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Water Balance Analysis for a Nebraska Sand Hills Wetland Mitigation Site

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Final Report

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WATER BALANCE ANALYSIS FOR A NEBRASKA SAND HILLS WETLAND MITIGATION SITE

FINAL REPORT
(NDOR Project Number: P591)

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16. Abstract

The objective of this study was to explore the potential for estimating parameters within the water balance equation for the Rose Southeast Wetland Mitigation Bank Site, located in the Sand Hills region of Rock County, Nebraska, USA, from September 21, 2006 through September 14, 2007, to meet regulatory performance standard specifications and to make use of measured estimates to meet credit certification of the site for further use as a banking instrument for future crediting toward Nebraska Department of Roads (NDOR) projects. Secondary objectives were to determine if methods used could be reproduced on a similar budget under similar site conditions. The development of a water balance for a wetland mitigation site, for purposes of addressing performance standards outlined by the United States Army Corps of Engineers, is an essential task to determine viability of the site to, within reason, maintain functions replaced due to Section 404 procedures of The Clean Water Act. The history of compensatory mitigation within the Sand Hills region of north-central Nebraska is poorly-defined and nearly non-existent. Studies focusing primarily on the enhancement and/or restoration within mitigation are lacking, but essential in maintaining regionally-specific aquatic resources.

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ABSTRACT

The objective of this study was to explore the potential for estimating parameters within the water balance equation for the Rose Southeast Wetland Mitigation Bank Site, located in the Sand Hills region of Rock County, Nebraska, USA, from September 21, 2006 through September 14, 2007, to meet regulatory performance standard specifications and to make use of measured estimates to meet credit certification of the site for further use as a banking instrument for future crediting toward Nebraska Department of Roads (NDOR) projects. Secondary objectives were to determine if methods used could be reproduced on a similar budget under similar site conditions. The development of a water balance for a wetland mitigation site, for purposes of addressing performance standards outlined by the United States Army Corps of Engineers, is an essential task to determine viability of the site to, within reason, maintain functions replaced due to Section 404 procedures of The Clean Water Act. The history of compensatory mitigation within the Sand Hills region of north-central Nebraska is poorly-defined and nearly non-existent. Studies focusing primarily on the enhancement and/or restoration within mitigation are lacking, but essential in maintaining regionally-specific aquatic resources. Utilizing on-site meteorological instrumentation and data analysis via the Bowen-ratio energy budget approach, surface energy balance ET measurements were correlated with the influence of the highly variable water table depth and on-site surface water retention and flow. Groundwater and surface water flows were assessed via subsurface monitoring wells and portable flume. Daily ET rates throughout

the study were highly variable, particularly during the growing season with a range of 0.4 to 8.0 mm day^{-1} and a daily average of 3.4 mm day^{-1}. Total discharge through the flume measured from March 31, 2007 to September 14, 2007 totaled 8.2 x 10^{-4} m^3 t^{-1} for the given time period. Total groundwater flow computed from May 13, 2007 to September 14, 2007 toward the surface within the historic Gracie Creek alone amounted to 10.5 x 10^{-4} m^3 t^{-1}. An estimated change in storage could be obtained for the May 13, 2007 to September 14, 2007 time period, representative of most of the growing season, resulting in a positive balance of 2.7 x 10^{-4} m^3 t^{-1}. The estimated annual change in storage for the east half-section totaled 30.4 x 10^{-4} m^3 t^{-1}. Approximately 85% of water input was supplied by rainfall, with a total depth of 0.24 m covering the entire east half-section after ET.

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I. INTRODUCTION

A. BACKGROUND

Estimating the extent of wetlands on a global scale is difficult. The most commonly cited approximation is roughly 4 to 6 percent of the earth's land surface is considered wetland (Mitsch and Gosselink, 2000). Nationwide, the conterminous 48 states alone contain an estimated 104 million acres, by 1980 estimates. In comparison to 1780 estimates (based on hydric soils), the United States has lost 116 million acres (~53%), primarily due to urban development and agriculture. Regionally, Nebraska attributes most of its 1 million acre loss (~35%) to the conversion of wetland systems into viable cropland (Dahl, 1990). These losses have exacerbated flood damage, abated bird populations, and decreased buffering for filtering chemicals out of the nation's freshwater systems. Society now realizes the impact wetlands have on our world as "sources, sinks, and transformers of a multitude of chemical, biological, and genetic materials" (Mitsch and Gosselink, 2000). As a component of the hydrologic cycle, wetland systems cleanse polluted waters from both natural and human sources as well as constitute a major source of recharge to underlying groundwater.

Increased recognition of freshwater ecotones throughout the 19^{th} Century and their ability to maintain a healthy well-balanced ecosystem generated a multitude of laws attempting to protect wetlands. The Federal Water Pollution Control Act (FWPCA) of 1972, commonly referred to as the "Clean Water Act" as amended in 1977, sought to "prevent, reduce, and eliminate pollution…" in freshwater systems, including wetlands (Code of Federal Regulations, 1986). As a result, the preservation and mitigation of wetlands has been recognized as a necessity in following the national policy of "no net loss". Successful compensatory mitigation is largely based on the ability of managers to determine the quality of mitigation supported by functional assessment techniques rather than the traditional standard of only quantity measured in acreage. The U.S. Army Corps of Engineers (USACE) require replacement of lost wetland functions within a given watershed to maintain regionally-specific aquatic resources (USACE, 2002). To meet these goals, certain hydrologic conditions must be met, which are better understood when proper identification of water sources and sinks are assessed (Lott and Hunt, 2001). Such conditions are dependent upon climatic factors ultimately leading to deviation of precipitation, run-off, groundwater flux, surface water infiltration, and evapotranspiration. In turn, hydrologic conditions affect the success rate of biota that develop within the wetland system and ultimately determine the wetland function (Mitsch and Gosselink, 2000). Hydrologic conditions vary from season to season and are best articulated with the rise and fall of a wetland's surface and subsurface water levels. Commonly referred to as the hydroperiod, the constancy of a wetland's inflows and outflows are dependent upon an array of factors encompassing terrain relief, radiative properties, location, subsurface geology, soil conductivity rates, and the existing water conditions when acted upon by precipitation (Mitsch and Gosselink, 2000).

B. PURPOSE OF STUDY

This paper presents the results of a one year field study of evapotranspiration, groundwater flow, and surface water influences at a Nebraska Sand Hills semi-arid wetland mitigation site. The objective of this study was to develop an overall representation of the water balance for the site in order to meet regulatory performance standard specifications, and to make use of measured estimates in order to meet credit certification of the site for further use as a banking instrument for future crediting of Nebraska Department of Roads (NDOR) projects. Secondary objectives were to determine if methods used could be replicated on a similar budget under similar site conditions. Utilizing on-site instrumentation, ET measurements, via a Bowen-ratio energy budget approach, were correlated with the influence of water table encroachment and surface water retention and flow to characterize the movement of water within a restored wetland system. Such information would benefit NDOR for monitoring and possible acquisition of additional land, leading to potential mitigation within similar geographic service areas[(1)].

C. IMPLICATIONS

The development of a water balance (the mass of water moving through the various portions of the hydrologic cycle) for a wetland mitigation site for purposes of addressing performance standards outlined by the USACE is an essential task to determine viability of the site to, within reason, maintain functions replaced due to Section 404 procedures outlined within the Clean Water Act of 1977. Section 404 is the permit system regulating the discharge of dredged or fill material into "waters of the

[(1)] The geographic area within which a mitigation bank is authorized to provide compensation for unavoidable impacts authorized by Department of Army Permits (Federal Register, March 28, 2006).

United States" which affect interstate commerce. Use of a water balance equips wetland managers with a foundation for properly mitigating lost wetland acres through selection of an optimal location. However, lack of planning typically results in the inability of wetland managers to foresee and properly adjust for varying site conditions due to constantly shifting climatic influences. The reduction or potential loss of water sources due to drought conditions is a frequent example of the lack of planning, which may lead to site failure. Adaptive management techniques may be required to rectify any deficiencies resulting from unforeseen changes (USACE, 2002). Prevention of such deficiencies begins with selection of a site conducive to sustaining a wetland flora, contingent upon a substantial supply of water, rather than the mere reliance upon the purchase of available land, often lacking a sustainable water supply. Coupled with efficient planning based on use of a water balance, an improved hydrologic characterization of the site would likely undermine the typical mitigation site which commonly fails to meet original design criteria in order to replace lost functional wetland systems (Kusler and Kentula, 1989).

Successful calculation of a water balance is difficult considering the estimation of several parameters within the equation that are often associated with large errors (Rovansek, 1996). Improvements in calculating any component of the water balance will aid wetland managers in measuring wetland hydrology more accurately, which may facilitate mitigation success (Lott and Hunt, 2001). The parameters in the equation vary in importance depending upon the type of wetland observed; not all terms are incorporated due to site-specific characteristics (e.g., inland wetland systems lacking tidal influences). The result is the observance of increasingly large variability of flows in and out of the wetland system (Mitsch and Gosselink, 2000).

D. EVAPOTRANSPIRATION

Evapotranspiration (ET) is a major component of the hydrologic balance observed in most wetland systems (Lafleur 1990, Kim and Verma 1996, Burba et al. 1999, Lott and Hunt 2001, Jacobs et al. 2002, Stanndard et al. 2004). Partitioning of two parameters combined into one, 1) evaporation from water and/or ground surface, and 2) transpiration from vegetated cover, ET constitutes a significant portion of the water balance. In the absence of human involvement, ET and precipitation are often associated as the principal controls of water table depth (Kim and Verma, 1996), however, other factors may dominate in some systems. Dependent upon the deviation of site characteristics and climatic conditions worldwide, ET ranges between near 0 percent (not a frequent occurrence in wetlands) up to 90 percent of the local water balance in wetlands resulting in high seasonal variability (Kim and Verma 1996, Burba et al. 1999b, Mitsch and Gosselink 2000, Winter et al. 2001,). Variability is greatly reliant upon available open water and soil water content commonly classified into two stages. The first stage has adequate water near the soil surface with the second experiencing limited encroachment of the water table near the surface. First stage ET is energy dependent, with its primary limiting factor as the availability of energy from radiative and sensible heat sources. First stage ET is fairly well understood and readily measured, with most wetland systems comprised of emergent vegetation with a saturated and/or inundated soil surface.

Second stage conditions are primarily water dependent and lack exchange into the atmosphere under dry circumstances (Jacobs et al., 2002). Jacobs further explains that constructed wetland systems often experience water table depths that fluctuate below a relatively shallow wetland plant's root zone, resulting in plant stress, a common observation in semi-arid regions similar to the Nebraska Sand Hills. Although the benefit of an ever-changing water table depth induces variability in observed wetland plants on site, the drawback is the potential for invasive species to take over a mitigation site.

Energy budget methods are the most accurate way of estimating ET, however, they are used less often due to their expense. In effect, evapotranspiration estimates become a residual term or are merely calculated using off-site data (Harbeck et al. 1958, Gosselin et al. 2006). Such off-site estimates calculate for potential evapotranspiration (ET_p) which assumes well-watered conditions based on reference crop coefficients as demonstrated via the Penman combination method (Penman 1948, Robinson and Hubbard 1990). These estimates can be erroneous and overestimated for semi-arid regions where water is scarce and crop coefficients are negligible. When on-site data are collected, measurements are interpolated through simple meteorological equations such as the Bowen-ratio energy balance equation. Although most focused ET measurements are made while evaluating natural wetland systems (Lafleur 1990, Kim and Verma 1996, Burba et al. 1999a., Burba et al. 1999b., Winter et al. 2001, and Jacobs et al. 2002), little attention has been given to constructed or managed systems (Lott and Hunt, 2001). The result is a poorly quantified loss of water vapor, undermining the evapotranspiration term in the water balance equation for such sites.

E. GROUND WATER

The influence of groundwater in wetland hydrology is in general poorly understood due to difficulties in accurately quantifying flux and infiltration rates from surface waters (Hunt and Krabbenhoft, 1996). Nevertheless, the potential effect groundwater has on wetland function is important with respect to water uptake by the wetland flora. Where groundwater levels are relatively shallow, plant stress is unpronounced, allowing for a close approximation of ET when correlated with sub-surface deviations of groundwater (Gosselin et al., 2006). Groundwater reserves are dependent upon infiltration rates controlled by direct precipitation, surface water systems (e.g., lakes and streams), and possible artesian influences. Numerous studies have examined the effects of groundwater flux utilizing Darcy's equation and/or isotopic movements in natural systems (Hunt and Krabbenhoft 1996, Gosselin et al. 1999, Winter et al. 2001, and Szilagyi et al. 2003), but relatively few have examined the impact exchange of groundwater on evapotranspiration in a managed wetland (Hunt and Krabbenhoft 1996, Lott and Hunt 2001).

F. SURFACE WATER, PRECIPITATION & SURFACE STORAGE

Surface water flow, precipitation, and retention in a managed wetland are recognized as fundamental portions within the water balance equation. Considered the boundary layer of exchange between the atmosphere and the underlying groundwater reserve, surface water encounters a myriad of inputs and outputs, contributing to the overall storage capacity. Influenced directly by precipitation, water table depth, and atmospheric vapor flux; surface water regimes vary in their amount contributed to overall evaporation (E) rates (Jacobs et al., 2002). Various studies have examined the variability of E from open water systems (Lafleur 1990, Rovansek et al. 1996, Kim and Verma 1996, Burba et al. 1999a, Burba et al. 1999b, Rosenberry et al. 2004), and as one may assume is based largely on climatic influences previously described. Most wetland systems, however, contain vegetation in the presence of standing surface water, again considered essential in proper mitigation for replacing most lost functions. Numerous studies have examined the explicit effect vegetation has on E rates in standing water and whether ET rates are reduced or equal to open water evaporation during peak growth (Linarce et al. 1970, Lafleur 1990, Burba et al. 1999b,). Conflicting results reveal the presence of inundated vegetation and open water systems producing different overall ET or E rates between sites. It is generally asserted that vegetation may hinder advective and radiative properties reaching the water surface, resulting in less water vapor flux. In contrast, many believe that vegetative transpiration (T) rates would replace the difference of E displaced by vegetation canopy interference (Mitsch and Gosselink, 2000). What the site condition may be, the connection between surface water, precipitation, and groundwater, with or without the presence of vegetation, is well documented in respect to the overall water balance. Relatively few studies (Burba et al. 1999b, Winter et al. 2001, Szilagyi et al. 2003, Gosselin et al. 2006,), however, have explored these connections within semi-arid regions similar to the Nebraska Sand Hills, and virtually none with regard to compensatory mitigation.

II. STUDY SITE & METHODOLOGY

A. STUDY SITE

1. SAND HILLS OVERVIEW

The Nebraska Sand Hills region, one of the largest grass-stabilized dune regions in the world, is approximately 58,000 kilometers² (km) in area, and contains nearly 5000 km² that possess wetland characteristics (Gosselin et al. 1999, Gosselin et al. 2006). Formed by eolian processes, a majority of the Sand Hills region is composed or underlain by the Valentine series soil composed of fine and coarse sands exhibiting high permeability and excessively drained characteristics (USDA-SCS, 1985). A critical and well studied component of the area is the interdunal topographic depressions exhibiting a relatively shallow water table in wet meadows, fens, and shallow lake systems (Kim and Verma 1996, Burba et al. 1999a, Burba et al. 1999b, Gosselin et al. 1999, Gosselin et al. 2006, Harvey et al. 2007). These highly saturated systems are often isolated wetlands, yet, they are connected hydrologically and depend upon the underlying groundwater system as a point of discharge. Utilized often for hay-grazing cattle operations, these interdunal wet meadows remain a staple in the local economy (Gosselin et al. 2006). Thought to be in danger due to excessive pumping from the approximate 6,700 registered groundwater wells within the Sand Hills region alone (USDA-NRCS, 2006), groundwater reserves continue to feed these unique ecological systems providing habitat for migratory waterfowl during spring and fall months.

The Sand Hills region is considered the main recharge area for groundwater in the Ogallala Group of the High Plains Aquifer, as a result of highly permeable characteristics observed within sandy soils also contributing to approximately 80% of the mean annual runoff when soil saturation is met. Infiltration rates due to precipitation of nearly 580 millimeters (mm) year^{-1} in southern Rock County contribute to the rise of the relatively shallow groundwater table. ET rates nearing 520 mm year^{-1} are common (Szilagyi et al., 2003).

2. SITE DESCRIPTION

The study was conducted at the Rose Southeast Wetland Mitigation Bank Site, located in the Sand Hills region of Rock County, Nebraska, USA (42° 6’ N, 99° 22’ W). The duration of the study was from September 21, 2006 through September 14, 2007 (Figure 4). The one square mile site (25.9 x 10^{-5} m^2) (T. 25 N, R. 18 W, S. 26) is currently owned by NDOR and serves as a mitigation bank for construction projects in the Sand Hills geographic service area. The Rose site was partially restored to replace a failed mitigation site located within the same geographic service area. The site falls within Gracie Flats and is considered the headwaters of Gracie Creek, which eventually flows south into Calamus Reservoir, located in Loup County. The site was purchased in mid-2003 and has four center pivot irrigation wells located on site. One center pivot well was installed in each quarter section in 1972 to provide water to assist with the production of corn, cane, and oats. Adjacent lands to the north, east and west are currently part of the U.S. Department of Agriculture-Natural Resources Conservation

Service (USDA-NRCS) Conservation Resource Program (CRP), and were previously planted with center-pivot row crop as well. Following site acquisition, NDOR removed the pivots and tile drains and filled portions of the channelized Gracie Creek to induce ponding. Channelized flow of Gracie Creek between east and west half-sections was re-directed back to its original flow line at a diagonal from northwest to southeast in the east half section.

Surface water flow into the site enters through one 40 centimeter (cm) and one 122 cm corrugated metal pipe culverts and is retained on site by construction of a temporary, now permanent, berm on the south edge to induce ponding. Under conditions of mass influx of water, some surface water accumulates such that overtopping of the berm is possible. Such conditions are experienced following snow melt and during spring rain with little to no inundation or soil surface saturation throughout the remaining year. The result of these changing conditions, the site experiences both first and second stage evapotranspiration. Prior to this study, it was assumed but not verified that groundwater in the southeastern quarter section, and within the abandoned center pivot well (CPW-2) were artesian. The abandoned center pivot wells vary in depth ranging from 48.8 to 54.8 meters (m) (54.8 meters in the southeastern quarter section). Wells are screened from a depth greater than 30.5 m to the maximum depth of the wells (Table 1).

Of the 2.6 km^2, approximately 1.5 km^2 were expected to be classified as wetlands assessed by the USACE 1987 Delineation Manual (Environmental Laboratory, 1987) utilizing Cowardin Classification Types (Cowardin et al., 1979). Of these approximately 0.06 km^2 were existing wetlands found mostly in drainage-ways created for agricultural runoff. An additional 1.0 km^2 of upland were expected to be established or preserved. Wetland and upland areas were seeded in the spring of 2004 and watered before center pivot removal. Wetland hay from a Sand Hills wetland was used as a seed source for the developing wetland areas. Dominant wetland vegetation included:

- *Typha angustifolia* L. (narrow leaf cattail)
- *Spartina pectinata* Link (prairie cordgrass)
- *Polygonum pensylvanicum* L. (pink smartweed)
- *Hordeum jubatum* L. (foxtail barley)
- *Carex sp.* L. (sedge)

USDA-NRCS provided NDOR with a seeding list of native grasses and forbs for the upland to include:

- *Andropogon gerardii* subsp. *Hallii* (Hack.) J. Wipff (sand bluestem)
- *Koeleria macrantha* (Ledeb.) Schult. (prairie junegrass)
- *Calamovilfa longifolia* (Hook.) Scribn. (prairie sandreed)
- *Eragrostis trichodes* (Nutt.) A.W. Wood (sand lovegrass)
- *Schizachyrium scoparium* (Michx.) Nash (little bluestem)
- *Sorghastrum nutans* (L.) Nash (indiangrass)
- *Andropogon gerardii* subsp. *Gerardii* Vitman (big bluestem)
- *Amorpha canescens* Pursh (leadplant)
- *Astragalus crassicarpus* Nutt. (groundplum milkvetch)
- *Cleome serrulata* Pursh (Rocky Mountain beeplant)
- *Helianthus maximiliani* Schrad. (Maximilian sunflower)

- *Liatris punctata* Hook. (dotted gayfeather)
- *Penstemon grandiflorus* Nutt. (large beardtongue)
- *Petalostemum pupureum* Vent. (purple prairie clover)
- *Ratibida columnifera* (Nutt.) Wood. & Standl. (upright prairie coneflower)
- *Rosa arkansana* Porter (prairie rose)
- *Liatris squarrosa* (L.) Michx. (scaly blazing star)

Since site establishment in 2004, the proliferation of woody perennial species has resulted in cottonwood saplings *Populus deltoides* Bartr. *Ex* Marsh. Var. *occidentalis* Rydb. (plains cottonwood) dominating the site surface. NDOR utilized a somewhat unique system of managing invasive species through the introduction of goats for grazing, in 2005 and 2006. Cottonwood eradication results were discouraging, leading to alternate management techniques to include mowing in spring 2007 and application in August 2007 of Hi-Dep 2,4-D broadleaf herbicide (PBI/Gordon Corporation, Kansas City, Missouri).

B. METHODOLOGY

1. EVAPOTRANSPIRATION

Evapotranspiration was measured using a Bowen-ratio energy budget system (Bowen, 1926), located approximately 130 m SSE from the southeastern quarter section center pivot well CPW-2 (Figure 4). The location provided an upwind fetch of 469-564 m in the W, WNW, NW and NNW, 320-428 m in the E, ESE, SE and SSE, and about

290 m in the S. These fetch distances merely pertain to distances from edge of the southeastern quarter section and should not be considered definitive leading edges. It is important to note that adequate fetch was assumed within this study. Adequate fetch is essential when calculating the Bowen-ratio energy budget system as air moves from one surface type to another (e.g. upland to wetland). The result is a gradual change in vapor pressure and temperature gradients downwind of the transition zone commonly referred to as the leading edge. With increased fetch, the air moving becomes increasingly affected by the energy fluxes from the below ground surface (e.g. wetland) and less from the upwind surface type (e.g. upland) (Stannard et al., 2004).

Solar and far infrared radiation (Rn) was measured with a net radiometer (Kipp & Zonen, Inc., model CNR1, The Netherlands) with built-in pyranometers and pyrgeometers at 1.9 m above the vegetated surface. The radiometer was attached to a horizontal bar on a vertical pole, separated from the tower and was oriented due south for maximum radiation exposure. Air temperature and humidity gradients were measured with two shielded, non-aspirating temperature/humidity probes (Vaisala, Inc., model HMP45C, Helsinki, Finland) placed at fixed heights of 1.85 and 3.7 m. To validate and test the accuracy and precision of the air temperature/humidity probes, measurements were taken on the East Campus of the University of Nebraska-Lincoln every 10 seconds (s) and averaged every 30 minutes from August 30, 2006 through September 8, 2006 prior to site introduction by setting sensors at the same height, to measure any deviation. Results of a paired t-test for air temperature showed sufficient evidence to conclude that the average of the differences between the two sensors was not significantly different from zero ($p=0.92$). Thus, approximately 92% of the time, the difference between the two sensors was near zero validating the use non-exchanging air temperature probes in this study. Results of a paired t-test for actual vapor pressure showed evidence to conclude that the average of the differences between the two sensors was significantly different from zero ($p=1.16\ e^{-05}$). This resultant p-value is not an accurate representation of the differences between the two sensors because little deviation occurs between the differences resulting in an underestimated p-value. Instead, it may be better to address the average of the differences (0.00028) to indicate the accuracy of the two sensors.

Soil heat flux (S_s) was determined by averaging two soil heat flux plates (Radiation and Energy Balance Systems, Inc., model HFT3, Bellevue, Washington) that were placed at a depth of 0.05 m. The given amount of soil heat flux at the soil surface is to be utilized as a portion of the energy consumed in initiating ET. A comparative study (Billesbach et al., 2004) between fast-response eddy covariance systems and a slow-response system similar to the one used in this study reveals an adequate degree of energy closure in the absence of correcting for the storage heat term above the soil heat flux plates. However, it must be noted that the energy closure was based on dry soils, contrasting the soil conditions in this study during times of saturation or inundation. The use of energy balance closure as an indicator of the accuracy of eddy covariance flux terms is a controversial topic (Wilson et al., 2002). Nevertheless, it is indicative in demonstrating the consistency of the results between two systems (Billesbach et al., 2004).

Wind direction and speed (U) were measured with a wind monitor (R. M. Young Company, model 05103, Traverse City, Michigan) placed at a height of 4.0 m above the ground surface. Atmospheric pressure (P) was measured with a barometric pressure sensor (Vaisala, Inc., model CS105, Helsinki, Finland). Photosynthetic photon flux density (PPFD) was also monitored (LI-COR, Inc., model LI190SB, Lincoln, Nebraska).

All meteorological measurements were collected every 10 seconds and averaged over each half hour interval from September 21, 2006 through September 14, 2007 (Appendix A). From those data, a value of ET (millimeters) was calculated, totaled for each day, month, and throughout the term of the study. To facilitate the water balance computation, ET was then multiplied by the area of the study to yield a volumetric rate of flow. Data were collected on-site with a datalogger (Campbell Scientific, Inc., model CR1000, Logan, Utah) equipped with a relay multiplexer (Campbell Scientific, Inc. model AM16/32, Logan, Utah) for additional terminal sensor hookups. ET rates were compared to daily ET_p (Potential Evapotranspiration) calculated using the via Penman combination method from the Barta High Plains Regional Climate Center's (HPRCC) Automated Weather Data Network station, located approximately 27 km WNW of the Rose mitigation site (Penman 1948, Robinson and Hubbard 1990). Data analyses were conducted using SAS 9.1 statistical programs (Appendix B).

2. GROUNDWATER

Water table depth and static water levels were determined from June 22, 2006 through September 14, 2007 once every hour using nine Levelogger Gold pressure transducers (Solinst Canada, Ltd., model 3001 LT M5/F15, Georgetown, Ontario, Canada) equipped to measure both temperature and absolute pressure. Transducers were placed in eight subsurface observation wells (OW-1 through OW-8) installed in mid-2004 by HWS Consulting Group (Lincoln, Nebraska), and existing center pivot well number 2 (CPW-2) (Figure 4). Center pivot wells 1, 3 and 4 were not utilized in this study due to presence of oil, most likely from the pre-existing hydraulics of the center pivot, which could potentially ruin the equipment. Two additional observation wells affixed with drive well points (Water Source, Ltd., Grimes, Iowa) were installed May 13, 2007, one within one meter of Gracie Creek and one approximately 80 m from standing water. Both of these wells were located adjacent to existing observation wells in the southeast and northeast quarter sections (Figure 4). Water levels were computed after the data had been corrected for barometric pressure measured with an on-site barologger (Solinst Canada, Ltd., model 3001 LT M5/F15). The calculated difference between the total pressure measured by the levelogger and that of the barologger had a maximum error of +/- 0.003 meters.

Each of the eight subsurface observation wells, two located in each quarter section, are approximately 1.5 m in depth and are screened from the bottom up to 0.15 m below the ground surface. Materials consist of 0.05 m schedule 40 PVC slotted 0.003 m screen. Construction then consisted of 0.05 m schedule 40 PVC casing from 0.15 m below the ground surface to approximately 1.2 m above the ground surface encased within a 0.1 m by 0.1 m steel protective cover set in a concrete pad at the ground level. The two drive well points (sand points) are approximately 2.4 m in depth and screened from 1.5 m to 2.3 m. Closed galvanized 0.03 m pipe with couplings are attached to the points and continue to a height of approximately 1.0 m above the ground surface (Table 1 and Figure 1).

All center pivot wells and subsurface observation wells are registered by the Nebraska Department of Natural Resources (DNR, 2007). Water table depth was measured biannually on-site (southwest quarter section center pivot well CPW-3, Registered Well G-038571) by the Lower Loup Natural Resources District from 1973 to early 2006. Measurements were taken mostly in April and October and averaged 1.9 m below the ground surface. Levels averaged 2.1 m following removal of the pivots in mid-2004 (USDA-NRCS, 2006).

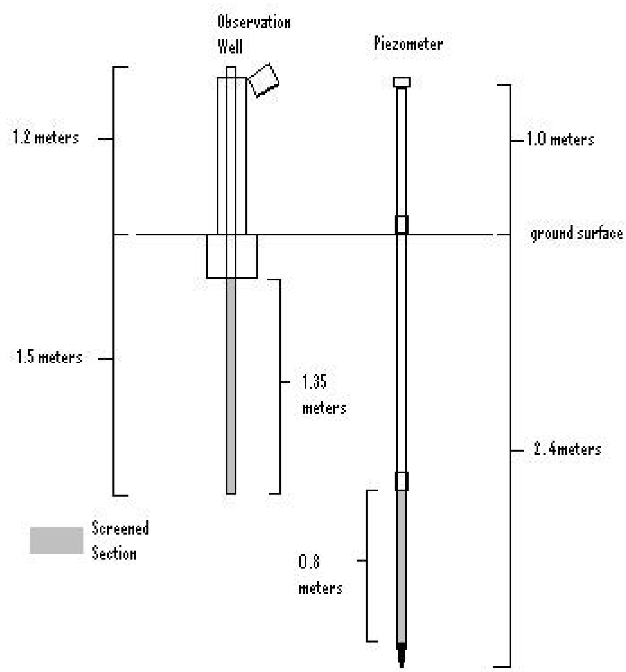


Figure 1. Observation and piezometer wells

3. SURFACE WATER

Wet precipitation amounts were measured using a tipping bucket (Texas Electronics, Inc., model TE525, Dallas, Texas) over the course of the study and were later compared to 30-year norms from the Rose National Weather Service Cooperative Weather Network station, located approximately 27 km WNW of the Rose mitigation site. Streamflow into the site was measured with an Adjust-a-flume (Nu-way Flume and Equipment Co., model AF2, Delta, Colorado) adjustable-sill, rectangular-throated flume. The flume had a maximum flow rate of 2 ft^3 s^{-1} (0.057 m^3 s^{-1}), and a minimum flow rate of 0.1 ft^3 s^{-1} (0.003 m^3 s^{-1}) and was accurate within +/- 3%. The flume was installed on-site immediately downstream of the divergence of the channelized ditch on the pre-existing Gracie Creek flow-line (Figure 4). Investigators discovered in mid-January 2007, prior to flume installation, that the berm separating the channelized flow of Gracie Creek was not yet removed to divert the flow back to the historic Gracie Creek as called for under site construction. Investigators created a 0.15 m wide cut through the berm in late March 2007 to allow some flow of retained waters to flow onto the site. Immediately following, NDOR personnel were able to access the site and remove a substantial portion of the berm on April 3, 2007.

A volumetric value for surface storage was computed using the ArcGIS 9.2 3D Analyst extension Surface Volume Tool. The tool uses a Triangular Irregular Network (TIN) file created from the connection of three known elevations, surveyed approximately nine meters apart, to yield a triangle with three known elevations. Multiple elevations are interpolated between each the three survey points on the plane of the triangle. The triangles are connected to form a landscape with known elevations at every point on the surface. The TIN file is used in conjunction with one Levelogger Gold (Solinst Canada, Ltd., model 3001 LT M5/F15, Georgetown, Ontario, Canada) pressure transducer installed on-site on March 15, 2007 and located approximately 360 m SSE of the southeast center pivot at the interface of the ground/water surface on a vertical metal rod within an area of inundation (Figure 4). The Surface Volume Tool computes the volume between the TIN file surface and the water surface.

4. MODIFICATIONS

Between three days, there was a total of six missing or duplicated half hour data measured by the ET tower as a result of the Loggernet program (Campbell Scientific, Inc., version 3.2, Logan, Utah) automatically setting the CR1000 datalogger clock to the laptop time during downloading of the data. Re-setting the clock caused a duplication or removal of a measured half hour interval. The duplicated data was not removed and the missing data was not replaced or approximated due to the relatively small amount of error it would cause to the overall ET rate. Soil heat flux density data from October 24, 2006 through December 8, 2006 were lost due to rodents eating the wires connecting the soil heat flux density plates to the datalogger. In order to estimate ET, the missing values were replaced with data averaging the 48 half hour measurements from the 15 days prior to and 15 days following the time lapse. The estimated soil heat flux density data for each half hour increment from the averaged values were utilized for each day missing values. Surface water discharge data were calculated for data between the maximum and minimum flow, however, there were several occurrences in which the maximum flow-rate was exceeded resulting in water overtopping the flume. These data were set to the maximum flow rate of 2 $ft^3 s^{-1}$ (0.057 $m^3 s^{-1}$). TE525 rain gauge was designed for measuring wet precipitation, however some precipitation which was assumed to be a product of snowmelt during the month of December 2006 was measured and added to the precipitation total. Wet precipitation data was not corrected for the addition. Groundwater data for OW-4 are absent after March 14, 2007 due to infiltration of debris causing difficulty of removing the transducer.

III. THEORETICAL BACKGROUND

A. WATER BALANCE

Conceptualizing a simple and effective water balance equation on a regional scale is difficult considering the lack of definitive boundaries. For a given time period (Δt), the following equation can be written as:

$$P_w - G_{in} + Q - ET + G_{out} = \Delta S \tag{1}$$

where P_w is wet precipitation (Lt^{-1}) to be assessed for a given area (L^3t^{-1}); G_{in} is groundwater inflow or infiltration (L^3t^{-1}); Q is the net flux (L^3t^{-1}) of surface water flow (Q_{in} - Q_{out}); ET is evapotranspiration (Lt^{-1}) also to be assessed for a given area (L^3t^{-1}); G_{out} is groundwater outflow or exfiltration (L^3t^{-1}); and ΔS is the change in storage over the given time period for a particular area (L^3t^{-1}) (Mitsch and Gosselink, 2000). Although ΔS is commonly omitted from most hydrologic equations, when no significant climatic trends or storage modifications occur over a long time frame, it was included in this study due to the comparatively short time span of one year. The change in storage in this study was compared to the calculated surface volume storage. This was done to ascertain the volume of water leaving the site surface throughout the study compared to the amount that remained. In addition to estimating movement of water and storage values, characterization of water table depth was utilized as an indicator of the influential effect groundwater has on plant uptake and transpiration within *ET* in both first and second stage evapotranspiration. This study did not include the amount of groundwater seepage across site boundaries and any possible anthropogenic activities such as drawdown from nearby by groundwater pumping.

B. EVAPOTRANSPIRATION

With the exception of minor components such as biomass heat storage and photosynthesis, the approximated energy balance for the mitigation site can be written as:

$$R_n - S_s - \lambda E - H \approx 0 \qquad (2)$$

where R_n is available energy from net radiation (Watts meter^{-2}); S_s is the heat storage term in soil (Wm^{-2}); λE is latent heat flux (Wm^{-2}) with λ representing the latent heat of vaporization (~ 2.45 MegaJoules kilogram^{-1} x 10^6) and E the flux of water vapor (mm day^{-1}); H is the energy used to heat the atmosphere as sensible heat flux (Wm^{-2}).

The energy available at the soil surface can be partitioned into a ratio of H to λE yielding the Bowen ratio β which is computed by:

$$H = p_a C_p K_h \left(\frac{\Delta T}{\Delta z} \right) \qquad (3)$$

$$\lambda E = p_a \left(\frac{M_w}{M_a} \right) \left(\frac{\lambda}{P} \right) K_w \frac{\Delta e}{\Delta z} \qquad (4)$$

$$\beta = \left(\frac{H}{\lambda E}\right) \longleftrightarrow \beta = \gamma\left(\frac{\Delta T}{\Delta e}\right) \tag{5}$$

where p_a is the density of dry air (~1.2 kg m^{-3}); C_p is the specific heat of air (~ 1000 J kg^{-1} °C^{-1}); K_h and K_w are the turbulent exchange coefficients for momentum for sensible heat and water vapor, respectively (assumed to be equal within this study); γ is the psychrometric constant which is a function of the specific heat of air, standard atmospheric pressure P (~101 kilopascals), and the molecular weight of water vapor to dry air (M_w/M_a); ΔT and Δe are the vertical gradients measured at two different heights (Δz) for air temperature and actual vapor pressure, respectively (Bowen, 1926). Utilizing the Bowen ratio within Equation 2 (isolates λE) leads to:

$$\lambda E = \left(\frac{R_n - S_s}{1 + \beta}\right) \tag{6}$$

which calculates the amount of water vapor flux as E when:

$$E = \left(\frac{\lambda E}{\lambda}\right) = ET \tag{7}$$

Water vapor flux is a combination of evaporation from open water or the saturated soil surface and transpiration from vegetative cover. The water vapor flux within this study was assumed to be a product of this combination, herein after referred to as evapotranspiration (ET).

Throughout the study, vapor pressure gradients during some early mornings and late afternoons were extremely small or zero. This led to large errors in computing the Bowen ratio as observed by Burba et al., 1999a. Data for such observations were removed and set to 10^{10} (representing a value nearly infinite due to a tangible temperature gradient divided by a virtually non-existent vapor pressure gradient). In doing so, an λE value most representative of observed parameters yielded a term near zero indicating little if any evaporation and/or transpiration. It was also found that λE values greater than the available energy for the day (R_n-S_s), and at times opposite in sign, were caused primarily by air temperature and vapor pressure gradients being near similar in magnitude giving an overall Bowen ratio near -1. In computing λE within Equation 6, values greater than the available energy for the day and less than -30 Wm^2 were removed and predicted using gap-filling techniques. Predicted values were found using a quadratic regression equation fitting a polynomial curve for each day based on 48 observations (half-hour increments), typical of most λE values throughout a clear day. *ET* values were calculated by finding the area underneath the predicted curve for each day. These daily values were totaled throughout the study and compared to the summed daily averages yielding values that were within 1%.

C. GROUNDWATER

The total discharge of groundwater into and away from the soil surface on a horizontal plane is calculated using Darcy's equation:

$$Q = -K_v A\left(\frac{\Delta h}{\Delta l}\right) \tag{8}$$

where Q is the volumetric rate of flow (L^3t^{-1}); K_v is the saturated hydraulic conductivity of the soil medium in the vertical direction (Lt^{-1}); Δh (L) is the difference in total hydraulic head between the subsurface observation wells in each piezometric nest; and Δl is the difference in elevation between the center of the screened sections of the observation wells to that of the drive well points (L).

Vertical hydraulic conductivity (K_v) rates were estimated utilizing soil texture classification percentages from sieve analyses and bulk density (grams centimeters^{-3}) for the present Loup soil series (USDA-NRCS-NSSC, 2006—Appendix C). These values were inserted into the Rosetta Model (Schaap, 2000) to yield values ranging from 4.01 x 10^{-4} cm s^{-1} to 3.0 x 10^{-3} cm s^{-1}. Taking the average of the five measured soil layers constrains the value to 1.15 x 10^{-3} cm s^{-1}. The Rosetta Model assumes isotropic conditions and most of the data used to calibrate the model were likely from vertical flow experiments (Schaap and van Genuchten, personal communication, 30 August 2007 and 12 September 2007).

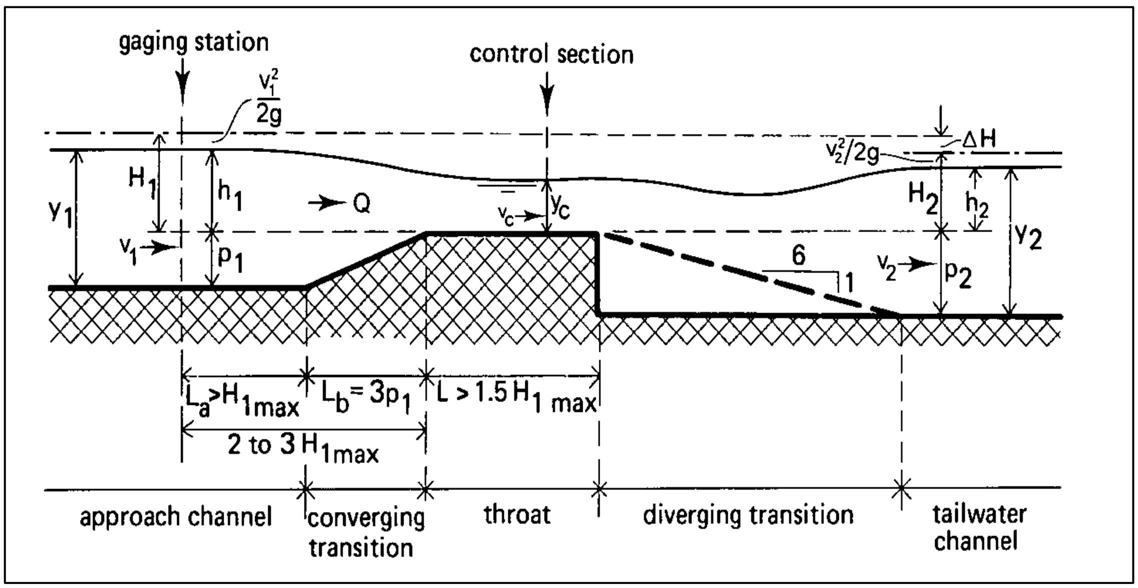
Vertical hydraulic gradients are commonly ascertained using "nested" piezometers ("nested" refers to a number of observation wells of varying depth at one location). Other Sand Hills hydrology studies (Harvey et al. 2007, Gosselin et al. 2006) have employed such measuring techniques which were also utilized in this study. Gradients were assessed separately for the southeast and northeast quarter sections and calculated for the 1808 m length of channel based on a time rate of change (Δt). Upward gradients were considered positive values within this study. June 22, 2006 to September 20, 2006 measurements were not analyzed in conjunction with *ET* measurements within this time frame due to *ET* measurements beginning September 21, 2006.

D. SURFACE WATER

Effective and accurate surface water discharge measurements can occur when a known cross-sectional area of a stream channel is correlated with velocity. Considering the potential for erosional and scouring activities, devices such as weirs and flumes are commonly utilized for constancy and operate by producing critical flow through a control section of known dimensions. The relation between critical flow and geometric dimensions is essential in computing discharge at a given moment. Total discharge for the long-throated adjustable-sill flume was computed by Clemmens et al., 2001:

$$Q = 0.6549\ (h_1)^{1.579} \qquad (9)$$

where Q is discharge (L^3t^{-1}) and h_1 is upstream pressure head above sill height which is a function of flow. Variability in Equation 9 is proportional to changes in adjusting of the sill height (set to four inches or 101 mm within this study), ultimately affecting the critical flow and discharge computation. Discharge is subject to a sill-height-dependent converging transition length of 0.38 m, a constant 0.31 m flume width, 0.22 m approach channel length and 0.32 m throat length (Figure 2).



Clemmens et al., 2001

Figure 2. Computation parameters within the long-throated adjustable-sill flume

IV. RESULTS & DISCUSSION

A. CLIMATE DATA

Monthly air temperature averages ranged from -6.9 °C in February to 23.2 °C in July, with an annual average of 8.4 °C, as compared to the 30-year span averaging 9.0 °C (Figure 5). Monthly average temperatures during the growing season ranged from 6.9 °C to 23.2 °C with an average of 15.1 °C. As compared to the 30-year averages, the growing season in this study was only 0.8 °C less. The average monthly air temperature of -1.7 °C outside of the growing season was near similar to the 30-year average of -1.5 °C.

Monthly precipitation totals over the course of the study ranged from 9 millimeters (mm) to 170 mm. Total annual wet precipitation amounted to 811 mm, in contrast to the 562 mm 30-year annual average. Similar to the 30-year norms (1971-2000) from the Rose National Weather Service Cooperative Weather Network station, 27 km WNW, precipitation was most concentrated during spring and summer (Figure 6). Approximately 60% (480 mm) of the total precipitation occurred during the growing season, April 26, 2007 to October 13, 2007. The ratio of the growing season precipitation total (480 mm) to the annual total (811 mm), amounting to 60%, contrasts the near 80% ratio measured by other studies in similar locales (Burba et. al 1999a and Gosselin et al. 2006). However, greater annual precipitation and growing season totals were measured within this study as compared to the other studies. The reason for this is greater precipitation amounts outside of the growing season in December, February, March, and early to mid-April, as compared to the 30-year average. December wet precipitation was a product of snowmelt from the area snowstorm, as recorded by the Rose NWS station on the 20th and 21st resulting as 120 mm of snow. The Rose NWS station measured approximately 58 mm of wet precipitation during and immediately following the snow event which is near similar to the 54 mm of wet precipitation measured at the Rose mitigation site for the given time period.

The growing season is determined by the Rock County SCS soil survey as the beginning and ending dates of freeze (based on the "28 °Farenheit or lower" temperature threshold at a frequency of "5 years in 10"). For wetland determinations, the "growing season" is defined as the portion of the year in which the soil temperature at or near 20 inches (50.8 cm) is above biological zero (5 °C) (Environmental Laboratory, 1987). Considering most wetland delineations do not utilize soil temperature sensors to measure biological zero, the growing season can be approximated instead by the beginning and ending of frost-free days.

B. GROUND WATER

1. PHYSICAL HYDROGEOLOGY

Hydrographs for each of the eight observation wells and CPW-2 show a seasonal rise in ground water between Mid-February and June, coinciding with the precipitation which in part results in groundwater recharge (Figures 7 a-i). Short-term rapid rises of the water table occurred in all wells (except CPW-2) following various precipitation events (Figure 8), and increased in intensity and duration throughout the topographically lower Gracie Creek. All observation wells including CPW-2 and both drive point wells experienced rises in the water table that reached the ground surface and at times fluctuated above the ground surface by at most 10 cm, as observed in OW-5 in mid-March. It is assumed this 10 cm rise is attributed mostly to head pressure, but the rise may contain some error due to GPS survey equipment accuracy standards within +/- 3 cm. Observation wells 2 and 3 experienced annual lows, averaging 1.2 m below the ground surface and 0.8 m for CPW-2. Annual lows could not be obtained for Observation wells 1, 4-8 due to depth of water falling below transducer depth. With the exception of CPW-2 (and OW-1 due to water table depth below transducer depth), all other observation wells also experienced a sharp rise in mid to late December. The sharp rise could be attributed to the 54 mm (~450% increase in December from 30-year averages) of precipitation received as snowfall and wet precipitation (Figure 9). The sharpest rise was measured with increasing intensity in ascending order for wells 3-6. Data collected for all observation wells on January 6, 2007 reflect this increasing intensity with a directional flow across the site following the historic Gracie Creek NNW to SSE (Figure 10). Between December 20th and 21st, observation well 6 experienced a one day positive swing of 0.5 m (Figure 11). CPW-2 experienced a minimal 0.1 m rise following the same snowstorm leading up to its maximum height in mid-January of 0.63 m below the ground surface. The minimal water table rise observed in CPW-2 following the snowstorm, which contrasts OW-6, is a result of the screened section beginning approximately 30 m below the ground surface and the slow rates of progression reaching the screened section. This delayed water table rise does not resemble the intensity observed by the shallow observation wells (OW-6) because of the greater distance the water must travel to reach the screened section coupled with decreasing infiltration rates at greater depths due to already saturated conditions.

Immediately following the late January rainfall event (5.8 mm), groundwater depth subsided to a depth ranging from 0.8 m to 1.0 m below the ground surface. Observation well 5 experienced the sharpest drop from 0.0 m to 0.83 m on February 4th. With no precipitation recorded until February 12th, OW-5 and others showed similar oscillating effects of groundwater increasing to 0.43 m below ground surface. This is attributed to the relatively little 0.8 mm daily average of *ET* during the same time period contrasting the 1.7 mm daily average nine days preceding and nine days after.

Five major rain events (March 24th-31th, April 22rd –25th, May 3th – 5th, May 22rd – 30st and June 6th – 13th) contributed to the extreme rises observed in all wells throughout the growing season followed closely by a recession as observed in OW-8 from May 5-May 20, 2007. Following the main June rain events amounting to 134 mm, water depth in observation wells 2,3,5,7,8 and CPW-2 declined to near January levels averaging between 0.8 m and 1.2 m. Observation wells 1,4 and 6 levels could not be obtained due to depth of water falling below transducer depth or removal of OW-4 (OW-1 0.65 m, OW-6 0.84 m).

Piezometer nest 1 (OW-3 and Drive Point Well 1) data indicates the area to generally be a dominant groundwater discharge zone, with an average difference of 0.16 m, and the drive point well having the higher hydraulic head (Figure 12). With the exception of May 30th and June 13th, groundwater flow was predominantly in the positive direction, toward the ground surface (Figure 13). Although it has no bearing on vertical flow, it must be acknowledged that horizontal flow was not computed within this study and may contribute to extensive seepage across the sites' boundary considering horizontal hydraulic conductivity rates can range between 10 to 100 times greater than those of vertical rates (Gosselin et al., 2006). Higher ratios of horizontal to vertical *K* are observed under anisotropic conditions where impermeable horizontal layers confine most groundwater flows to these boundaries. Although some anisotropy may occur at the study site, the soil is considered relatively homogenous and somewhat isotropic below the immediate ground surface. Two dates of exception May 30th (-483 m^3 day^{-1}) and June 13th (-558 m^3 day^{-1}) were in the negative direction, toward the lower soil layers, due to the excessive rain amounts received on May 29th - 30th (68 mm) and June 12th - 13th (103 mm) which caused infiltration. This is most likely due to excessive precipitation amounts received on those days, causing large infiltration amounts and saturation to the surface, followed by a ponding event due to precipitation exceeding hydraulic conductivity rates. Thus, reducing exfiltration (discharge) to the surface as a result of near similar hydraulic pressure heads between the more shallow observation well and the deeper drive point well. The ponded water is converted into surface run-off. Piezometer Nest 2 (OW-6 and Drive Point Well 2) data were unavailable after June 26th, the date at which the depth of water dropped below the depth of the transducer. Depth of the transducer in OW-6, to include all wells, was not set at the maximum depth of 1.5 m due to the present build up of silt. Consequently, Piezometer Nest 2 was not utilized in the calculation of groundwater discharge within this study. However, available piezometer nest 2 data indicates the area to be a groundwater discharge zone with an average difference of 0.11

m, with the drive point well having the higher hydraulic head (Figure 14). Piezometer nest 1's average difference between the observation and drive point wells was greater than piezometer nest 2, and is not out of the ordinary since piezometer nest 2 was not located along Gracie Creek where greater head pressure would be measured by the deeper drive point well if the channel was considered a discharge zone. The greater head pressure measured by the drive point well near the stream is due to the flow of groundwater toward the topographically lower elevation which, in this study, was piezometer nest 1 (Figure 3). Piezometer nest 2, however, was in a discharge zone and could be attributed to the lower topography acting as a discharge interdunal basin. Total groundwater flow measured from May 13th to September 14, 2007 toward the surface within the historic Gracie Creek alone amounted to 10.5 x 10^{-4} m^3 $time^{-1}$.

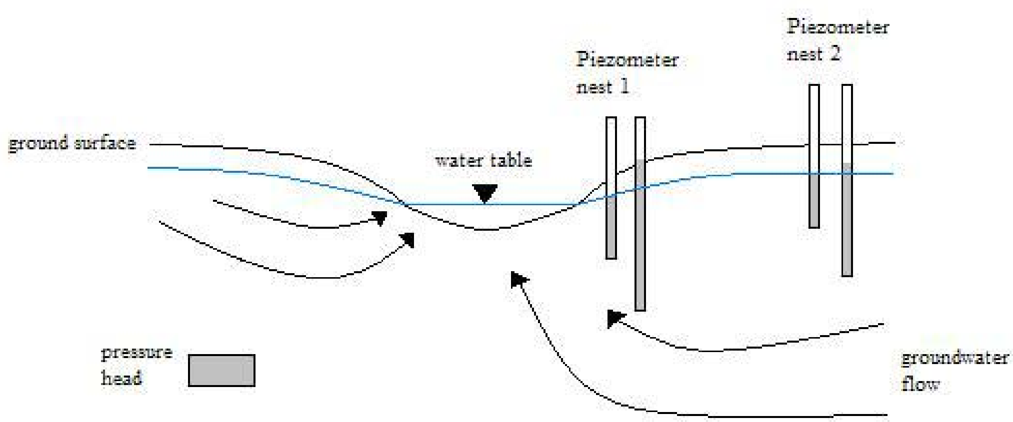


Figure 3. Groundwater flow toward piezometer nest 1

2. REGULATORY SPECIFICATIONS

Efforts have been made to accurately measure hydrologic zones based on frequency, timing, and duration of saturation (Appendix D). For purposes of identifying wetland hydrology according to USACE standards, a wetland system must be continuously saturated to the ground surface for at least 5% of the growing season (Environmental Laboratory, 1987). Percentages are classified into functional categories derived from percent of saturation (minimum of 5%) to the surface. These percentages are based on a 50% probability of recurrence over a non-specified time duration and could not be properly assessed within this study. Although tangible observation well data were not available to confirm a 50% recurrence probability of saturation to the ground surface since site restoration, visual observations of the site since 2003 have shown considerable saturation or inundation during a majority of the early growing season. According to the collected data, inundation and/or saturation to the surface (with the exception of OW-4) ranged from 1.9% to 12.5% of the growing season (Table 2). Observation well 5 had the greatest growing season percentage, as well as the longest continuous saturation of 3% between May 29th through June 3rd. Observation well 7 had the smallest growing season percentage of 1.9%, as well as the shortest continuous saturation of 1% observed between June 12th through June 14th. Although none of the wells met the minimum 5% of continuous saturation throughout the growing season, OW-5 did exhibit a 22 day continuous saturation or inundation event between March 24th and April 15th, not accounted for within the growing season calculations. Similarly, all other observation wells showed the same saturation or inundation event with varying durations, also, not incorporated within the growing season calculations. Five of eight observation wells had saturation or inundation to the surface over 5% percent of the growing season. However, these percentages are not continuously measured events and according to Theriot (1993), sporadic (not continuous) saturation events are less influential on the wetland vegetation. Continuous saturation or inundation have more effect on vegetation and soils than the frequency of saturated or inundated events throughout the growing season.

Wetland indicators characterize a condition of the environment and aid in determining whether an area has suitable wetland hydrology. Most wetland delineations lack gaging data due to availability, therefore, visual observation of soil saturation becomes one of many primary indicators used to properly identify the presence of wetland hydrology. Soil saturation within the upper 12 inches (30.5 cm) is a primary indicator due to the impact soil saturation has on wetland vegetation root systems within this depth. Soil saturation was considered to be the water table depth (pressure head) within this study. According to collected data from the Rose mitigation site, saturation within the upper 33 cm (30 cm to include the +/- 3 cm accuracy error) ranged from 9.9% to 39.6% annually and 8.2% to 25.9% throughout the growing season (Table 2). Observation well 5 had the highest percentage and OW-3 the lowest, both annually and during the growing season. Considering one primary indicator is enough to consider a wetland to have sufficient wetland hydrology, these ranges would suffice in demonstrating adequate wetland hydrologic characteristics in the absence of gaging data.

The influence of hydrology in defining whether a soil is hydric is recognized by the criteria outlined (Appendix E) by the National Technical Committee for Hydric Soils (NTCHS, 2000). The present Loup soil series (Lo) with a soil taxonomic subgroup of *Typic Haplaquolls* is characterized as a Mollisol soil. These soils exhibit aquic moisture regime conditions that undergo reducing conditions (Environmental Laboratory, 1987). This near poorly drained soil meets the criteria outlined by the NTCHS as a hydric soil due to its soil properties and saturation of the soil to the surface for an un-specified amount of time during the growing season. The more dominant Els-Ipage complex (EpB) with similar soil taxonomic subgroups of *Aquic Ustipsamments* is characterized as an Entisol soil with extremely sandy textures and an ustic soil moisture regime where moisture may be somewhat limited, but present during times of excessive plant growth. These soils are somewhat poorly drained to moderately well drained and meet the criteria outlined by the NTCHS as a hydric soil due to the moisture regime and saturation of the soil to the surface for an unspecified amount of time during the growing season.

C. SURFACE WATER

1. FLUME MEASUREMENTS

The streamflow hydrograph (Figure 15) shows the rise and fall of water entering the site mostly in the form of run-off. As with the groundwater data, four major rain events (April 22rd –25th, May 3th – 5th, May 22rd – 30st and June 6th – 13th) contributed to rises exceeding 4000 m^{-3} day^{-1} observed in the flume hydrograph (Figure 15). The well-defined peak rises followed by quick hydrograph recessions shows the permeable nature of the local unconsolidated soils have on flow. A peak discharge of 4894 m^3 day^{-1} for the flume was measured for both June 13th and June 14th, as observed by the leveling out of the hydrograph curve (Figure 15). The incident does not illustrate a natural hydrograph and is simply a result of the flume overtopping. Within this study, any measurements above the flume's maximum allowable discharge of 2 ft^3 s^{-1} (0.057 m^3 s^{-1}) were set to 2 ft^3 s^{-1}. Visual observation of the flume on April 3rd demonstrates the inability of the flume to completely capture the entire streamflow when NDOR personnel removed a major portion of the berm resulting in 1024 m^3 day^{-1} of streamflow. Similarly, due to the inability of the flume to accurately measure discharge below the 0.003 m^3 s^{-1} minimum, it is certain that a great amount of water went around the flume without being measured. The error lies with the investigator's ignorance in calculating the approximate discharge for Gracie Creek due to the lack of gaging data within the area from previous years and lack of visual observation considering recent berm removal. Aside from the difficulties, the flume was able to measure a total discharge from March 31st to September 14, 2007 of 8.2×10^{-4} m^3 $time^{-1}$.

2. SURFACE STORAGE

Volumetric surface storage calculated by the 3D-Analyst Surface Volume Tool from March 15, 2007 through July 17, 2007 averaged approximately 1.1×10^{-4} m^3. Numerous precipitation events contributed to the hydrograph peaks (Figure 16). Maximum surface storage calculated for the southeast quarter section on June 14th had a volume of 2.1×10^{-4} m^3, approximately 0.5 m above the transducer. The maximum twodimensional area coverage in the southeast quarter section was 7.3 m^2 (approximately 18 acres) nearly coinciding with the -0.02 m water table depth for OW-6 (elevation 736.7 m). Minimum surface storage could not be accurately obtained due to positioning of the transducer in a location approximately 0.63 m above the lowest elevation found via ArcGIS following site introduction. Also, the volumetric surface storage should not be considered the definitive amount of surface storage available on site due to similar storage areas found in the southwest and northeast quarter sections. Visual observation of the site on September 15, 2007 revealed no inundation in all quarter sections to include the southeast.

D. EVAPOTRANSPIRATION

Daily *ET* rates throughout the study had high variability, particularly during the growing season, with a range of 0.4 mm day^{-1} to 8.0 mm day^{-1} and a daily average of 3.4 mm day^{-1} (Table 3 and Figure 17). Burba et al. (1999a, 1999b) reported similar results of 4.1 mm day^{-1} for open water, 3.8 mm day^{-1} for *Phragmites australis* (common reed) and 3.5 mm day^{-1} for *Scirpus (Schoenoplectus) acutus* (bulrush) from June through October in a north-central Nebraska Sand Hills wetland. Total *ET* for the growing season amounted to 558 mm in contrast to 1999 estimates of a central Nebraska interdunal wet meadow calculated by Gosselin et al. (2006) of 770 mm. Growing season *ET* rates totaled approximately 78% of the annual total (720 mm), as compared to ET_p which was 69% of the annual total (1583 mm), measured by the Barta Brothers Ranch AWDN station for the same time period. Measured *ET*, on average, was within +/- 49% of ET_p

throughout the growing season and +/- 58% throughout the term of the study indicating a wetland that may be water limiting indicative of second stage evapotranspiration or ET_p values are overestimated. In contrast, Kim and Verma (1996) observed rates that were within +/- 15% for a fen in northcentral Minnesota from May through October, where the water table fluctuated within the 0.0 to 0.4 m dominant root zone and available midday incident solar radiation averaged between 560 to 670 W m^{-2} as compared to 688 W m^{-2} measured in this study, signifying a higher available energy for the Rose mitigation site. The moisture deficit (ET_p minus precipitation) for the entire measurement period was approximately 772 mm, indicating an overestimate of ET_p due to the presumption that all plants are well watered (Figure 18). Considering the inconsistent and highly variable water table in this particular study and the inability of the highly permeable soil to remain saturated year-round, ET_p is a gross calculation in this and similar geographic regions that fail to consider the irregularity of the landscape and vegetation. The ratio of ET to ET_p for the growing season ranged between 0.14 and 2.28, with an average of 0.55 (Figure 19). Values > 1 for ET/ET_p coincide with recent precipitation events, resulting in well watered conditions. Kim and Verma (1996), however, attribute the greater values to advective enhancement properties and/or surface geometry in which greater ET rates are driven by greater exposure (increased area) of the vegetated surface of a leaf to the atmosphere.

Measured ET and its response to groundwater are illustrated in Figure 20 as a relationship between the average depth of groundwater in OW-5 for each day and daily ET rates. When the water table, measured at observation well 5, was below the -0.3048 m soil horizon (indicates depth below the upper one foot of soil which constitutes a primary indicator for hydrology in wetland regulatory specifications), *ET* was 51% of ET_p. Fitting a polynomial curve to the data shows a general rise of *ET* with the rise in groundwater (Figure 21). This rise may be attributed to water needs from deeply rooted vegetation resulting in higher transpiration (T) rates within *ET*. The presence of the deeply rooted *Populus deltoides* Bartr. *ex* Marsh. var. *occidentalis* Rydb. (plains cottonwood) at the study site may have contributed to increased transpiration rates. At the time this study was ending, the cottonwood saplings were responding to the application of the herbicide and *ET* rates could not be assessed and compared to before application rates.

When the water table, measured at observation well 5, was within the upper -0.3048 m of the soil horizon but not inundated (commonly the major portion of the root zone), *ET* was 58% of ET_p. Fitting a polynomial curve to the data shows a negative relationship between *ET* and groundwater depth (Figure 22). It appeared that there was little if any impact the rise of the water table had on transpiration needs contributing to overall *ET* within the upper foot of the ground surface. A negative sloping effect from the left side of the graph to the right side is explained by precipitation events coupled with the available energy for each day. The data on the right side of the graph have higher groundwater depths caused by a receding water table following a recent rainfall. The lower *ET* rates, compared to the left side of the graph, are caused by the little available energy due to cloud cover. The smaller amount of radiation results in a smaller amount of energy partitioned into available energy for evapotranspiration. Higher *ET* rates on the left side of the graph are a result of higher available energy (relatively no cloud cover) measured a couple of days following the rainfall event. The same effect occurs when the water table depth measured at observation well 5, was at the ground surface or inundated during the growing season (Figure 23). Data for these days show an ET/ET_p ratio of 74%, which indicates a greater *ET* rate closer to maximum ET_p rates. *ET* rates are controlled mostly by available radiation energy during the growing season. Similar to Kim and Verma (1996), a declining water table (other than inundation) did have a noticeable effect on *ET*. This may signify a lack of transpiration from vegetation at greater water table depths. Considering the site is relatively young and seeded wetland vegetation are still becoming established, evaporation controlled by surface water influences would seem to be the most logical explanation of increasing *ET* at greater water table depths. When the water table was near the surface, higher *ET* rates may be related to a rising capillary fringe or small pockets of inundation on site rather than a direct correlation to transpiration needs. This possibility is based on a 2006 monitoring report conducted on-site by Olsson Associates consulting firm that found the dominant plants species in the southeast quarter section to be *Hordeum jubatum* L. (foxtail barley) and *Ambrosia psilostachya* DC. (cuman ragweed), with percent cover ranges of 15-70% and 5-70%, respectively. These species are at times considered invasive and ornamental (*H. jubatum*) and lack extensive leaf area to transpire large amounts of water vapor into the atmosphere. *A. psilostachya* is a warm-season forb commonly found in dry, sandy, unproductive sites similar to the Nebraska Sand Hills. This C_4 plant is tolerant of drought conditions and requires less energy for photorespiration and exhibits lower transpiration rates (Schacht et al., 2000). *H. jubatum* is a salt-tolerant plant with a shallow root system that can tolerate various moisture regimes and drought conditions, indicative of lower transpiration rates. Another 10-50% percent cover was open bare ground where vegetation was sparse and nearly non-existent due to the inability of wetland seed to establish.

E. WATER BALANCE

Water balance parameters could not be estimated accurately for the entire site throughout the term of the study since several parameters could not be measured including, seepage across site boundaries (G_{out}); groundwater exfiltration prior to May 13, 2007 (G_{out}); lack of drive point wells in the west half section (G_{in} - G_{out}); surface water flow out of the site (Q_{out}); and inability of the Bowen ratio energy budget tower to estimate rates (ET) in areas contrasting site-specific conditions similar to the northeast and southeast quarter sections. However, a reasonable balance (change in storage) could be estimated for the eastern half-section with the caveat that groundwater flow is not quantifiable, again, due to late site introduction of the drive point wells.

Measurements taken between May 13, 2007 through July 16, 2007 did utilize all devices (Figure 24). Four rain events (May 22nd, May 29th-31st, June 6th-7th, and June 12th-14th) contributed to the rise of surface volume storage, which coincides with the increase of the change in storage within the water balance equation. Considering the change in storage measured is the volume of flow toward or away from the ground surface (assuming no seepage and/or offsite runoff), a volume of water would either recharge the underlying groundwater reserves, or result in ponding (surface volume storage). The average surface volume storage (9541 m^3) in this study would equal the volume of change in storage (8.7×10^{-4} m^3 t^{-1}) over the given time period. However, seepage and/or runoff did occur, resulting in 7.7×10^{-4} m^3 of water leaving the site unaccounted for, in conjunction with the 36.3×10^{-4} m^3 of water lost due to *ET* during this time frame. Visual observation of the site on September 15, 2007 revealed multiple scours cut through the southeast quarter section berm, thus, reaffirming that most of the surface water did escape.

The annual change in storage from September 21, 2006 through September 14, 2007 amounted to 30.3×10^{-4} m^3 t^{-1} (Table 4). The annual rate was 126.7×10^{-4} m t^{-1}, mostly data taken from the flume. The flume had a discharge of 8.2×10^{-4} m^3 t^{-1} and the groundwater flow measured by piezometer nest 1 was 10.5×10^{-4} m^3 t^{-1}. Evapotranspiration totals neared wet precipitation with 93.3×10^{-4} m^3 t^{-1} and 104.5×10^{-4} m^3 t^{-1}, respectively. Approximately 85% of the water flow entering the site was in the form of precipitation amounting to a total depth, after annual *ET*, of 0.24 m covering the entire east half-section (Table 4).

V. CONCLUSIONS

A. MANAGEMENT IMPLICATIONS

Rehabilitation of the permanent berm in the southeast quarter section is one of many needs to keep more water on site. Plans have been made to raise the berm and repair scouring associated with surface water runoff. A water control structure will be placed in the berm to eliminate and reduce overtopping, which induces scouring. Permanent removal of the berm separating the channelized Gracie Creek to the historic Gracie Creek is needed to allow surface water to flow onto the site. Allowing the large volumes of water measured throughout the study to collect on site would greatly improve wetland vegetation coverage, enhancing its functional quality and ease of credit debiting. Best Management Practices (BMPs) should be used when applying herbicides to stop the invasion of cottonwood and willow saplings. Application of the Hi-Dep 2,4-D broadleaf herbicide in August 2007 greatly impacted saplings in the southeast and northeast quarter sections, where they were most abundant, without harming many of the common wetland species. Future management should include occasional grazing, following seeding of cool season grasses to better manage the spread of tree saplings. Further groundwater monitoring is necessary to demonstrate annual comparative changes not measured within this study.

Suggestions for future work include placement of multiple drive point wells on-site (in conjunction with present observation wells), similar to the procedure utilized by Harvey et al. (2007), which employed a Thiessen polygon system of evenly distributed nests throughout an interdunal valley. This method would eliminate a considerable amount of inaccuracy within this study and help to quantify the movement of water within the west half-section. Additional research needs include placement of a flume or weir at the outlet of the study site to measure the amount of water lost downstream. In doing so, the surface water parameters within the water balance would be better constrained. Placement of an additional Bowen-ratio energy budget tower in the west half-section would measure the amount of water lost in this upland dominated area. These additions would be reasonable to better characterize the parameters within the water balance equation for the site, however, monetary requirements may be an issue.

B. APPLICATIONS

The study indicated an inability to accurately measure all hydrologic parameters in the water balance equation for a mitigation site of this size, with a limited budget. Not including initial purchase and restoration of the site, as well as installation of center pivot and observation wells, the total cost for this study was estimated at $40,000 over two years (with one year of data collection). This estimate includes operating costs, equipment purchase, personnel wages and benefits, and indirect costs. Replication of these costs at other similar mitigation sites presumably would not be of concern in light of initial site purchase, restoration, and management costs (typically > $1 million). The exception would occur at mitigation sites that are comparatively smaller in area, which require less time to meet credit certification because of fewer performance standard conditions considered during monitoring. Generally, the larger a mitigation site, more performance standards need to be addressed. Under similar site conditions, approximation of missing hydrologic parameters could be measured with additional drive point wells (~$80) and weir (~$40 when made from a wood plank) at a relatively low cost. ET estimates in upland regions (of a site) would require purchasing another Bowen-ratio energy budget tower (~$15,000), or similar system.

C. REEVALUATION OF REGULATORY SPECIFICATIONS

The presence of hydrophytic vegetation, in the absence of continuous saturation to the ground surface for greater than 5% of the growing season, suggests frequency may be as important as duration in wetland vegetative succession at the Rose Wetland Mitigation Bank Site. The minimum threshold for wetland hydrology in non-tidal areas, as cited in the hydrologic zone classification table within the USACE 1987 Delineation Manual, is based on continuous saturation/inundation for at least 5% of the growing season. The USACE hydrologic zone classification (Appendix D) was slightly modified from ecological zones found in Bottomland Hardwood (BLH) forests in the lower Mississippi River Region (Clark and Benforado, 1981). The ecological zones were partly based on the ability of water tolerant plant species to achieve maturity and reproduce along a 100-year floodplain transect where the soils exude anaerobic conditions due to periodic saturation throughout the growing season, and the lack of non-tolerant species to germinate in such areas due to the same periodic saturation. Mature species are more tolerant than seedlings (Clark and Benforado, 1981), therefore, it must be noted that the ecological zones were developed from existing mature stands of hardwood forest and may not correlate with hydrologic conditions that support emergent herbaceous wetland development in the Sand Hills of Nebraska. Research suggests survivability of wetland species relies on a minimum duration, rather than frequency (Theriot, 1993). The Rose wetland areas were saturated up to 12.5% of the growing season to the surface, but on a non-continuous basis. The wetland areas experienced frequent saturation, but continuous saturation never exceeded 3% of the growing season. Site specificity must be considered when applying the adopted hydrologic zones to wetland areas with sandy soils as observed in the Nebraska Sand Hills. The Sand Hills soils are highly permeable which leads to sharp oscillations of the local groundwater table before and after major precipitation events. The 5% continuous saturation threshold was never met, yet hydrophytic vegetation thrived. Wetland vegetation may normally develop under conditions of continuous saturation, however, the Rose site is evidence that hydrophytic vegetation can thrive under non-continuous saturation as long as a certain frequency of saturation is met. The adapted hydrologic zones may not effectively apply to all wetlands, considering the specificity of the workshop which focused only on BLH forests in an area with high clay content and longer duration events. As a result, the usage of these hydrologic zones in areas that differ from BLH forests may be inappropriate (Clark and Benforado, 1981), especially for Sand Hills wetlands where soils are comparatively more porous and dominated by herbaceous vegetative communities.

The presence of hydrophytic vegetation, in the absence of continuous saturation to the ground surface during the growing season, also suggests saturation within the root zone may be sufficient to support wetland vegetative succession. In a study on wet meadows in the Nebraska Sand Hills (Moore and Rhoades, 1966), it was found that one-half to two-thirds of wetland herb roots were located within the upper 2 inches, and mostly in the upper 6 in. (Sipple, 1992). Wetland herbaceous species within the Sand Hills region experience groundwater and surface water inundation/saturation events that not only stimulate growth of species tolerant to anaerobic conditions, but also inhibit non-tolerant species from surviving. Although the observation wells at the Rose Wetland Mitigation Bank Site did not indicate saturation to the ground surface on a continuous basis for at least 5% of the growing season, hydrophytic vegetation was dominant. This was apparently due to the saturation observed within the relatively shallow root soil layer and the influence of capillary action within that layer. According to a 2007 monitoring report conducted on-site by Olsson Associates, dominant species in the southeast quarter section included *Hordeum jubatum* L. (foxtail barley), a facultative wet species with an estimated 67% to 99% probability of occurring in wetland areas; *Spartina pectinata* (prairie cordgrass), another facultative wet species; and *Schoenoplectus fluviatilis* (Torr.) M.T. Strong (river bulrush), an obligate species with an estimated 99% probability of occurring in wetland areas. Considering the dominance of wetland vegetation at the Rose study site, a reevaluation of the USACE standard of saturation to the surface may be necessary.

The presence of hydrophytic vegetation under non-continuous saturation events gives reason to reevaluate the USACE minimum of 5% continuous surface saturation in areas other than BLH forests. Further, saturation within the root zone may be a better measure of wetland hydrology than saturation to the ground surface, as evidenced by the wetland vegetative succession at the study site. The hydrologic zones adopted by the USACE from Clark and Benforado, 1981 may be too generalized and do not accurately represent differences of site specificity between all wetlands.

V. SUMMARY

A water balance equation was used to characterize the hydrologic parameters for a Nebraska Sand Hills wetland mitigation site located in southern Rock County, Nebraska, U.S.A. for one year. This approach was not complete because of the inability to accurately capture and measure all surface water passing the flume, late introduction of nested piezometers, seepage across the sites' boundaries, lack of measurements for all surface volume retention areas and inability to accurately obtain estimated ET rates for the western half section, due to monetary limits. An estimated change in storage for the eastern half-section could be obtained from May 13, 2007 through July 16, 2007 totaling 9.8×10^{-4} m^3 t^{-1}. This contrasts the 9541 m^3 surface volume storage average, and represents a 8.8×10^{-4} m^3 loss to surface runoff and seepage. The difference indicates inadequacies amounting to a 0.068 m depth loss for the given time period over the entire east half-section. An estimated change in storage could be obtained for the May 13, 2007 to September 14, 2007 time period, representative of most of the growing season resulting in a positive balance of 2.7×10^{-4} m^3 t^{-1} toward the ground surface.

Meeting regulatory performance standard specifications and making use of measured estimates to meet credit certification is dependent upon monetary needs. Results of this study indicate an inability to accurately measure all hydrologic parameters within the water balance equation for a mitigation site of this size within a realistic financial budget. Additional sensors are needed to adequately measure missing parameters within a mitigation site of this size. Similar methods would not be justified for smaller mitigation sites as there are fewer USACE performance standards to be addressed.

Regulatory specifications mandate a continuous saturation of the soil to the ground surface for 5% of the growing season to meet wetland hydrologic conditions. The longest continuous saturation amounted to 3%, observed in OW-5, which does not meet regulatory specifications for hydrology based on the USACE hydrologic zone classifications. However, the 12.5% non-continuous saturation observed within OW-5 and the dominant presence of wetland vegetation suggest frequency may be as important as duration in wetland vegetative succession. In addition, saturation within the root zone may be a better measure of wetland hydrology than saturation to the ground surface, as evidenced by the wetland vegetative succession at the study site. The growing season numbers bounded the saturation percentages and failed to consider the near continuous surface saturation from February 18, 2007 to April 15, 2007 observed in nearly all observation wells. The unaccounted saturation values may need consideration within USACE wetland standards because of the possible influence that saturation outside of the growing season, particularly late March to mid April, may have on wetland vegetation root systems.

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TABLES

Groundwater Well information				
Well Name	**Depth (m)**	**Screen Interval (m)**	**Ground Surface Elevation (m)**	**Completion Date**
Observation Well 1	1.5	0.15 – 1.5	741.1	3/16/2004
Observation Well 2	1.5	0.15 – 1.5	740.6	3/16/2004
Observation Well 3	1.5	0.15 – 1.5	739.1	3/16/2004
Observation Well 4	1.5	0.15 – 1.5	738.5	3/16/2004
Observation Well 5	1.5	0.15 – 1.5	737.8	3/16/2004
Observation Well 6	1.5	0.15 – 1.5	736.7	3/16/2004
Observation Well 7	1.5	0.15 – 1.5	738.6	3/16/2004
Observation Well 8	1.5	0.15 – 1.5	739.0	3/16/2004
Center Pivot Well 1	48.7	30.2 – 48.8	741.7	12/7/1972
Center Pivot Well 2	54.9	30.5 – 54.9	737.5	12/6/1972
Center Pivot Well 3	50.3	32.0 – 50.3	740.3	12/4/1972
Center Pivot Well 4	53.0	32.9 – 53.0	741.3	12/2/1972
Drive Point Well 1	2.4	1.5 – 2.3	738.9	3/15/2007
Drive Point Well 2	2.4	1.5 – 2.3	736.2	3/15/2007

Table 1. Observation and center pivot wells information

Percent of Saturation*				
	Annual 9/21/06 – 9/14/07	**Growing Season 4/26/07 – 9/14/07****		
Observation Well	**Saturation within -0.3348*** (%)**	**Saturation within -0.3348*** (%)**	**Saturation to Surface*** (%)**	**Longest Continuous Saturation *** (%)**
Observation Well 1	18.6	31.2	7	2.1
Observation Well 2	15.9	17	11.8	1.7
Observation Well 3	9.9	8.2	5.9	1.2
Observation Well 4	13.9	NA****	NA****	NA****
Observation Well 5	39.6	25.9	12.5	3
Observation Well 6	33.8	16.3	4.7	1.4
Observation Well 7	13.1	14.1	1.9	1
Observation Well 8	18.1	15	8.9	2.4

Table 2. Observation well data including percent of saturation and percent of continuous saturation to the ground surface during the growing season, also, the percent of saturation within the upper -0.3048 m (1 foot) of the ground surface annually and during growing season: April 26, 2007 to September 14, 2007

*Saturation is assumed to be water table depth
**Growing Season April 26, 2007 – October 13, 2007: No data collected following September 14, 2007
***Percent saturation included 0.03 m accuracy error of GPS survey standards
****No data collected following March 14, 2007 removal of transducer

Evapotranspiration vs. Potential Evapotranspiration				
	Monthly Totals 9/21/06 – 9/14/07		**Daily Average 4/26/07 – 9/14/07**	
Month	**ET (mm)**	**ET Potential (mm)**	**ET (mm)**	**ET Potential (mm)**
OCTOBER	31.6	116.9	1.0	3.8
NOVEMBER	11.5	81.2	0.4	2.7
DECEMBER	6.0	59.7	0.2	1.9
JANUARY	11.3	45.5	0.4	1.5
FEBRUARY	14.6	37.6	0.5	1.3
MARCH	50.9	116.2	1.6	3.7
APRIL	73.2	142.1	2.4	4.7
MAY	98.6	199.2	3.2	6.4
JUNE	145.1	213.0	4.8	7.1
JULY	130.1	245.5	4.2	7.9
AUGUST	100.3	193.9	3.2	6.3
SEPTEMBER*	47.3	132.5	1.9	5.3

Table 3. Monthly totals and daily averages for Bowen evapotranspiration compared to monthly totals and daily averages for potential evapotranspiration calculated via the Penman combination method from the High Plains Regional Climate Center's (HPRCC) Automated Weather Data Network station at the Barta Brothers Ranch: September 21, 2006 to September 14, 2007
*September data is a sum of data collected between September 21, 2006 – September 30, 2006 and September 1, 2007 – September 14, 2007

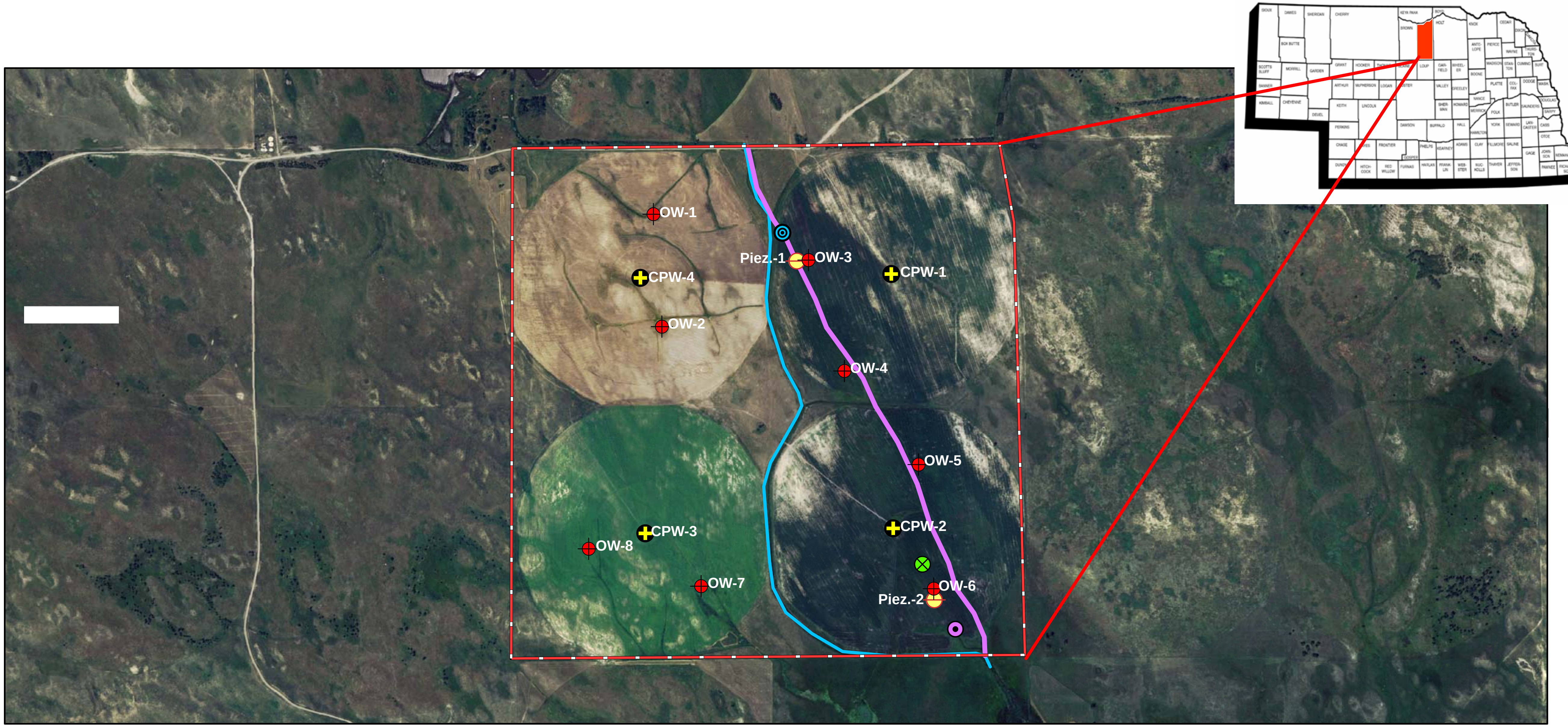
Water Balance Parameters*		
	Volume-Rate 9/21/06 – 9/14/07 (m^3 x 10^{-4} $year^{-1}$)	**Rate 9/21/06 – 9/14/07 (m $year^{-1}$)**
Rain	104.9	0.8
Flume	8.2	1266817.3
Piezometer Nest 1	10.5	19.2
Evapotranspiration	93.3	0.7 (720 mm)
Surface Volume Storage (Average)	1.1	NA
Change in Storage	30.4	1266836.5

Table 4. Hydrologic parameters for the east half-section: September 21, 2006 to September 14, 2007

*Water balance parameters do not reflect the potential additional inputs and outputs not accurately measured within this study

FIGURES

Figure 4. Aerial map: Rose Southeast Wetland Mitigation Bank Site, Rock County, Nebraska, U.S.A.



1000 0 1000

scale in feet

Observation Wells

Center Pivot Wells

Piezometer

Flume

Historic Gracie Creek

Channelized Gracie Creek

ET-Tower

Surface Volume Transducer

Data source: DNR 2003 Aerial Photography
Map source: NDOR

ROCK COUNTY
Nebraska, U.S.A.

University of Nebraska Lincoln

Rose Southeast Wetland Mitigation Bank Site

NDOR Nebraska Department of Roads

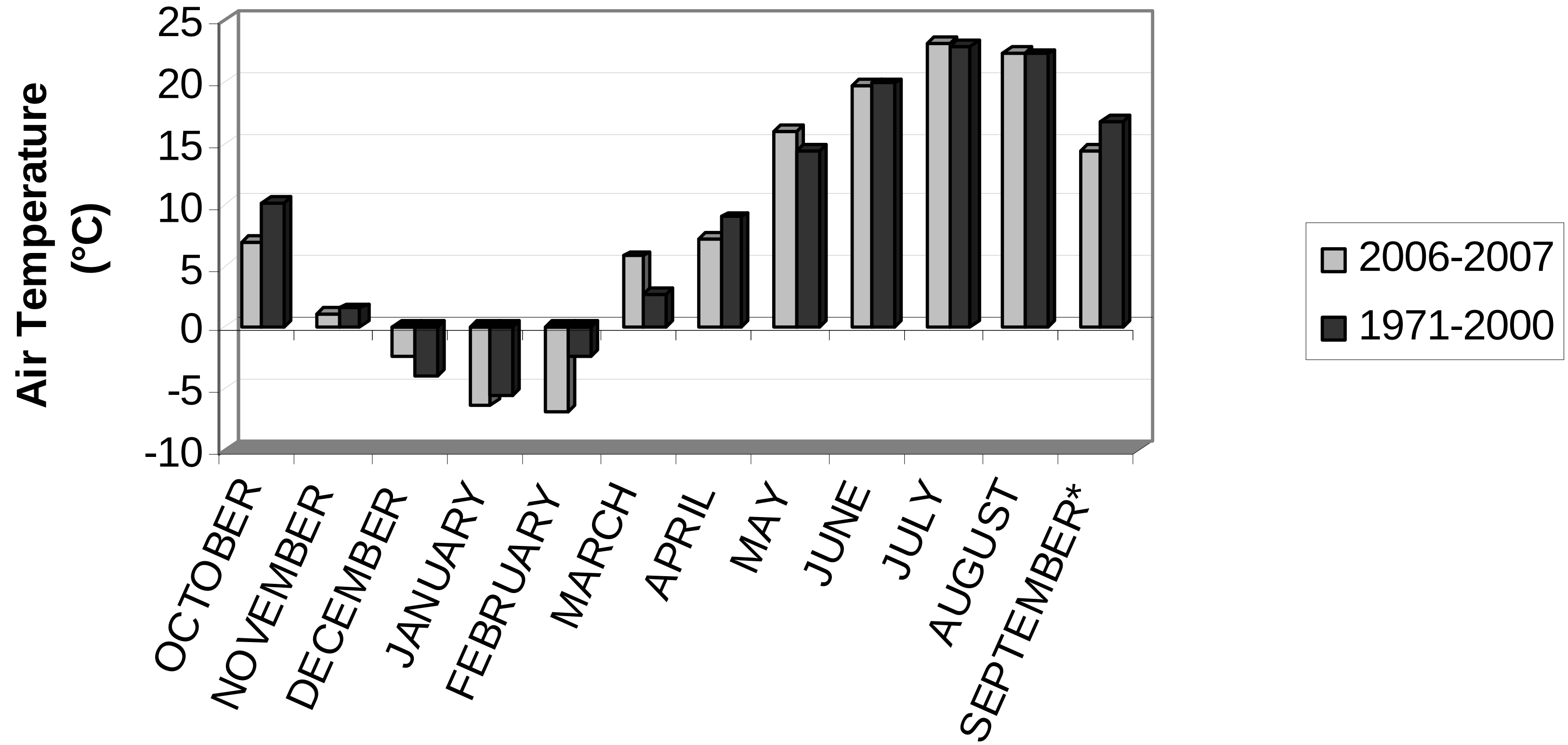


Figure 5. Average air temperature vs. 30 year average temperature norms from the Rose National Weather Service Cooperative Weather Network station

*September represents an average value of data taken at the Rose Mitigation Site from September 21st – September 30, 2006 and September 1st – September 14, 2007

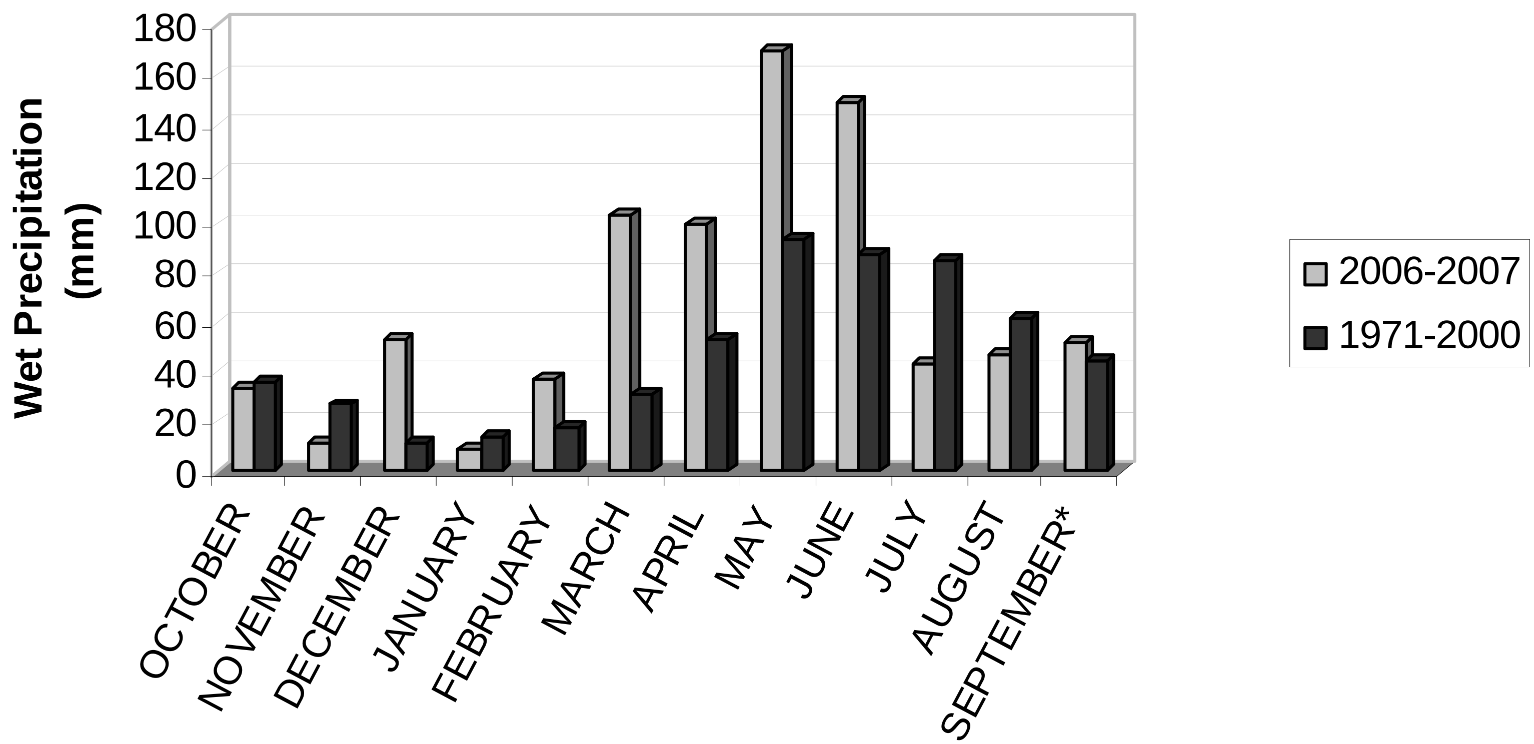


Figure 6. Monthly precipitation totals vs. 30 year average norms from the Rose National Weather Service Cooperative Weather Network station

*September represents summed totals of data taken from September 21st – September 30, 2006 and September 1st – September 14, 2007

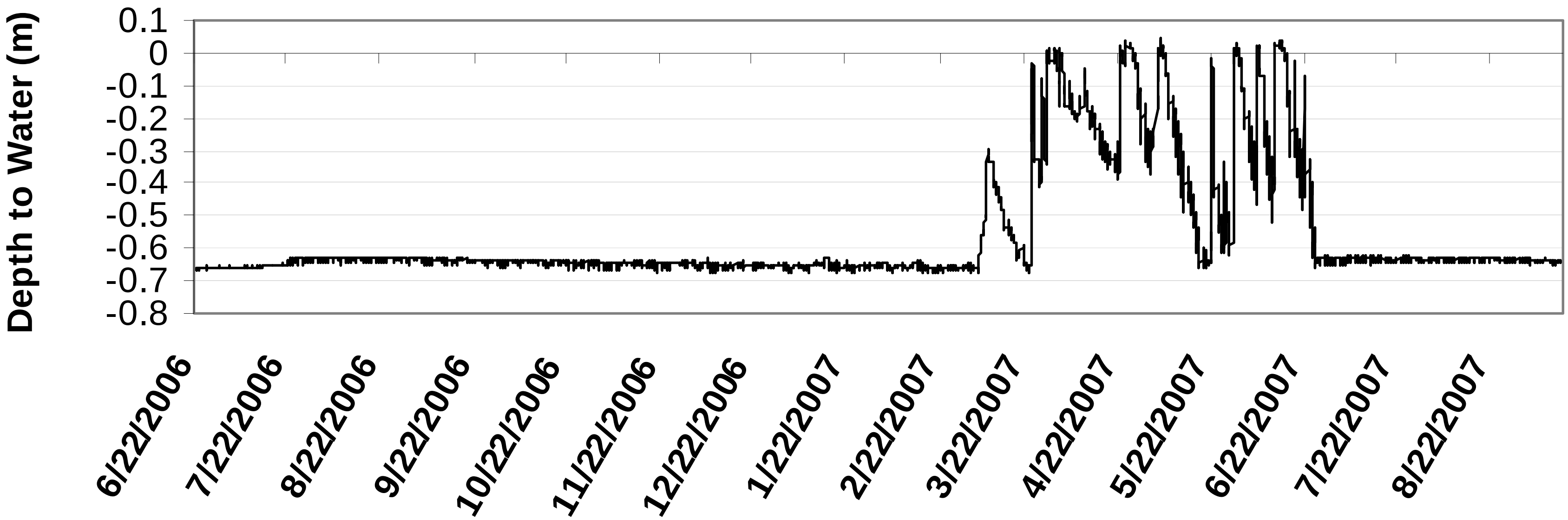


Figure 7 a. Observation well 1 hydrograph: June 22, 2006 to September 14, 2007

*Data collected below transducer depth of -0.65 meters is void

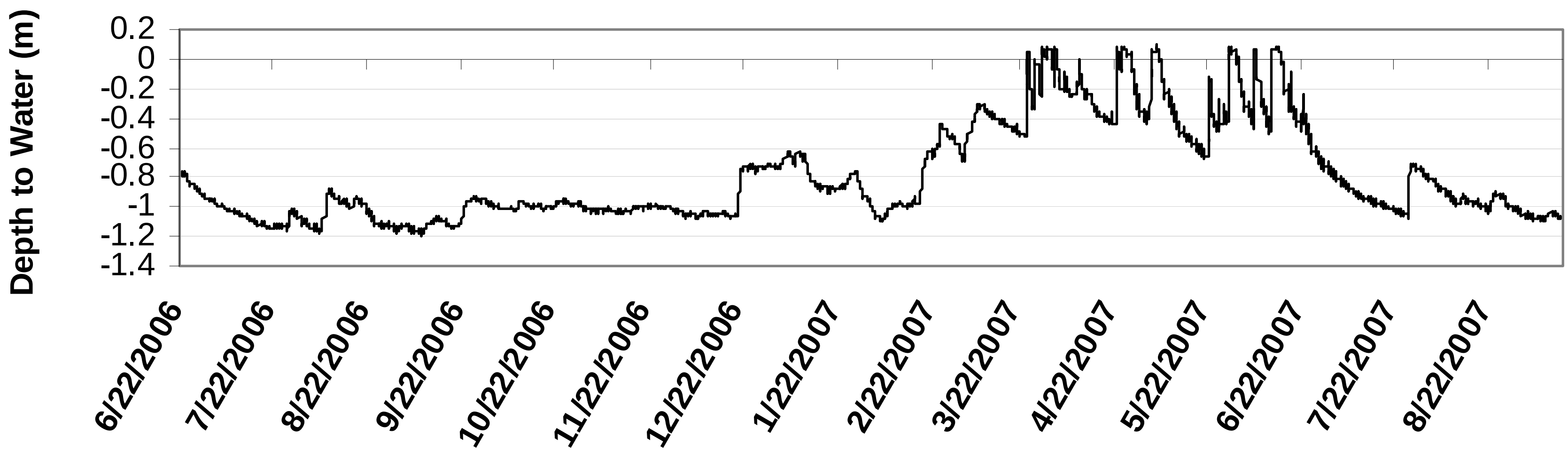


Figure 7 b. Observation well 2 hydrograph: June 22, 2006 to September 14, 2007

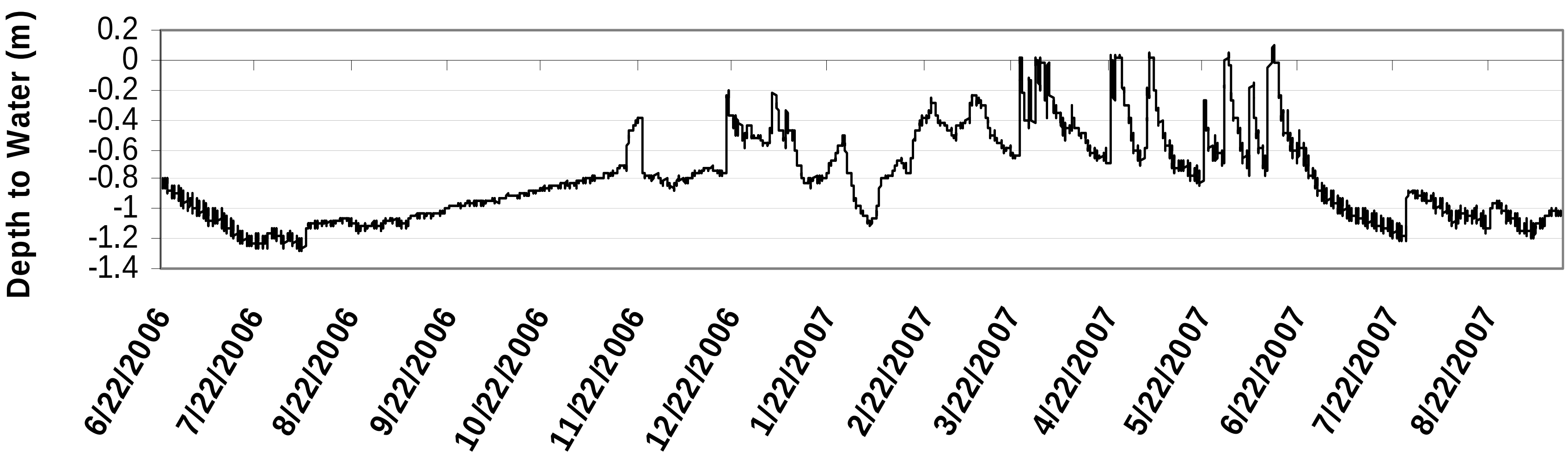


Figure 7 c. Observation well 3 hydrograph: June 22, 2006 to September 14, 2007

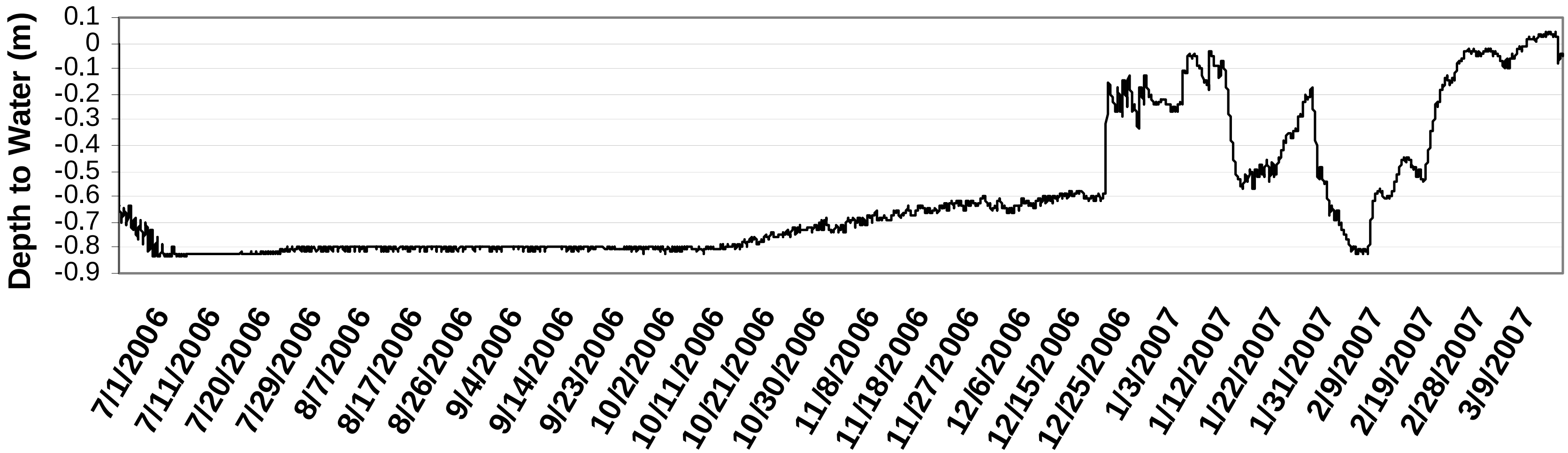


Figure 7 d. Observation well 4 hydrograph: June 22, 2006 to March 14, 2007

*Data collected below transducer depth of -0.83 meters is void
**No data was collected after March 14, 2007 due to debris infiltration causing difficulty removing transducer

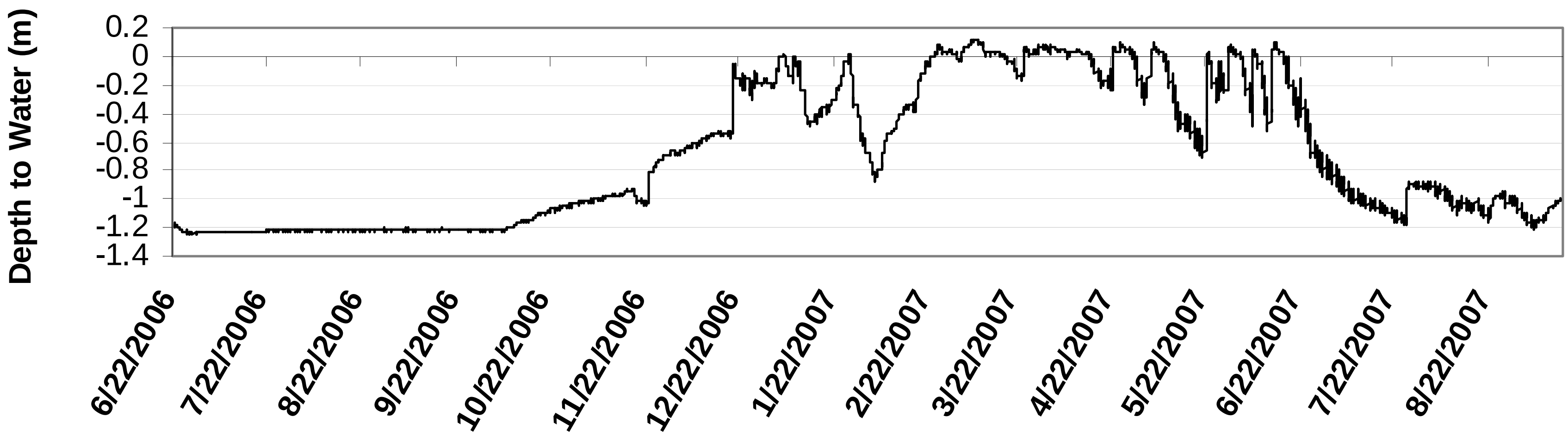


Figure 7 e. Observation well 5 hydrograph: June 22, 2006 to September 14, 2007

*Data collected below transducer depth of -1.24 meters is void

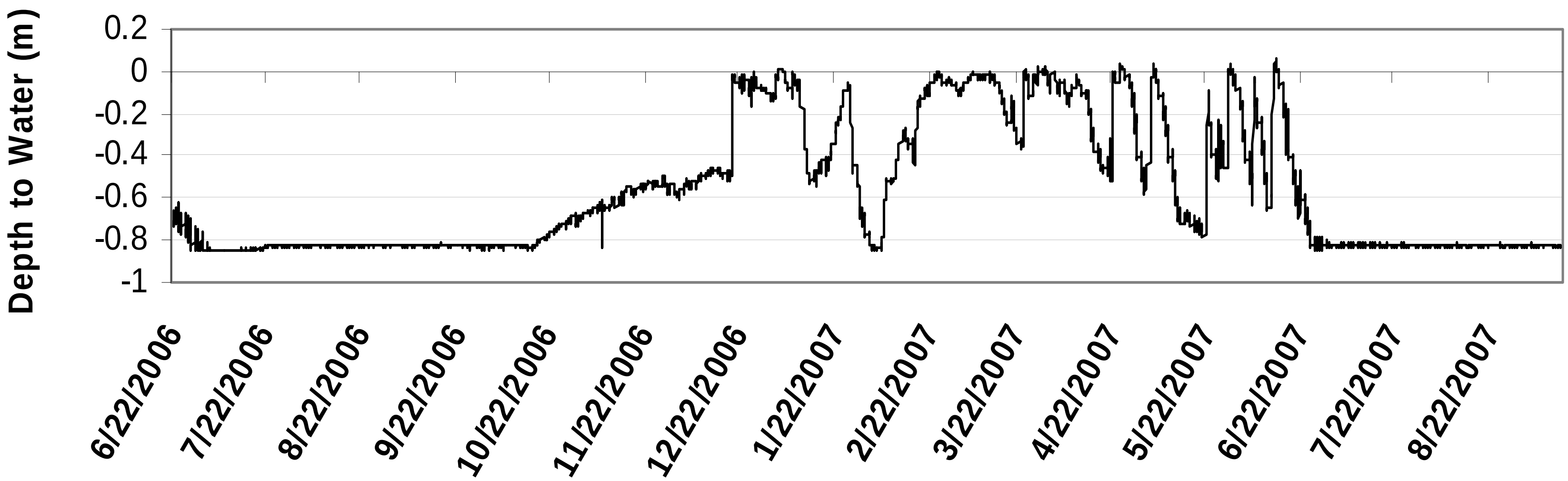


Figure 7 f. Observation well 6 hydrograph: June 22, 2006 to September 14, 2007

*Data collected below transducer depth of -0.85 meters is void

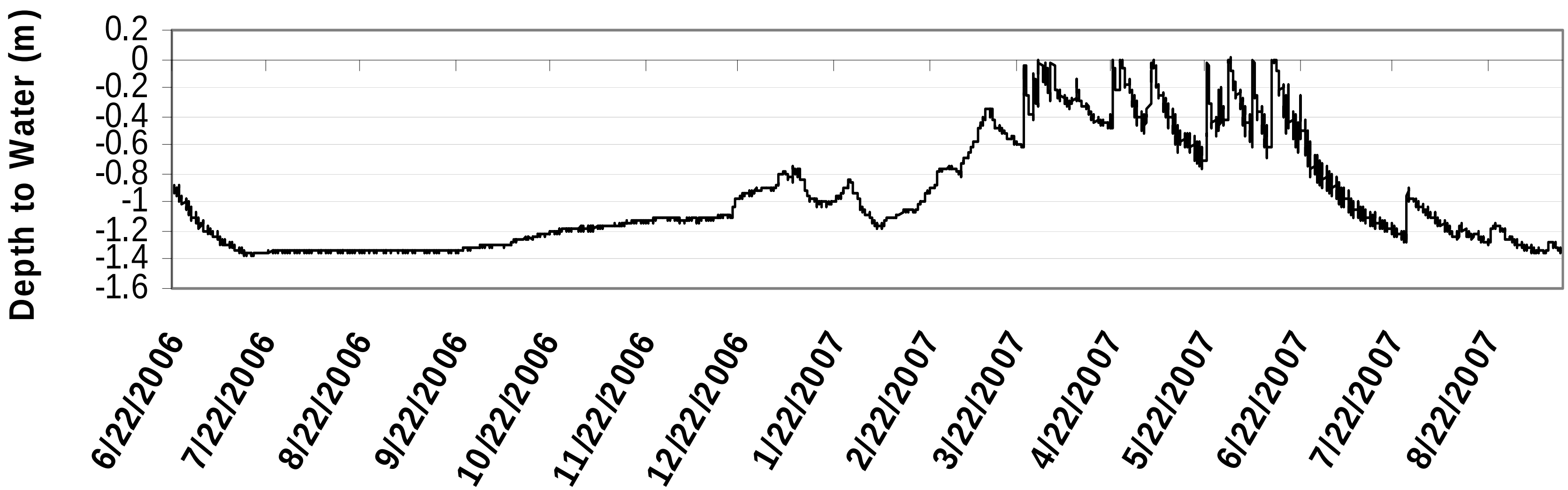


Figure 7 g. Observation well 7 hydrograph: June 22, 2006 to September 14, 2007

*Data collected below transducer depth of -1.37 meters is void

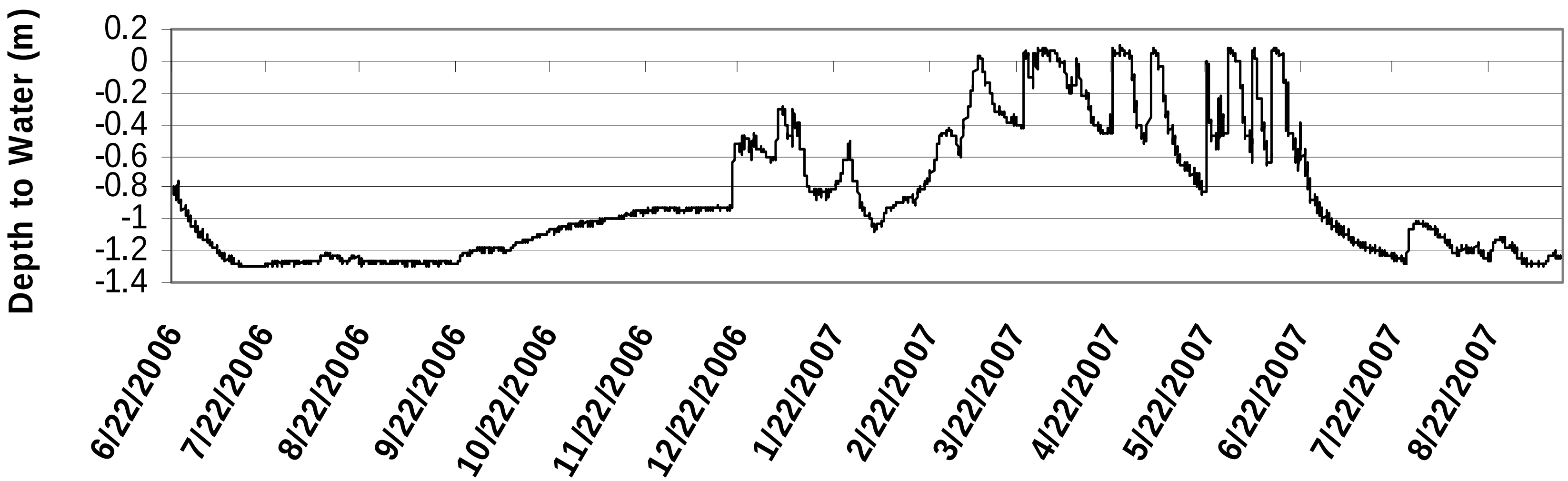


Figure 7 h. Observation well 8 hydrograph: June 22, 2006 to September 14, 2007

*Data collected below transducer depth of -1.30 meters is void

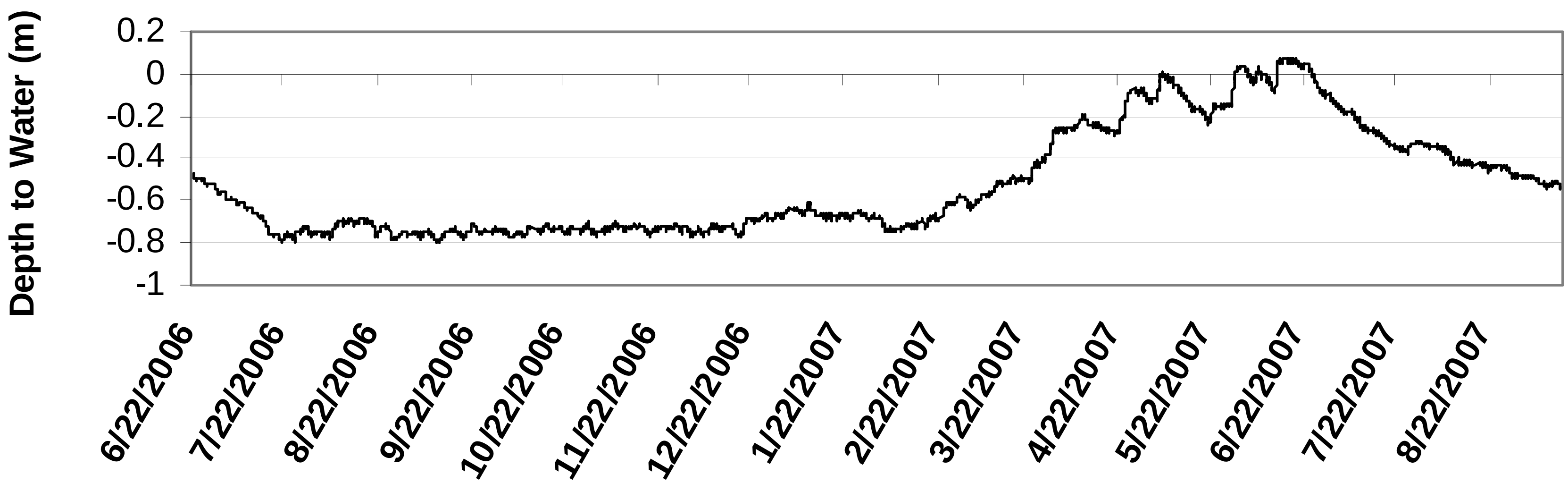


Figure 7 i. Center Pivot Well 2 hydrograph: June 22, 2006 to September 14, 2007

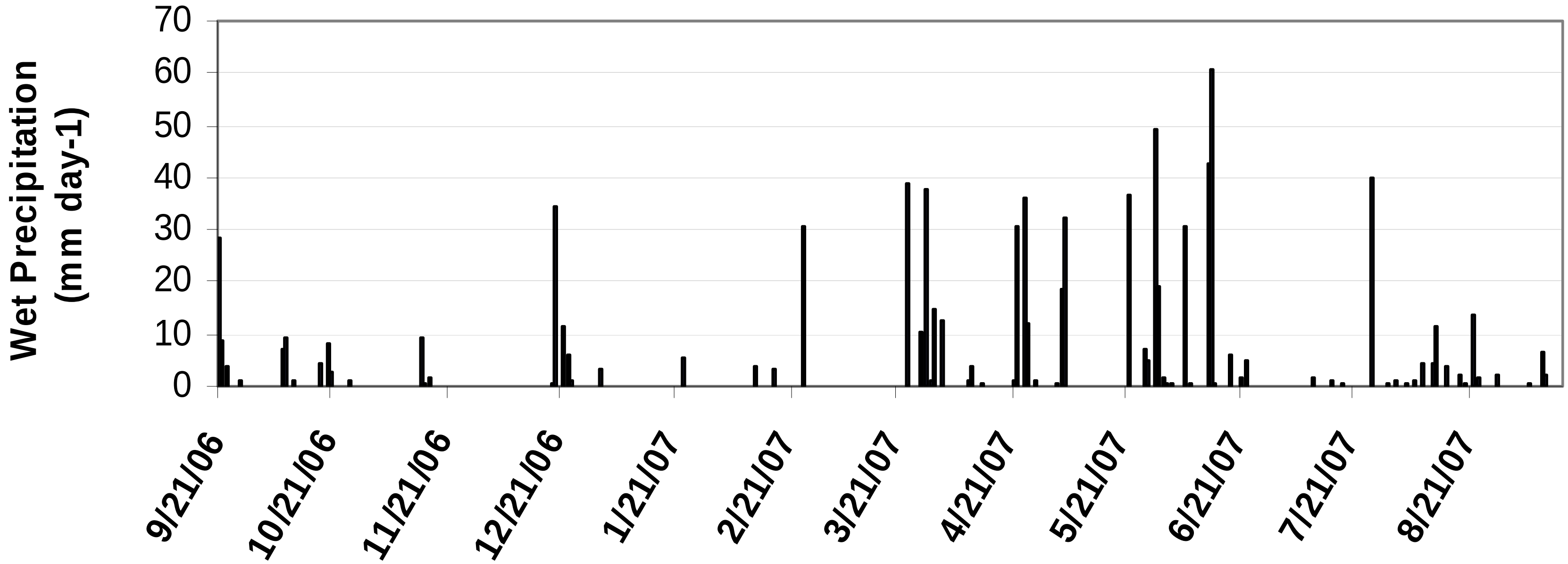


Figure 8. Hyetograph of annual wet precipitation: September 21, 2006 to September 14, 2007

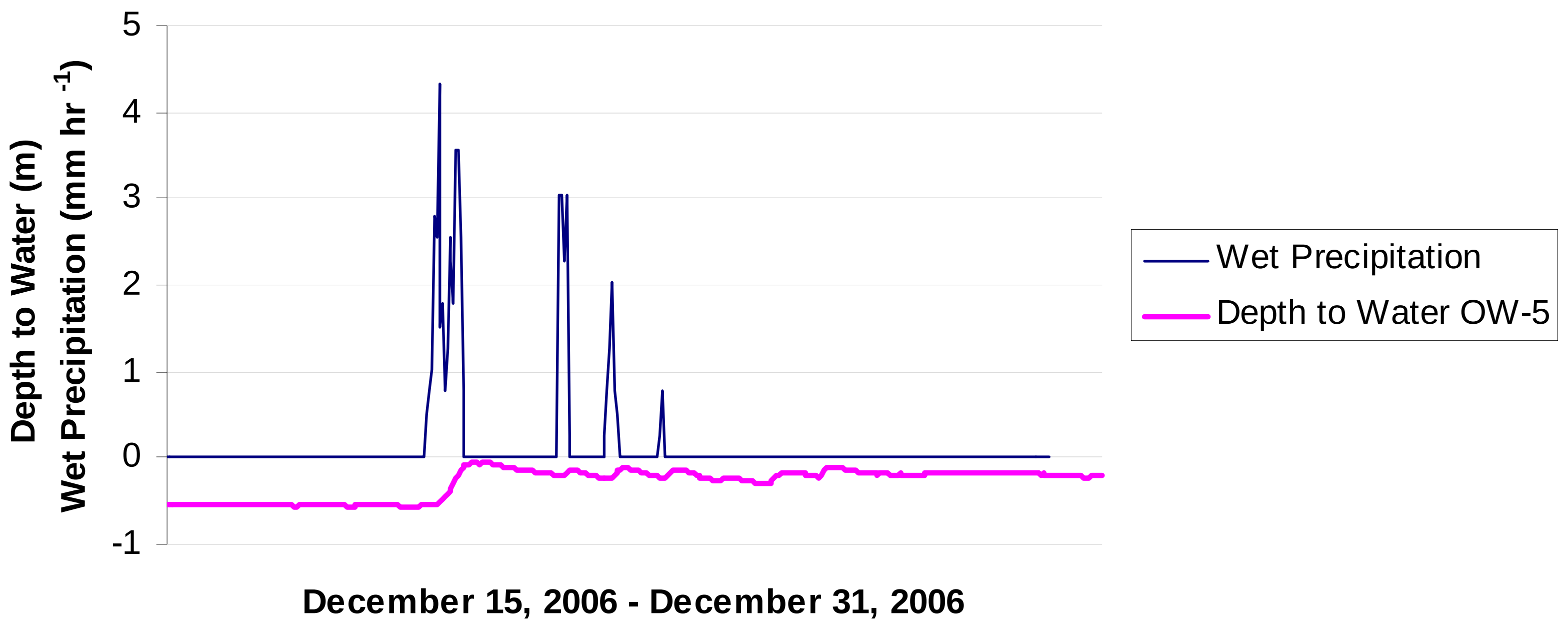
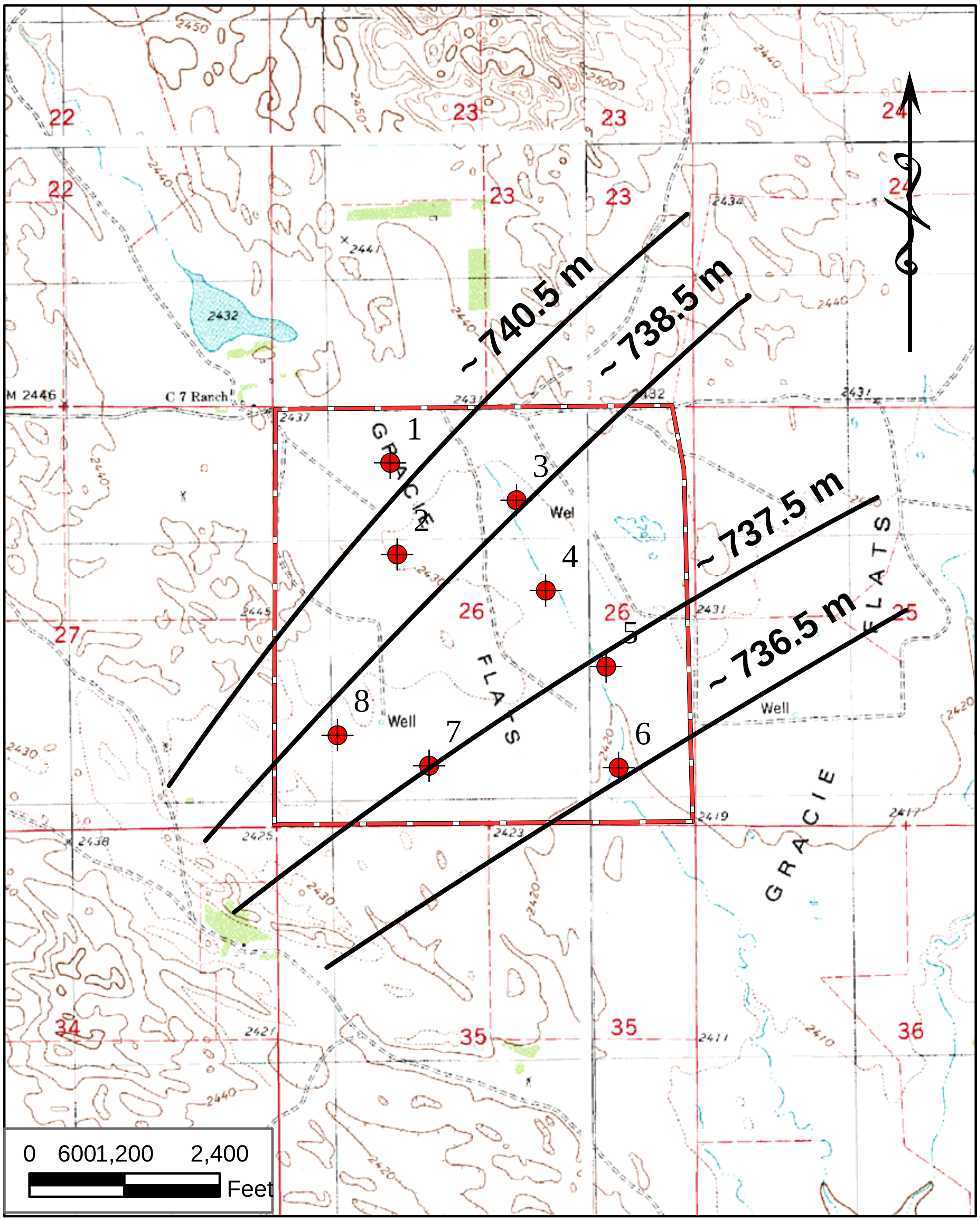


Figure 9. Relationship between wet precipitation and depth to water in observation well 5: December 15, 2006 to December 31, 2006

Figure 10. Water table contour map: January 6, 2007

Nebraska Lincoln

NDOR Nebraska Department of Roads



*Data collected 1/6/07

Rose Southeast Wetland Mitigation Bank Site

Water Table Contour Map

USGS 7.5 minute Topographic Map
Quad: Stonehouse Ranch & Stonehouse Ranch SW

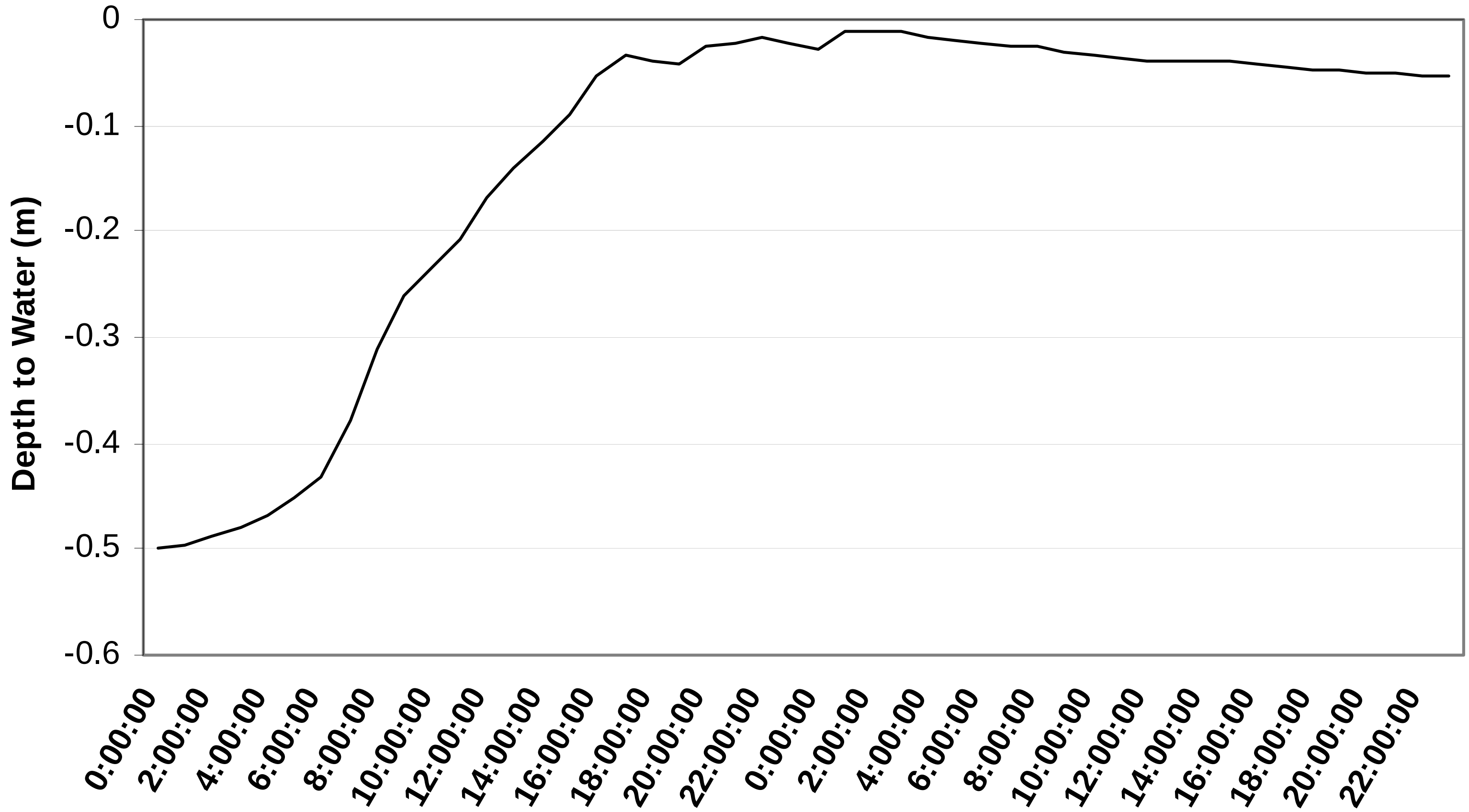


Figure 11. Change in groundwater depth for observation well 6: December 20, 2006 to December 21, 2006

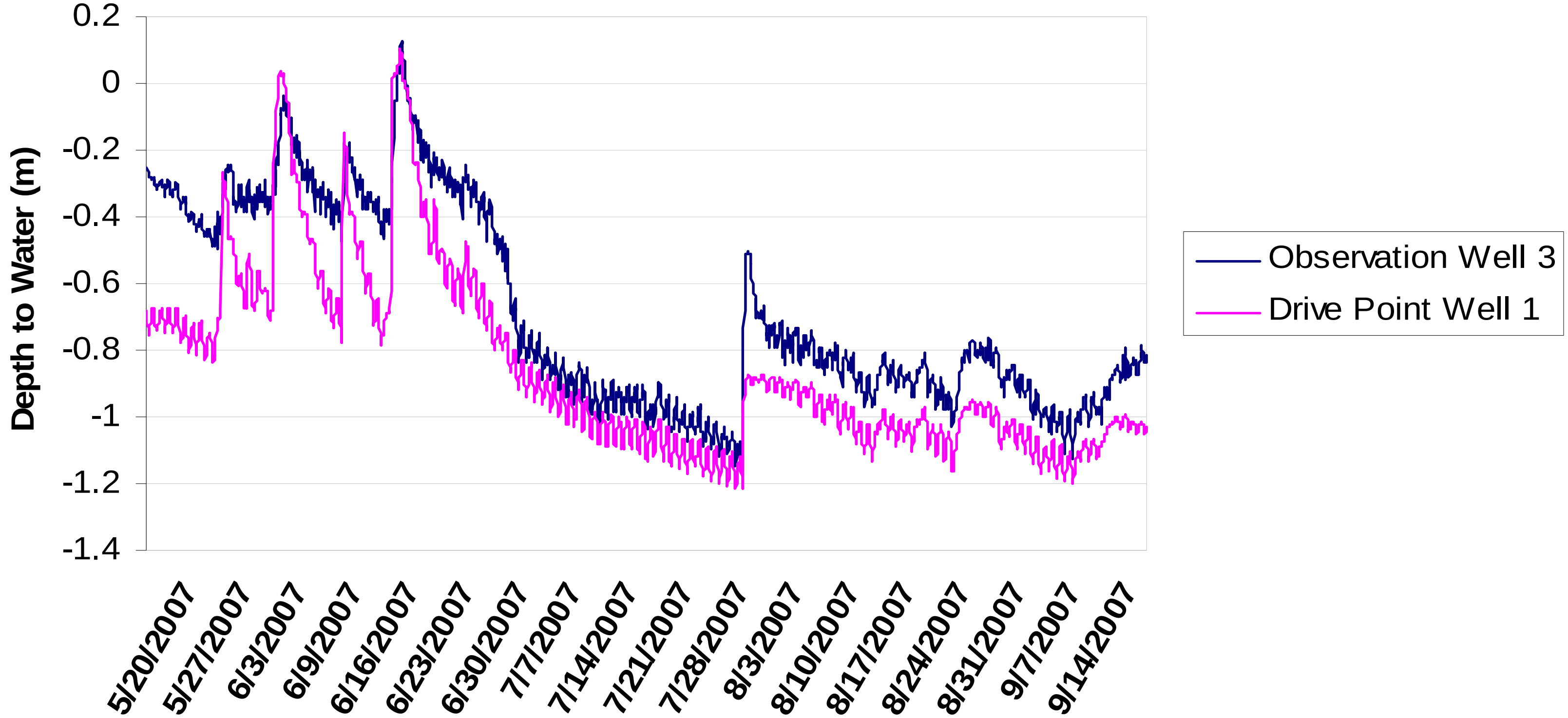


Figure 12. Piezometer nest 1 including observation well 3 and drive point well 1: May 13, 2007 to September 14, 2007

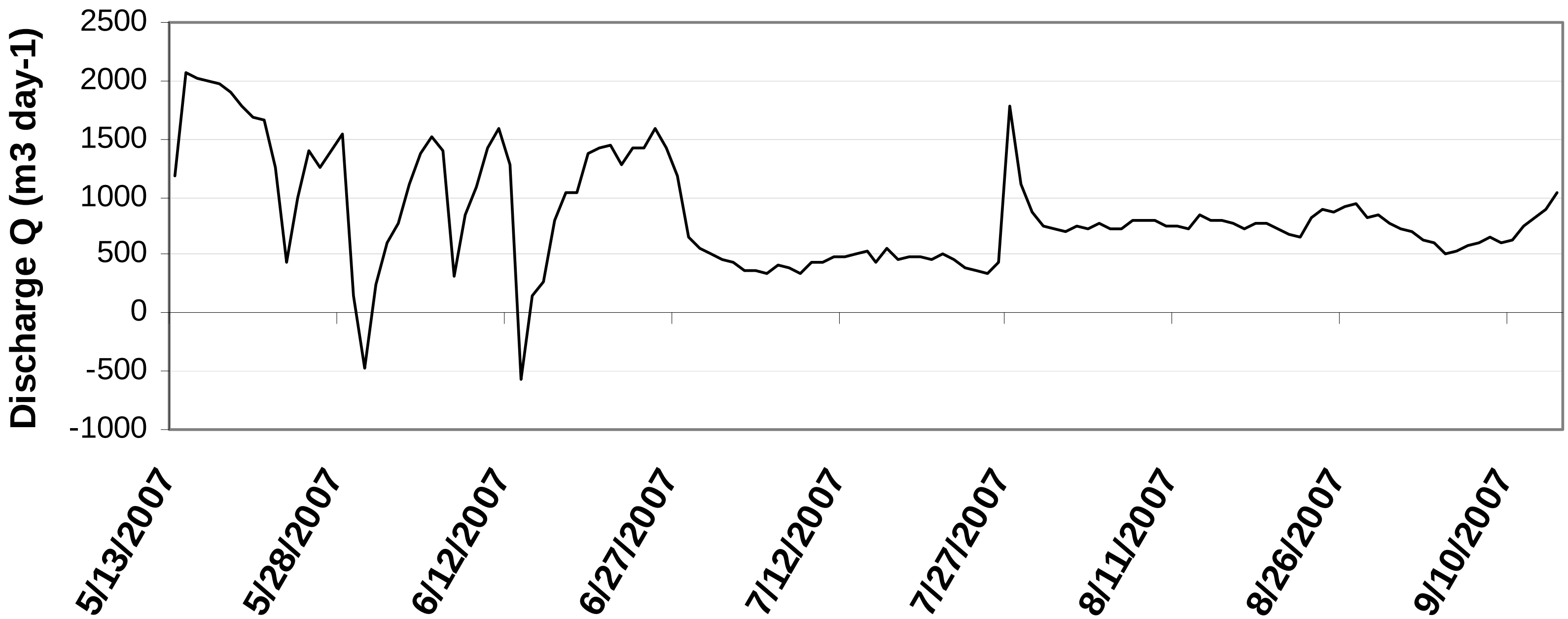


Figure 13. Groundwater flow calculated using the Darcy Equation including observation well 3 and drive point well 1: May 13, 2007 to September 14, 2007

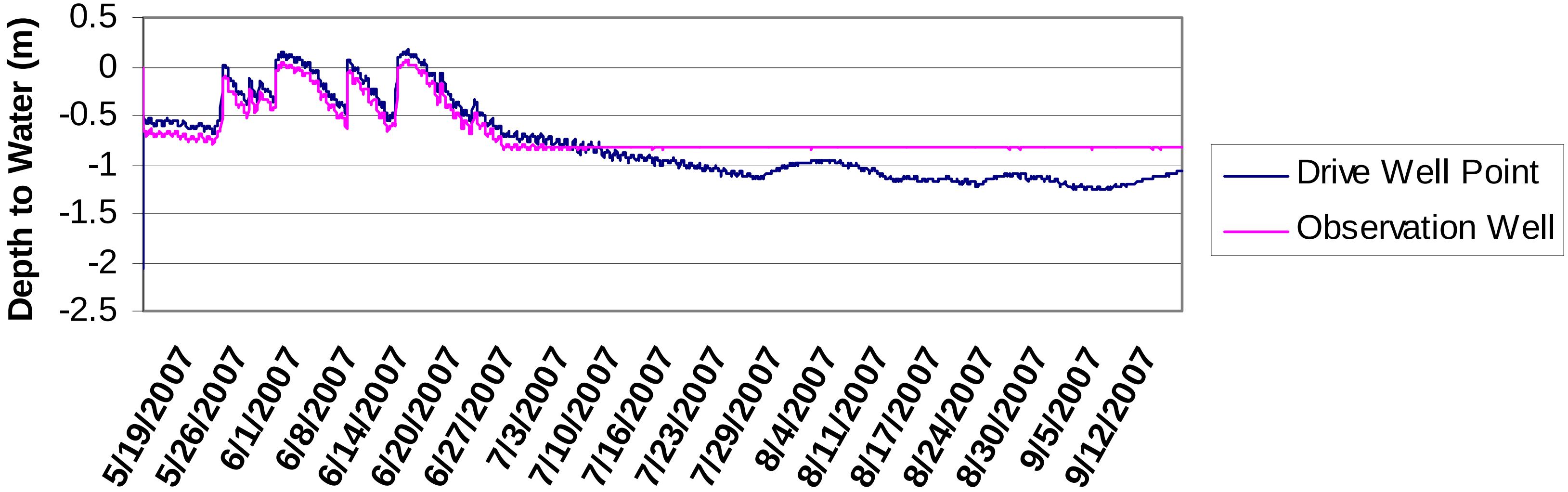


Figure 14 . Piezometer nest 2 including observation well 6 and drive point well 2: May 13, 2007 to September 14, 2007

*Data collected below Observation Well 6 transducer depth of -0.85 meters is void

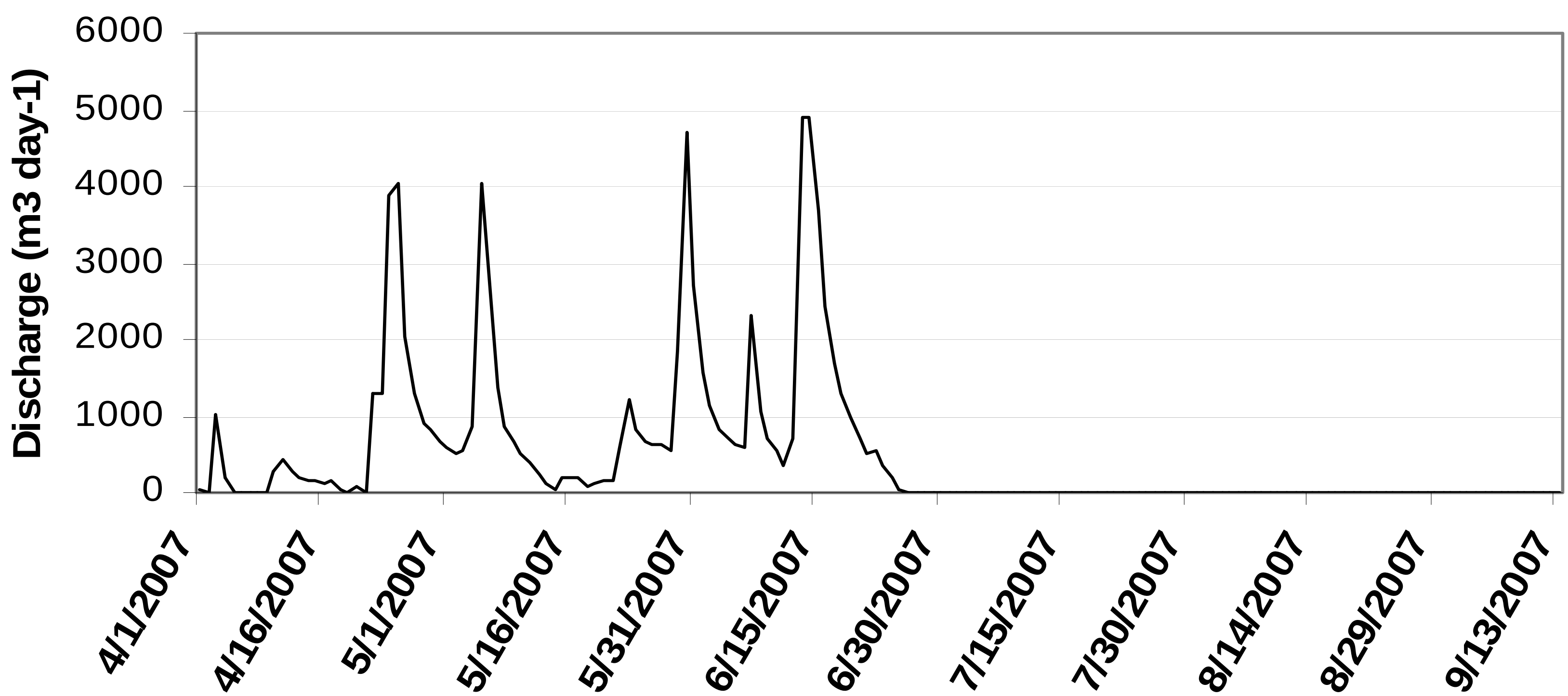


Figure 15. Flume discharge hydrograph: March 31, 2007 to September 14, 2007

*Flume discharge does not include water overtopping the flume or breaching the side wingwalls which occurred on April 3, 2007. Visual observation of additional overtopping and breaching could not be verified for other days, but is assumed to have occurred

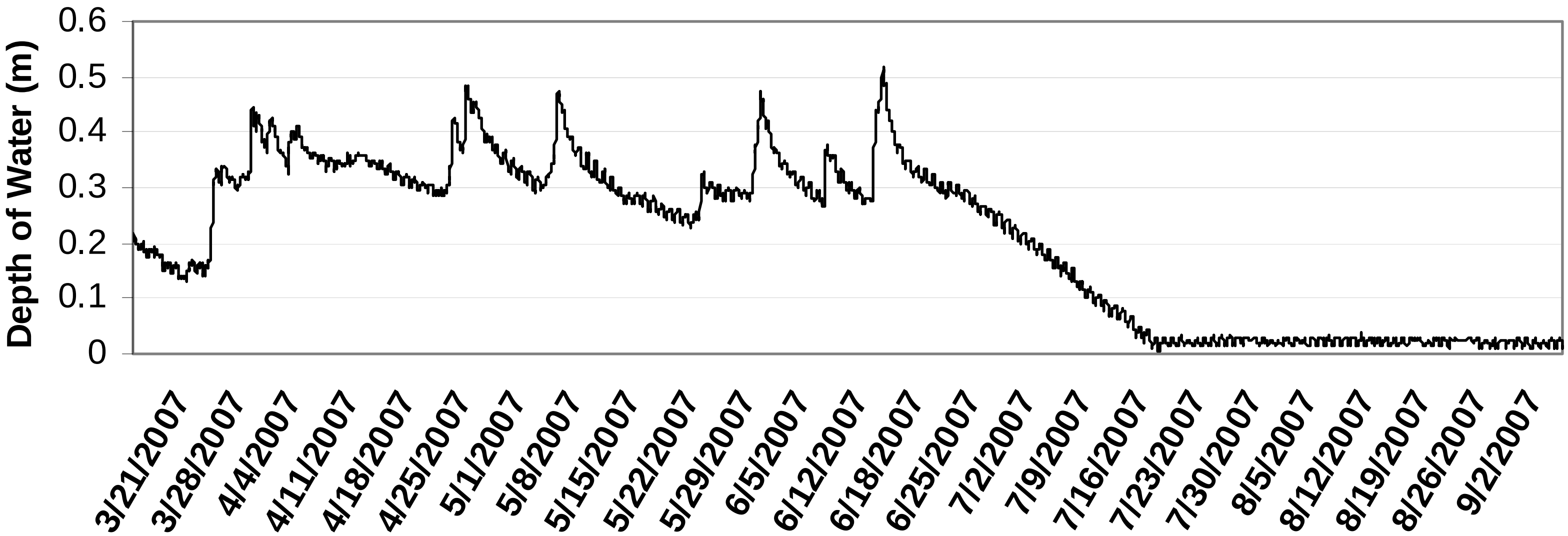


Figure 16. Surface volume storage transducer depth hydrograph: March 15, 2007 to September 14, 2007

*Data collected below transducer elevation of 735.96 meters is void

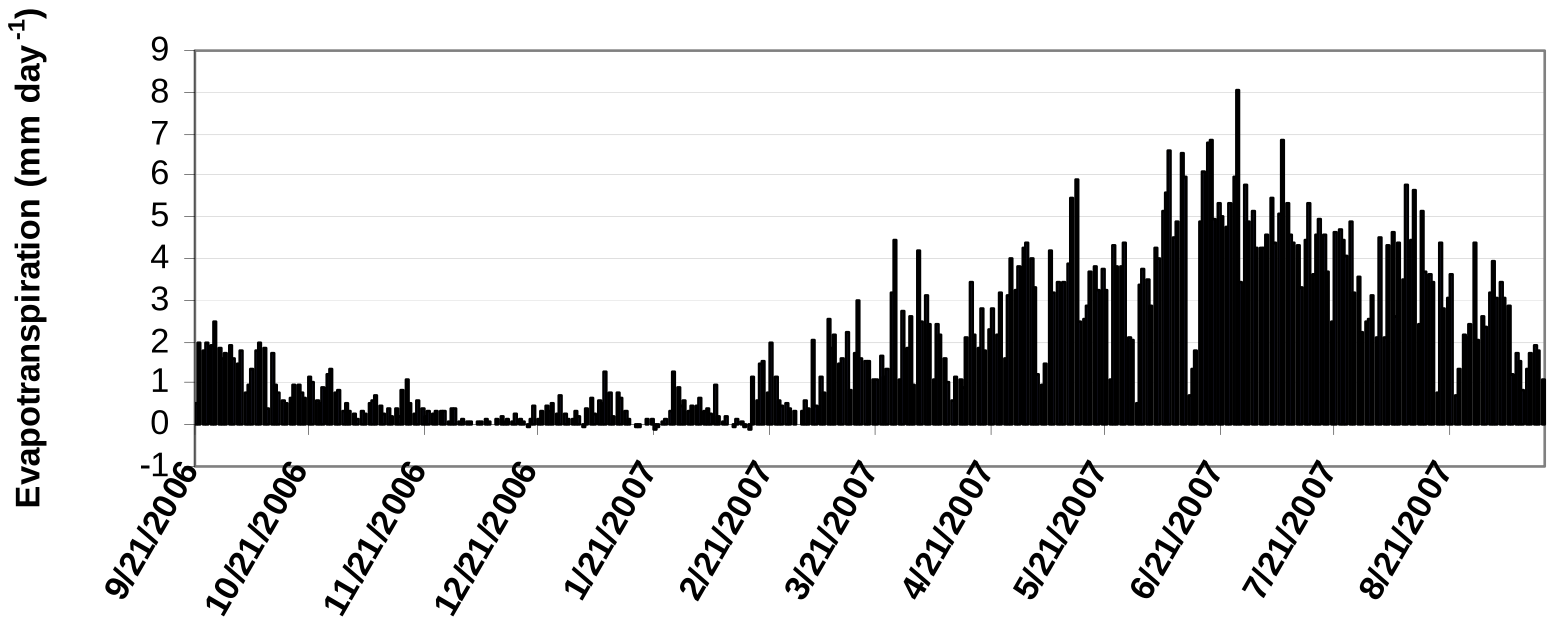


Figure 17. Annual evapotranspiration measured at the Rose Mitigation Site: September 21, 2006 to September 14, 2007

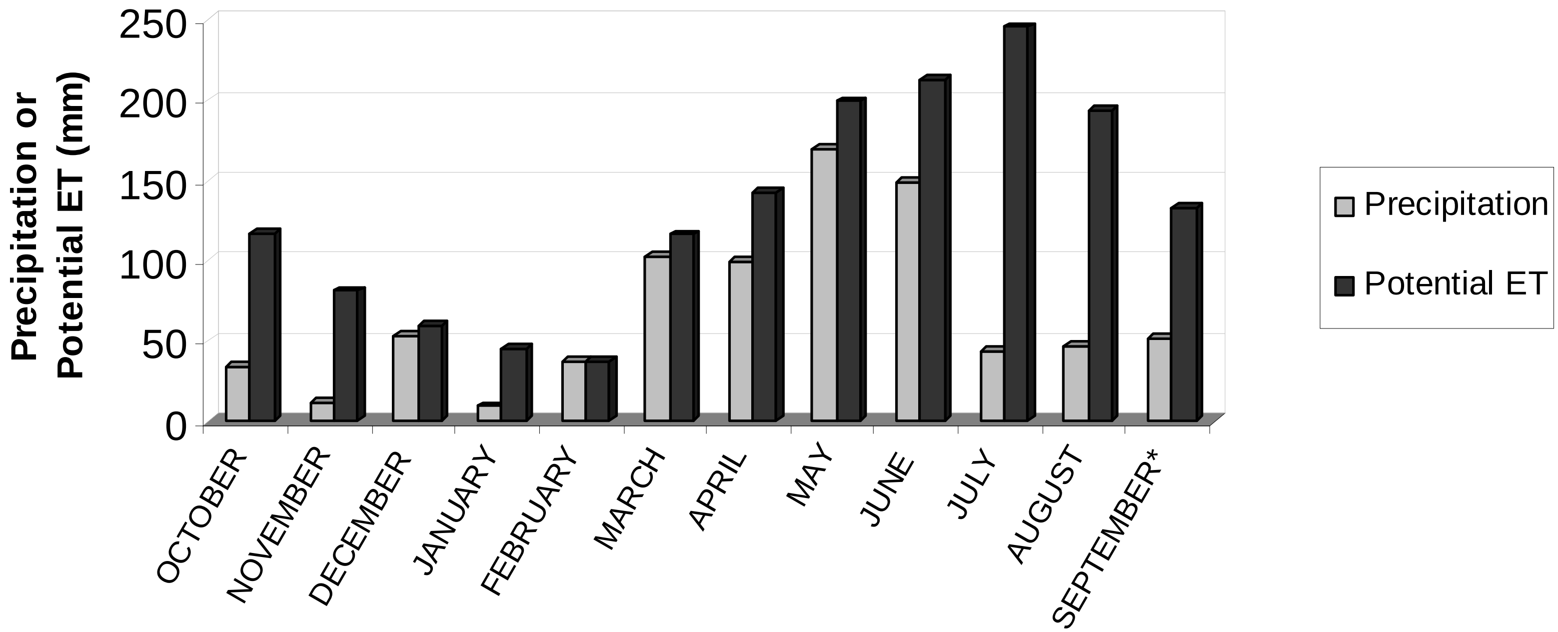


Figure 18. Monthly precipitation totals and potential evapotranspiration totals, moisture deficit: September 21, 2006 to September 14, 2007

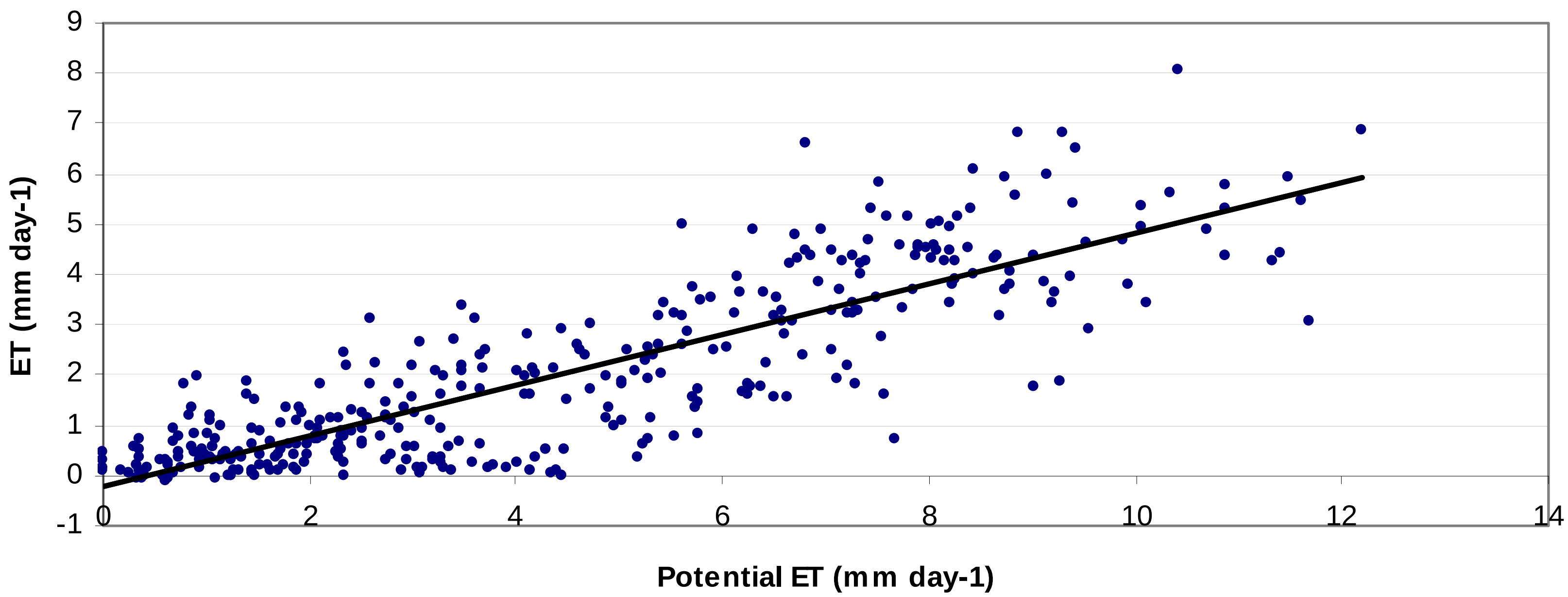


Figure 19. Comparison of measured evapotranspiration to potential evapotranspiration: September 21, 2006 to September 14, 2007

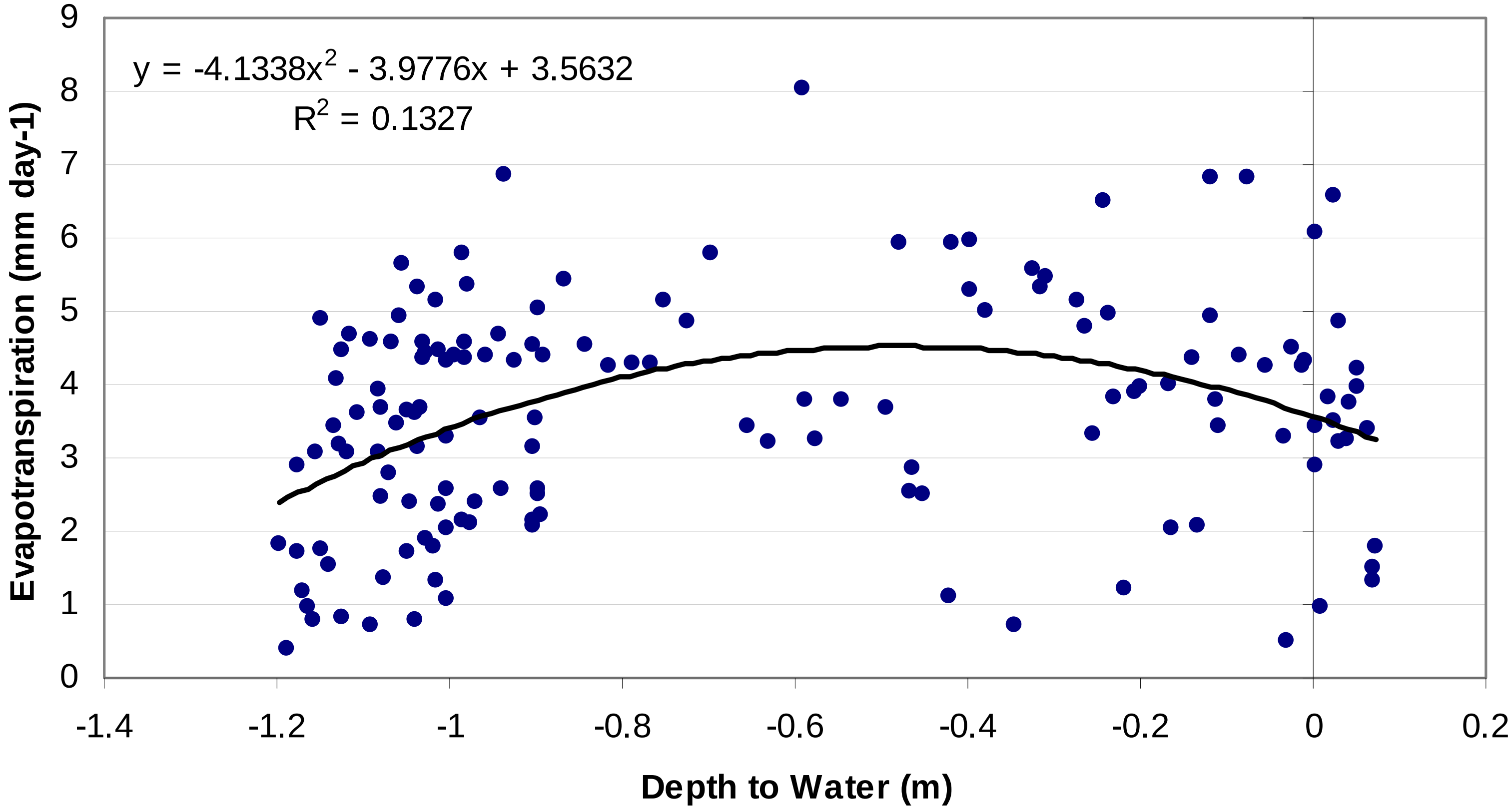


Figure 20. Relationship between evapotranspiration and depth to water in observation well 5: April 26, 2007 to September 14, 2007

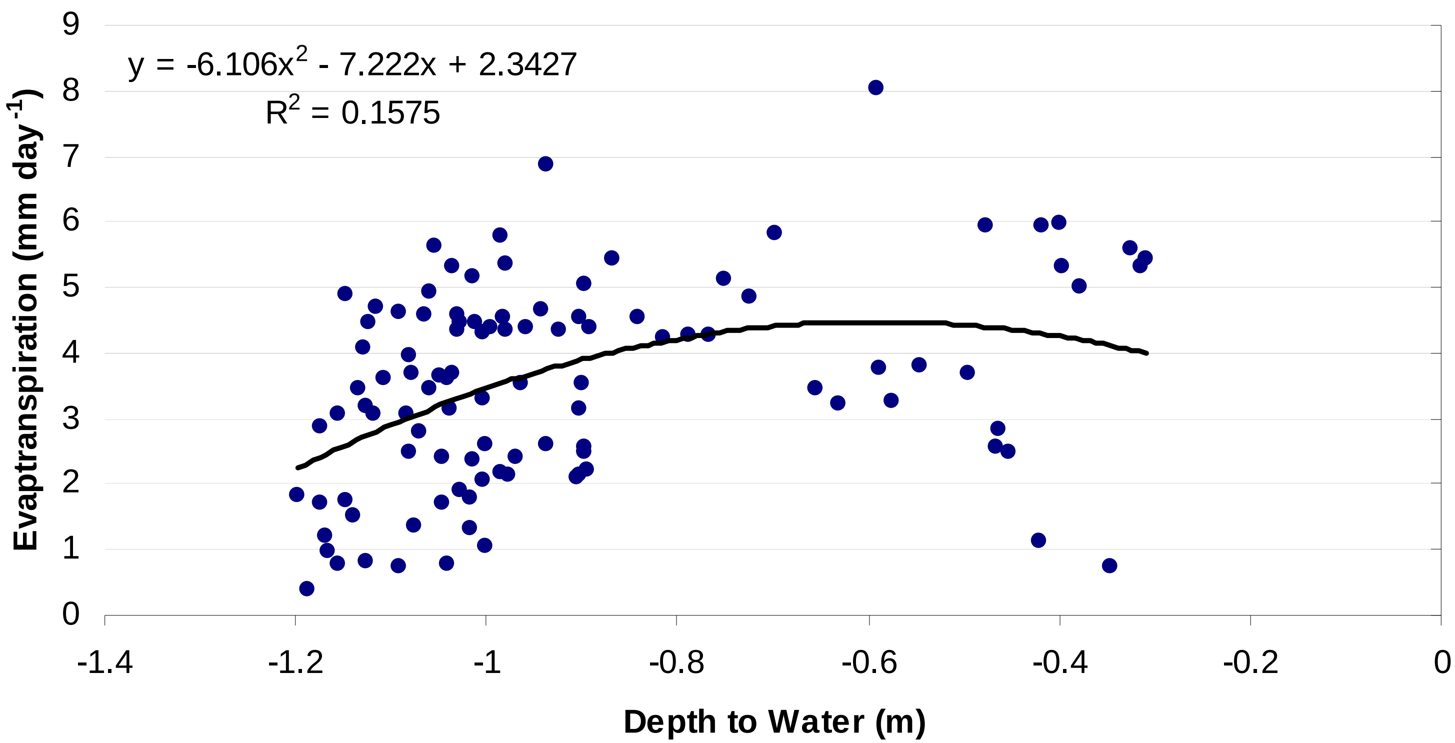


Figure 21. Relationship between evapotranspiration and depth to water in observation well 5 (below -0.3048 m: one foot regulatory indicator threshold for hydrology): April 26, 2007 to September 14, 2007

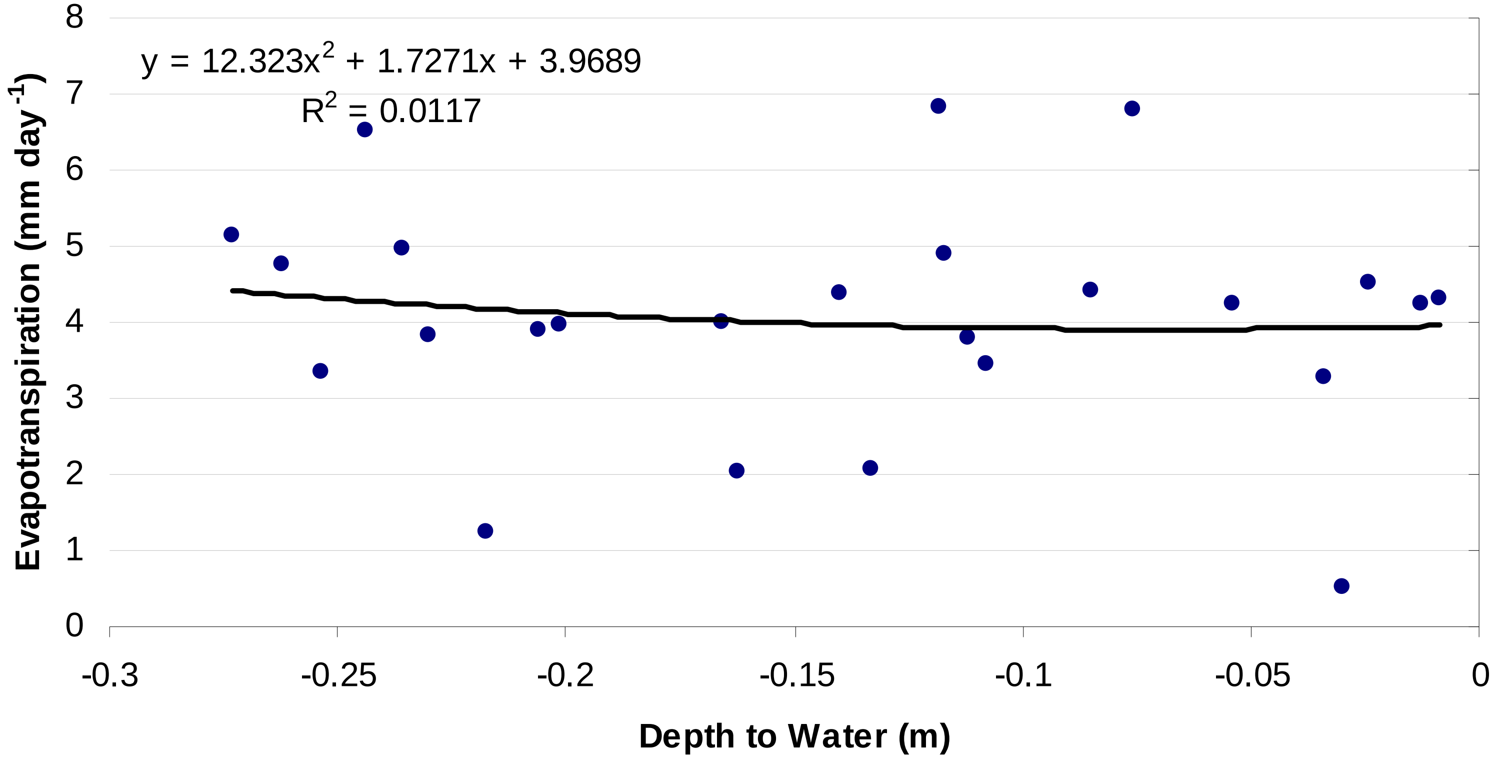


Figure 22. Relationship between evapotranspiration and depth to water in observation well 5 (within -0.3048 m: one foot regulatory indicator threshold for hydrology): April 26, 2007 to September 14, 2007

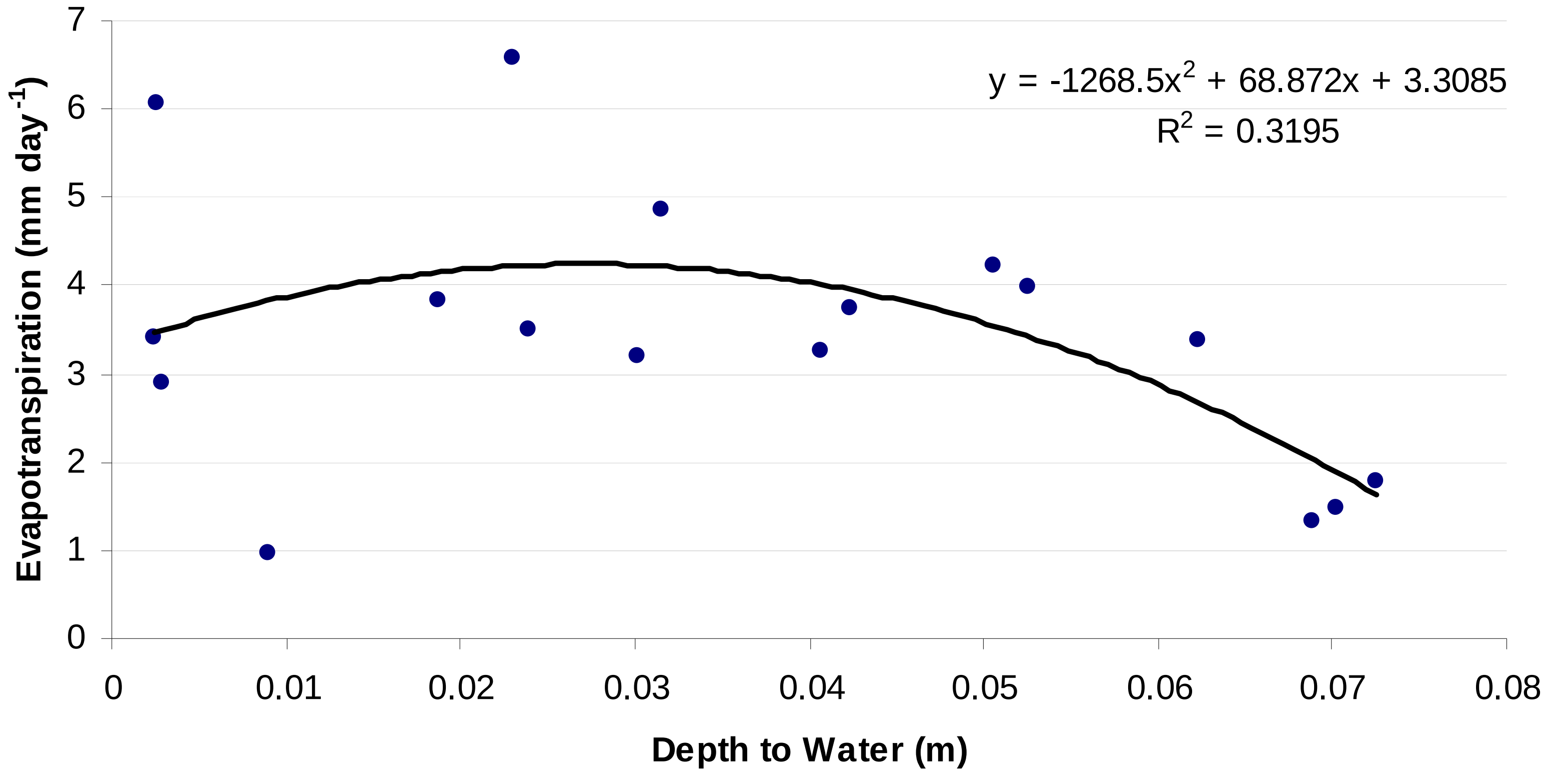


Figure 23. Relationship between evapotranspiration and depth to water in observation well 5 (inundation): April 26, 2007 to September 14, 2007

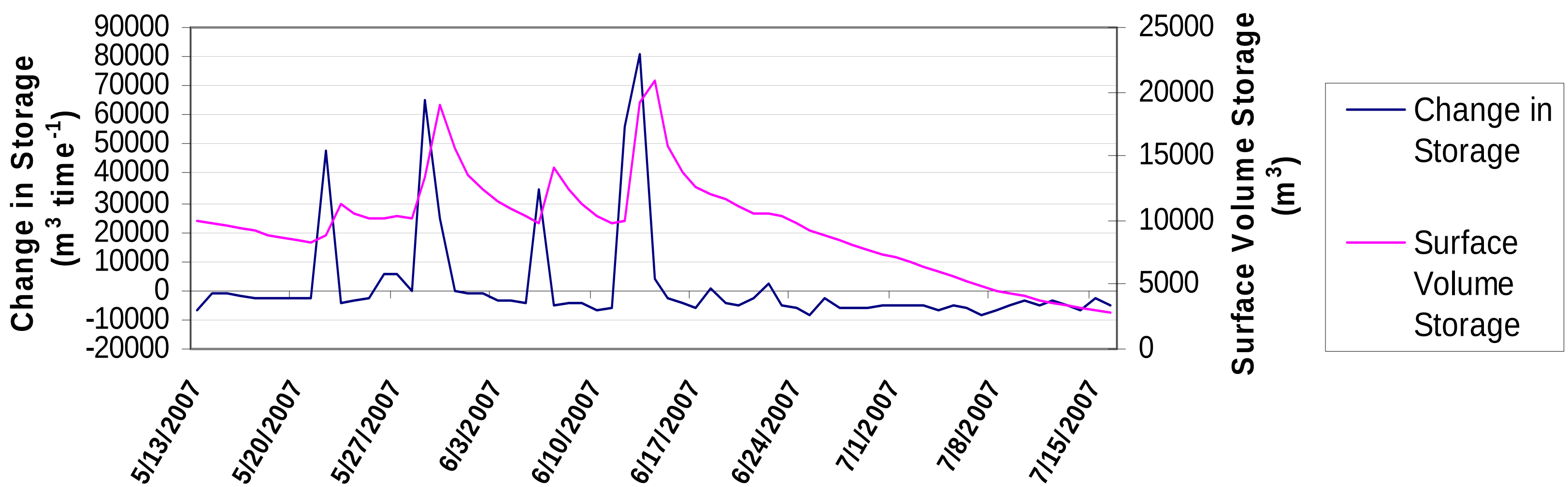


Figure 24. Change in storage vs. surface volume storage: May 13, 2007 to July 16, 2007

APPENDICES

APPENDIX A

CR1000 DATALOGGER PROGRAM

CR1000 Series Datalogger Program

```
'date: 7/6/2006
'program authors: Wyatt Webster/Bart Nef

SequentialMode
'Declare Variables and Units
Public Batt_Volt
Public BP_kPa
Public AirTempC1, AirTempC2
Public RH1, RH2
Public CNR1TC
Public CNR1TK
Public NetRs
Public NetRl
Public Albedo
Public UpTot
Public DnTot
Public NetTot
Public CG3UpCo
Public CG3DnCo
Public WS_ms, WindDir
Public VapPress1, VapPress2, SatVap1, SatVap2
Public MUX32(32), Rain_mm, PnlTempC, SiteElev
Public CNR1_Calib,HFT1_Calib, HFT2_Calib, LI190SB_Calib
Public StationStat(4)
Public StationChk as Boolean

'Declare Other Variables
Dim n  'Used as a counter for loops and such.

Alias MUX32(1) = CM3Up
Alias MUX32(2) = CM3Dn
Alias MUX32(3) = CG3Up
Alias MUX32(4) = CG3Dn
Alias MUX32(5) = HFT3_1
Alias MUX32(6) = HFT3_2
Alias MUX32(7) = LI190SB

Alias StationStat(1)= WatchDog
Alias StationStat(2) = Overrun
Alias StationStat(3)= LowBatt
Alias StationStat(4)= Signature
```

```
'Declare Units
Units Batt_Volt=Volts
Units BP_kPa=kPa
Units AirTempC1=Deg C
Units AirTempC2=Deg C
Units RH1=%
Units RH2=%
Units CM3Up=W/meter²
Units CM3Dn=W/meter²
Units CG3Up=W/meter²
Units CG3Dn=W/meter²
Units CNR1TC=Deg C
Units CNR1TK=K
Units NetRs=W/meter²
Units NetRl=W/meter²
Units Albedo=W/meter²
Units UpTot=W/meter²
Units DnTot=W/meter²
Units NetTot=W/meter²
Units CG3UpCo=W/meter²
Units CG3DnCo=W/meter²
Units WS_ms=meters/second
Units WindDir=Degrees
Units LI190SB=Par_Den
Units HFT3_1=W/meter²
Units HFT3_2=W/meter²


'Define Data Tables
DataTable(Thirty,True,-1)
	DataInterval (0,30,Min,2)
	Average (1,CM3Up,FP2,False)
	Average (1,CM3Dn,FP2,False)
	Average (1,CG3Up,FP2,False)
	Average (1,CG3Dn,FP2,False)
	Average (1,CNR1TC,FP2,False)
	Average (1,CNR1TK,FP2,False)
	Average (1,NetRs,FP2,False)
	Average (1,NetRl,FP2,False)
	Average (1,Albedo,FP2,False)
	Average (1,UpTot,FP2,False)
	Average (1,DnTot,FP2,False)
	Average (1,NetTot,FP2,False)
	Average (1,CG3UpCo,FP2,False)
	Average (1,CG3DnCo,FP2,False)
```

```
		Average (1,AirTempC1,FP2,False)
		Average (1,AirTempC2,FP2,False)
		Average (1,SatVap1,FP2,False)
		Average (1,SatVap2,FP2,False)
		Average (1,VapPress1,FP2,False)
		Average (1,VapPress2,FP2,False)
		Average (1,HFT3_1,FP2,False)
		Average (1,HFT3_2,FP2,False)
		Average (1,LI190SB,FP2,False)
		WindVector (1,WS_ms,WindDir,FP2,False,0,0,0)
		Totalize (1,Rain_mm,FP2,False)
EndTable

DataTable(Daily,True,-1)
		DataInterval(0,1440,Min,10)
		Minimum(1,Batt_Volt,FP2,False,False)
		Maximum (1,Batt_Volt,FP2,False,False)
		Minimum (1,PnlTempC,FP2,False,False)
		Maximum (1,PnlTempC,FP2,False,False)
		Minimum (1,AirTempC1,FP2,False,False)
		Maximum (1,AirTempC1,FP2,False,False)
		Minimum (1,RH1,FP2,False,False)
		Maximum (1,RH1,FP2,False,False)
		Minimum (1,AirTempC2,FP2,False,False)
		Maximum (1,AirTempC2,FP2,False,False)
		Minimum (1,RH2,FP2,False,False)
		Maximum (1,RH2,FP2,False,False)
		Minimum (1,BP_kPa,FP2,False,False)
		Maximum (1,BP_kPa,FP2,False,False)
		Maximum (1,WS_ms,FP2,False,True)
		SampleMaxMin (1,WindDir,FP2,False)
		Totalize (1,Rain_mm,FP2,False)
		Sample (4,StationStat(),FP2)
EndTable


'Define Subroutines
'Sub
'EnterSub instructions here
'EndSub
```

```
'Main Program
BeginProg
    SiteElev=737.616 '2420 feet.
    'Load CNR1 Calibration value from the factory. Units in uV/(W m^-2)
    CNR1_Calib=7.47
    'Load HFT_1 & HFT_2 calibration from the factory.
    HFT1_Calib=32.3
    HFT2_Calib=33.4
    'Load LI190SB-L from calibration sheet. Final value = the calibration sheet #.
    'times 0.604.
    LI190SB_Calib=6.69*0.604
    StationChk = true
    Scan(10,Sec,1,0)
        'Default Datalogger Battery Voltage measurement Batt_Volt:
        Battery(Batt_Volt)
        'Datalogger panel temperature.
        PanelTemp (PnlTempC,250)

        'Measure CNR1 PRT.
        BRhalf4W(CNR1TC,1,mV25,mV25,1,1,1,2100,True,True,0,_60Hz,1,0)
        PRT(CNR1TC,1,CNR1TC,1,0)
        CNR1TK=CNR1TC+273.18

        PortSet (1,1)
        n=1
        'Measure the four CNR1 sensors.
        SubScan (0,uSec,4)
            PulsePort (2,10000)

    VoltDiff(MUX32(n),1,mV25,3,True,0,_60Hz,1000/CNR1_Calib,0)
            n=n+1
        NextSubScan
        'Measure two HFT3 sensors.
        SubScan (0,uSec,2)
            PulsePort (2,10000)
            VoltDiff (MUX32(n),1,mV7_5,3,True,0,_60Hz,1,0)
            n=n+1
        NextSubScan
        'Measure the LI190SB
        SubScan (0,uSec,1)
            PulsePort (2,10000)
            VoltDiff (MUX32(n),1,mV25,3,True,0,_60Hz,1,0)
        NextSubScan
        PortSet (1,0)
```

```
'CNR1 Net Radiometer measurements CM3Up, CM3Dn, CG3Up,
CG3Dn, CNR1TC, CNR1TK,
'NetRs, NetRl, Albedo, UpTot, DnTot, NetTot, CG3UpCo, and
CG3DnCo:
NetRs=CM3Up-CM3Dn
NetRl=CG3Up-CG3Dn
Albedo=CM3Dn/CM3Up
UpTot=CM3Up+CG3Up
DnTot=CM3Dn+CG3Dn
NetTot=UpTot-DnTot
CG3UpCo=CG3Up+5.67*10^-8*CNR1TK^4
CG3DnCo=CG3Dn+5.67*10^-8*CNR1TK^4

'Adjust millivolt measurements to actual sensor values.
HFT3_1 = HFT1_Calib*HFT3_1
HFT3_2 = HFT2_Calib*HFT3_2
LI190SB = 1000/LI190SB_Calib*LI190SB

'CS105 Barometric Pressure Sensor measurement BP_kPa:
PortSet(3,1)
Delay (0,2,Sec)
VoltSE(BP_kPa,1,mV2500,7,1,0,_60Hz,0.184,600.0)
'Adjust barometric pressure to sea level.
BP_kPa=0.1*(BP_kPa+(1013.25*(1-(1-
SiteElev/44307.69231)^5.25328)))
PortSet(3,0)

'HMP45C #1 (6-wire) Temperature & Relative Humidity Sensor
measurements
'AirTempC1 and RH1
PortSet(9,1)
Delay(0,250,mSec)
VoltSE(AirTempC1,1,mV2500,8,0,0,_60Hz,0.1,-40.0)
VoltSE(RH1,1,mV2500,9,0,0,_60Hz,0.1,0)
'HMP45C #2 (6-wire) Temperature & Relative Humidity Sensor
measurements
'AirTempC2 and RH2
VoltSe (AirTempC2,1,mV2500,10,0,0,_60Hz,0.1,-40)
VoltSe (RH2,1,mV2500,11,0,0,_60Hz,0.1,0)
PortSet(9,0)
If RH1>100 And RH1<108 Then RH1=100
If RH2>100 And RH2<108 Then RH2=100
SatVP (SatVap1,AirTempC1)
SatVP (SatVap2,AirTempC2)
VapPress1= SatVap1*RH1/100
```

```
		VapPress2= SatVap2*RH2/100

		'05103 Wind Speed & Direction Sensor measurements WS_ms and
WindDir:
		PulseCount(WS_ms,1,1,1,1,0.098,0)
		BrHalf(WindDir,1,mV2500,12,2,1,2500,True,0,_60Hz,355,0)
		If WindDir>=360 Then WindDir=0
		If WindDir<0 Then WindDir=0

		'Rain gage measurements
		PulseCount (Rain_mm,1,2,2,0,0.254,0)
		If IfTime (0,1440,Min) Then StationChk = True
		If StationChk = True Then
			StationChk = False
			WatchDog = Status.WatchdogErrors
			Overrun = Status.SkippedScan
			LowBatt = Status.Low12VCount
			Signature = Status.ProgSignature
		Endif

		CallTable Thirty
		CallTable Daily

	NextScan
EndProg
```

APPENDIX B

SAS 9.1 CODING

SAS 9.1 Coding for Evapotranspiration (Authors: Kelly Kuzel and Wyatt Webster)

```
*Data Prediction for missing soil data;
Data PredictingMonth;
set AllData;
*15 Whole days before missing;
If Day > 19 and Day < 35 then output;
*15 Whole days after missing;
Else if Day > 80 and Day < 96 then output;
Keep HFT3_1_Avg HFT3_2_Avg Day;
run;

Data DayPredicted;
Infile 'F:\Wyatt\Thesis\DayPredicted.txt' DLM='09'x;
input HFT3_1_Avg HFT3_2_Avg;
run;

*Predicted values inputed for missing whole days;
Data PredictionMid;
set DayPredicted
…
Day Predicted;
run;

*Predicted values inputed for half first day;
Data PredictionFirst;
Infile 'F:\Wyatt\Thesis\PredictionFirst.txt' DLM='09'x;
input HFT3_1_Avg HFT3_2_Avg;
run;

*Predicted values inputed for half last day;
Data PredictionLast;
Infile 'F:\Wyatt\Thesis\PredictionLast.txt' DLM='09'x;
input HFT3_1_Avg HFT3_2_Avg;
run;

*Combines all predicted soil data into one file;
Data Prediction;
Set PredictionFirst
PredictionMid
PredictionLast;
run;

*Reads in the 2 Loggernet data files;
%let Vars=

TIMESTAMP: $16.     RECORD $          CM3Up_Avg $       CM3Dn_Avg $
CG3Up_Avg $         CG3Dn_Avg $       CNR1TC_Avg $      CNR1TK_Avg $
NetRs_Avg $         NetRl_Avg $       Albedo_Avg $  UpTot_Avg $
DnTot_Avg $         NetTot_Avg $   CG3UpCo_Avg $    CG3DnCo_Avg $
```

```
AirTempC1_Avg $      AirTempC2_Avg $      SatVap1_Avg $ SatVap2_Avg $
VapPress1_Avg $      VapPress2_Avg $      HFT3_1_Avg   HFT3_2_Avg
LI190SB_Avg  $       WS_ms_WVc_A          $        WS_ms_WVc_B $
        WS_ms_WVc_C $
Rain_mm_Tot $;

%macro Logger(Section, Location);
Data Logger&Section;
Infile &Location DLM='09'x;
input &Vars;
run;
%mend Logger;
%Logger(A,'F:\Wyatt\Thesis\ThesisDataA.txt');
%Logger(B,'F:\Wyatt\Thesis\ThesisDataB.txt');

*Combines the two Loggernet data sets;
Data Logger;
set LoggerA LoggerB;
OBS+1;
run;

*Reads in the +/- 48 observations for Each Day in Sequence;
Data Day;
Infile 'F:\Wyatt\Thesis\Days.txt' DLM='09'x;
input Day @@;
run;

*Merges Day Sequence file with Loggnernet Files;
data AllData;
merge Logger Day;
run;

*Inputs Predicted Soil data file into SAS;
Data PredictionA;
Infile 'F:\Wyatt\Thesis\PredictionA.txt' DLM='09'x;
input OBS HFT3_1_Avg HFT3_2_Avg;
run;

*Replaces missing soil data with predicted data within the original file;
Data AllData;
merge AllData PredictionA;
by OBS;
Rn=(NetRs_Avg + CG3UpCo_Avg - CG3DnCo_Avg);
S=((HFT3_1_Avg + HFT3_2_Avg)/2);
*Psychrometric constant;
y=0.066;
B=(y*((AirTempC2_Avg - AirTempC1_Avg)/(VapPress2_Avg - VapPress1_Avg)));
If B = '.' then B=100000000000;
LE=(Rn-S)/(1+B);
limit1=Rn-S;
```

```
run;

%macro ID(Group);
*Creates a new data file for each day from the original merged loggernet file;
Data A&Group;
set AllData;
If Day=&Group then output A&Group;
run;

*Finds the max Available energy (Rn-S) for each day (dataset);
proc iml;
load _all_;
use A&Group;
read all;
n=50;
a=j(n,1);
limit2=max(limit1);
limit=a*limit2;
create B&Group var {limit};
append;
quit;
run;

*Puts a '.' for each LE that is above the max or less than -30;
Data C&Group;
merge A&Group B&Group;
If LE > limit or LE < -30 then LE='.';
If OBS = '.' then delete;
run;

*Deletes some temp files to save room;
proc datasets library=work;
delete A&Group B&Group;
run;

*Predicts the limit for available energy and below -30 outliers;
proc mixed data=C&Group;
model LE=OBS OBS*OBS /solution outp=C&Group;
run;

*Inputs predicted LE values within '.';
Data C&Group;
set C&Group;
If LE='.' then LE=pred;
If LE < -30 then LE = 0;
ET=(LE*86400)/2450000;
run;

*Calculates the average daily ET to include zeros;
proc means data=C&Group;
```

```
var ET;
output out=F&Group mean=Avg;
run;

*Loop for predicting and inputting for each day;
%mend ID;
%ID(    1          );
…
%ID(    359       );

*Combines all days to include predicted values into one file;
Data Final;
set C1
…
C359;
run;

Data Final2;
set F1
…
F359;
run;
Data Final2;
set Final2;
total+Avg;
run;

*Predicts polynomial curve and finds area underneath the curve;
Data Reading48;
Infile 'F:\Wyatt\Thesis\Reading48.txt' DLM='09'x;
input Reading @@;
run;

Data Reading17;
Infile 'F:\Wyatt\Thesis\Reading17.txt' DLM='09'x;
input Reading @@;
run;

Data Reading50;
Infile 'F:\Wyatt\Thesis\Reading50.txt' DLM='09'x;
input Reading @@;
run;

Data Reading47;
Infile 'F:\Wyatt\Thesis\Reading47.txt' DLM='09'x;
input Reading @@;
run;

Data Reading45;
Infile 'F:\Wyatt\Thesis\Reading45.txt' DLM='09'x;
```

```
input Reading @@;
run;


Data Reading27;
Infile 'F:\Wyatt\Thesis\Reading27.txt' DLM='09'x;
input Reading @@;
run;
Data Reading;
set Reading48
…
Reading48;
run;

Data Final3;
merge final Reading;
run;

%macro ET(Day);
Data F&Day;
set Final3;
If Day=&Day then output;
Drop Pred StdErrPred DF Alpha Lower Upper Resid;
run;

ODS output SolutionF = G&Day;
proc mixed data=F&Day;
model ET=Reading Reading*Reading /solution;
run;

%mend ET;
%ET(   1          );
…
%ET(   359      );

Data HDay;
set G1
…
G359
run;

Data ETDays;
Infile 'F:\Wyatt\Thesis\ETDays.txt' DLM='09'x;
input ETDay @@;
run;

Data ETDays;
merge HDay ETDays;
run;
```

```
Data ETDays;
set ETDays;
by ETDay;
Drop StdErr DF tValue Probt;
Retain ETDay;
If Effect='Intercept' then do;
EstimateA=Estimate;
Retain EstimateA;
end;
Else If Effect='Reading' then do;
EstimateB=Estimate;
Retain EstimateB;
end;
Else If Effect='Reading*Reading' then do;
EstimateC=Estimate;
end;
If last.ETDay then output;
Drop Estimate Effect;
run;

proc iml;
load _all_;
use ETDays;
read all;
x1=((EstimateB##2-4*EstimateA#EstimateC)##.5-EstimateB)/(2*EstimateC);
x2=(-((EstimateB##2-4*EstimateA#EstimateC)##.5+EstimateB))/(2*EstimateC);
create ETDays2 var {x1 x2};
append;
quit;
run;

Data ET;
Merge ETDays ETDays2;
run;

Data Area;
set ET;
XminA=min(x1,x2);
XmaxA=max(x1,x2);
If XminA>0 then Xmin=XminA;
Else Xmin=0;
If XmaxA<1 then Xmax=XmaxA;
Else Xmax=1;

*estimating ET on predicted curve;
y=(EstimateA*1+EstimateB*(1/2)*1+EstimateC*(1/3)*1)-
(EstimateA*0+EstimateB*(1/2)*0+EstimateC*(1/3)*0);
Total+y;
Keep ETDay y Total;
run;
```

APPENDIX C

LOUP SOIL SERIES—PRIMARY CHARACTERIZATION DATA

*** Primary Characterization Data ***

(Rock, Nebraska)

Pedon ID: 80NE149001

Print Date: Aug 28 2007 11:09AM

Sampled as : Loup ; Sandy, mixed, mesic Typic Haplustoll
Revised to correlated: Loup ; Sandy, mixed, mesic Typic Haplaquoll

SSL - Project CP80NE127 BROWN AND ROCK COUNTIES
- Site ID 80NE149001 Lat: 42° 34' 40.00" north Long: 99° 28' 43.00" west MLRA: 65
- Pedon No. 80P0188
- General Methods 1B1A, 2A1, 2B

United States Department of Agriculture
Natural Resources Conservation Service
National Soil Survey Center
Soil Survey Laboratory
Lincoln, Nebraska 68508-3866

Layer	Horizon	Orig Hzn	Depth (cm)	Field Label 1	Field Label 2	Field Label 3	Field Texture	Lab Texture
80P00942	A1	A11	0-18				FSL	FSL
80P00943	A2	A12	18-25				FSL	FSL
80P00944	AC	AC	25-36				LS	LS
80P00945	C1	C1	36-74				FS	FS
80P00946	C2	C2	74-89				LS	FSL

Pedon Calculations

Calculation Name	Result	Units of Measure
Weighted Particles, 0.1-75mm, 75 mm Base	66	% wt
LE, Whole Soil, Summed to 1m	0	cm/m
CEC Activity, CEC7/Clay, Weighted Average	0.56	(NA)
Volume, >2mm, Weighted Average	0	% vol
Clay, carbonate free, Weighted Average	5	% wt
Clay, total, Weighted Average	5	% wt

Weighted averages based on control section: 25-100 cm

PSDA & Rock Fragments

Layer	Depth (cm)	Horz	Prep	-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-	-14-	-15-	-16-	-17-
				(----- Total ------)			(-- Clay ---)		(---- Silt -----)		(------------ Sand ------------)					(Rock Fragments (mm))				
				Clay	Silt	Sand	Fine	CO_3	Fine	Coarse	VF	F	M	C	VC	(-------- Weight --------)				>2 mm
				< .002	.002 -.05	.05 -2	< .0002	< .002	.002 -.02	.02 -.05	.05 -.10	.10 -.25	.25 -.50	.5 -1	1 -2	2 -5	5 -20	20 -75	.1- 75	wt % whole soil
				(------------------------- % of <2mm Mineral Soil -------------------------)												(------- % of <75mm ------)				
				3A1	3A1	3A1		3A1	3A1	3A1	3A1	3A1	3A1	3A1	3A1	3B1	3B1	3B1		
80P00942	0-18	A1	S	18.6	25.6	55.8		2.2	12.0	13.6	10.9	26.3	16.5	1.9	0.2	tr	tr	--	45	tr
80P00943	18-25	A2	S	13.6	11.2	75.2			5.0	6.2	12.4	39.4	21.7	1.6	0.1	tr	--	--	63	--
80P00944	25-36	AC	S	6.9	8.1	85.0			2.8	5.3	13.8	45.4	23.5	2.1	0.2	--	--	--	71	--
80P00945	36-74	C1	S	3.2	3.2	93.6			2.0	1.2	11.0	52.3	26.8	2.8	0.7	tr	--	--	83	--
80P00946	74-89	C2	S	11.8	10.1	78.1			4.9	5.2	12.6	43.6	20.5	1.3	0.1	--	--	--	66	--

*** Primary Characterization Data ***

(Rock, Nebraska)

Pedon ID: 80NE149001

Print Date: Aug 28 2007 11:09AM

Sampled As : Loup ; Sandy, mixed, mesic Typic Haplustoll
USDA-NRCS-NSSC-National Soil Survey Laboratory ; Pedon No. 80P0188

Bulk Density & Moisture

Layer	Depth (cm)	Horz	Prep	-1- (Bulk Density) 33 kPa	-2- (Bulk Density) Oven Dry	-3- Cole Whole Soil	-4- Water Content 6 kPa	-5- Water Content 10 kPa	-6- Water Content 33 kPa	-7- Water Content 1500 kPa	-8- Water Content 1500 kPa Moist	-9- Ratio AD/OD	-10- WRD Whole Soil	-11- Aggst Stabl 2-0.5mm	-12- (Ratio/Clay) CEC7	-13- (Ratio/Clay) 1500 kPa
				(- - - g cm^{-3} - - -)			(- - - % of < 2mm - - -)						cm^3 cm^{-3}	%		
				4A1d	4A1h				4B1c	4B2a		4B5	4C1		8D1	8D1
80P00942	0-18	A1	S	1.30	1.50	0.049			21.3	15.8		1.015	0.07		1.06	0.85
80P00943	18-25	A2	S	1.55	1.72	0.035			15.4	8.1		1.010	0.11		0.90	0.60
80P00944	25-36	AC	S	1.64	1.75	0.022			10.9	3.8		1.004	0.12		0.81	0.55
80P00945	36-74	C1	S	1.81	1.84	0.005			2.9	1.3		1.001	0.03		0.59	0.41
80P00946	74-89	C2	S	1.70	1.81	0.021			14.5	5.8		1.007	0.15		0.69	0.49

Carbon & Extractions

Layer	Depth (cm)	Horz	Prep	-1- Total C	-2- Total N	-3- Total S	-4- Org C	-5- C/N Ratio	-6- Dith-Cit Ext Fe	-7- Dith-Cit Ext Al	-8- Dith-Cit Ext Mn	-9- Ammonium Oxalate Extraction Al+½Fe	-10- ODOE	-11- Fe	-12- Al	-13- Si	-14- Mn	-15- Na Pyro-Phosphate C	-16- Fe	-17- Al	-18- Mn
				(- - - % of <2 mm - - -)					(- - - % of < 2mm - - -)								mg kg^{-1}	(- - - % of < 2mm - - -)			
					6B3a		6A1c														
80P00942	0-18	A1	S		0.390		4.28	11													
80P00943	18-25	A2	S		0.064		0.71	11													
80P00944	25-36	AC	S		0.022		0.24	11													
80P00945	36-74	C1	S				0.05														
80P00946	74-89	C2	S				0.10														

CEC & Bases

Layer	Depth (cm)	Horz	Prep	-1- NH_4OAC Extractable Bases Ca	-2- Mg	-3- Na	-4- K	-5- Sum Bases	-6- Acid-ity	-7- Extr Al	-8- KCl Mn	-9- CEC8 Sum Cats	-10- CEC7 NH_4 OAC	-11- ECEC Bases +Al	-12- Al Sat	-13- Base Saturation Sum	-14- Base Saturation NH_4OAC
				(- - - cmol(+) kg^{-1} - - -)							mg kg^{-1}	(- - - cmol(+) kg^{-1} - - -)			(- - - % - - -)		
				6N2e	6O2d	6P2b	6Q2b		6H5a			5A3a	5A8b			5C3	5C1
80P00942	0-18	A1	S	40.1*	1.9	0.4	0.5						19.8			100	100
80P00943	18-25	A2	S	11.6*	1.1	0.1	0.4		1.5				12.3			90	100
80P00944	25-36	AC	S	5.4*	0.7	tr	0.3		1.2				5.6			84	100
80P00945	36-74	C1	S	2.1*	0.3	--	0.2	2.6	0.4			3.0	1.9			87	100
80P00946	74-89	C2	S	7.2*	1.1	--	0.4		1.4				8.1			86	100

*Extractable Ca may contain Ca from calcium carbonate or gypsum., CEC7 base saturation set to 100.

*** Primary Characterization Data ***
(Rock, Nebraska)
Sandy, mixed, mesic Typic Haplustoll

Pedon ID: 80NE149001
Sampled As : Loup

Print Date: Aug 28 2007 11:09AM

USDA-NRCS-NSSC-National Soil Survey Laboratory ; Pedon No. 80P0188

Salt

				-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-	-14-	-15-	-16-	-17-	-18-	-19-	-20-
				(- - - Water Extracted From Saturated Paste - - -)																			
Layer	Depth (cm)	Horz	Prep	Ca	Mg	Na	K	CO_3	HCO_3	F	Cl	PO_4	Br	OAC	SO_4	NO_2	NO_3	H_2O	Total Salts	Elec Cond	Pred Elec Cond	Exch Na	SAR
				(- - - - - mmol(+) L^{-1} - - - - -)				(- - - mmol(-) L^{-1} - - -)										(- - - - % - - - -)		(- - dS m^{-1} - -)		%	
				6N1b	6O1b	6P1b	6Q1b	6I1b	6J1b	6U1a	6K1c				6L1c	6W1a	6M1c	8A	8D5	8A3a	8I	5D2	5E
80P00942	0-18	A1	S	12.5	1.6	2.8	0.5	--	13.0	0.6	0.6				3.3	--	--	71.3	0.1	1.47	0.72	1	1
80P00943	18-25	A2	S																		0.17	1	
80P00944	25-36	AC	S																		0.10	--	
80P00945	36-74	C1	S																		0.05	--	
80P00946	74-89	C2	S																		0.08	--	

pH & Carbonates

				-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-
				(- - - pH - - -)						(- - Carbonate - -)		(- - Gypsum - - -)		
					$CaCl_2$					As $CaCO_3$		As $CaSO_4$*$2H_2O$		Resist
					0.01M	H_2O	Sat			<2mm	<20mm	<2mm	<20mm	ohms
Layer	Depth (cm)	Horz	Prep	KCl	1:2	1:1	Paste	Sulf	NaF	(- - - % - - -)				cm^{-1}
					4C1a2a	4C1a2a	8C1b			6E1g				
80P00942	0-18	A1	S		7.4	7.4	6.9			5				
80P00943	18-25	A2	S		6.6	7.2				--				
80P00944	25-36	AC	S		6.5	7.0				--				
80P00945	36-74	C1	S		6.6	7.0				--				
80P00946	74-89	C2	S		6.6	7.1				--				

APPENDIX D

HYDROLOGIC ZONES—NONTIDAL

Table 5
Hydrologic Zones[1]- Nontidal Areas

Zone	Name	Duration[2]	Comments
I[3]	Permanently inundated	100 percent	Inundation >6.6 ft mean 3 water depth
II	Semipermanently to nearly permanently inundated or saturated	>75 - <100 percent	Inundation defined as <=6.6 ft mean water depth
III	Regularly inundated or saturated	>25 - 75 percent	
IV	Seasonally inundated or saturated	>12.5 - 25 percent	
V	Irregularly inundated or saturated	>=5 - 12.5 percent	Many areas having these hydrologic characteristics are not wetlands
VI	Intermittently or never inundated or saturated	<5 percent	Areas with these hydro- logic characteristics are not wetlands

[1]Zones adapted from Clark and Benforado (1981).
[2]Refers to duration of inundation and/or soil saturation during the growing season.
[3]This defines an aquatic habitat zone.

APPENDIX E

HYDRIC SOILS CRITERIA—NTCHS

1. All Histels except Folistels and Histosols except Folists, or

2. Soils in Aquic suborders, great groups, or subgroups, Albolls suborder, Historthels great group, Histoturbels great group, Pachic subgroups, or Cumulic subgroups that are:

   a. Somewhat poorly drained with a water table* equal to 0.0 foot (ft) from the surface during the growing season, or

   b. poorly drained or very poorly drained and have either:

      i. water table* equal to 0.0 ft during the growing season if textures are coarse sand, sand, or fine sand in all layers within 20 inches (in),

         or for other soils

      ii. water table* at less than or equal to 0.5 ft from the surface during the growing season if permeability is equal to or greater than 6.0 in/hour (h) in all layers within 20 in,

         or

      iii. water table* at less than or equal to 1.0 ft from the surface during the growing season if permeability is less than 6.0 in/h in any layer within 20 in, or

3. Soils that are frequently ponded for long duration or very long duration during the growing season, or

4. Soils that are frequently flooded for long duration or very long duration during the growing season.

***water table:** the upper surface of ground water where the water is at atmospheric pressure. In the Map Unit Interpretation Record (MUIR) database, entries are made for the zone of saturation at the highest average depth during the wettest season. It is at least six inches thick and persists in the soil for more than a few weeks. In other databases, saturation, as defined in Soil Taxonomy (Soil Survey Staff. 1999), is used to identify conditions that refer to water table in Criteria 2.