loam with pebbles, carbonate concretions, bottom is more massive with lots of carbonate, iron along pebbles, very reactive. |
| 122-183 | a.a., massive, yellow-brown pebbly loam, much iron staining and mottles, very reactive throughout. |
| 183-244 | Loamy OU till. |
| 244-305 | Till a.a., more iron staining, very reactive. |
| 305-366 | OU till, violently reactive lots of iron and Mn staining along cracks, matrix grayer. |
| 366-427 | Transition from OU to UU till. |
| 427-442 | UU till. |

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