DITCH POND CAROLINA BAY RESTORATION PROJECT

AIKEN AND BARNWELL COUNTIES, SOUTH CAROLINA

PHASE II REPORT

STATE OF SOUTH CAROLINA
DEPARTMENT OF NATURAL RESOURCES

LAND, WATER AND CONSERVATION DIVISION

WATER RESOURCES
REPORT 44
2007

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Scott V. Harder, Joseph A. Gellici, and Andrew Wachob

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CONTENTS

Page

FIGURES

Page

FIGURES (continued)

Page

TABLES

Page

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ABSTRACT

Ditch Pond Bay is the central feature of the Ditch Pond Heritage Preserve, which is located along the Aiken-Barnwell county line near Williston, South Carolina. Water levels in the bay are believed to be below normal owing to the presence of several ditches at the site. One ditch extends from the interior of Ditch Pond Bay to an outlet culvert north of the bay, while a second ditch to the west-northwest drains an adjacent Carolina bay (White Pond Bay). The impact of these ditches on the water level in Ditch Pond Bay is unknown, and a study of the bay is under way to determine the current hydrologic dynamics of the bay, the impacts of the ditches, and the need for restoration. This report presents data on rainfall, evapotranspiration, ground water, and bay water for just over a 12-month study period from mid-March 2006 through March 2007. For the 12-month period from April 2006 through March 2007, rainfall was more than 9 inches below normal, and water elevations in the bay declined approximately 2 feet. Ground-water levels measured in most wells substantially declined below the surface water of the bay during the summer and fall periods of the study. Lateral hydraulic gradients measured between bay levels and marginal wells suggest predominantly ground-water outflow through this period, though some sections of the bay margin provided evidence of ground-water inflow. A monthly water budget also suggests that ground water is a significant component of the bay's hydrology. Well data show that the water table in the vicinity of the ditches has remained below the ditch bed for much of the study period, and little to no flow has been observed in these ditches. These results suggest that the ditch network has had little impact on the water level in Ditch Pond Bay during the relatively dry 12-month study period; however, additional data are needed for normal and wet weather conditions to fully assess the impacts of these ditches on the hydrology of Ditch Pond Bay.

INTRODUCTION

There are approximately 2,650 Carolina bays larger than 2 acres in South Carolina, and 97 percent of these bays have been disturbed (Bennett and Nelson, 1991). Main disturbances include conversion to agriculture or silviculture, where bays are often ditched and drained. Alteration of bay hydrology in these systems has degraded habitat for many plant and animal species. The Heritage Trust Program, currently administered by the South Carolina Department of Natural Resources (SCDNR), has highlighted the need to preserve and/or restore these unique ecosystems (Heritage Trust Act) and has identified a number of bays for protection (Bennett and Nelson, 1991). One such Carolina bay found suitable for preservation and possible restoration is Ditch Pond Bay, and this bay was acquired for preservation in December 2002.

Ditch Pond Bay (DPB) is a 25-acre Carolina bay on the border of Aiken and Barnwell Counties near Williston, S.C., and is a prominent feature of the Ditch Pond Heritage Preserve (Fig. 1). Water levels in the bay may be below normal because of a shallow ditch that extends from the bay to a drainage culvert underneath Weeks Road (State Road 215). A larger ditch, which drains an adjacent Carolina bay (White Pond Bay) just west of DPB, may be impacting the water levels by altering the local water table. DPB is relatively undisturbed as compared to most Carolina bays in South Carolina; however, the degree to which the hydrology at DPB has been altered from its natural state is uncertain.

Carolina bays are shallow wetland depressions that are characterized by an elliptical shape oriented in a northwest-southeast direction. These depressions are unique geometric features of the Atlantic Coastal Plain, occurring from New Jersey to northern Florida but heavily concentrated in North and South Carolina (Sharitz and Gibbons, 1982). Owing to the disturbance of many bays and their similarities to other types of wetland depressions in the Southeast, the identification of some systems as Carolina bays can be challenging. Estimates on the number of bays vary widely, ranging from 500,000 (Prouty, 1952) to a more probable number of 10,000–20,000 (Richardson and Gibbons, 1993). Carolina bays vary in size from thousands of acres to less than 1 acre, and their hydrologic regimes can range from permanently flooded to frequently dry.

As wetland systems, Carolina bays may have one or more associated wetland functions such as water storage, wildlife habitat, biodiversity conservation, or nutrient cycling (Lugo and others, 1990; U.S. Environmental Protection Agency, 1993; Sharitz and Gresham, 1998; Whigham and Jordan, 2003). Sharitz and Gibbons (1982) argued that the most important ecological role of Carolina bays is to provide habitat for a diverse range of flora and fauna. Several studies have also shown that depressional wetlands such as Carolina bays may contain rare plant species (Suter and Kral, 1994; Edwards and Weakley, 2001). Because fluctuating water levels in many Carolina bays inhibit the occurrence of

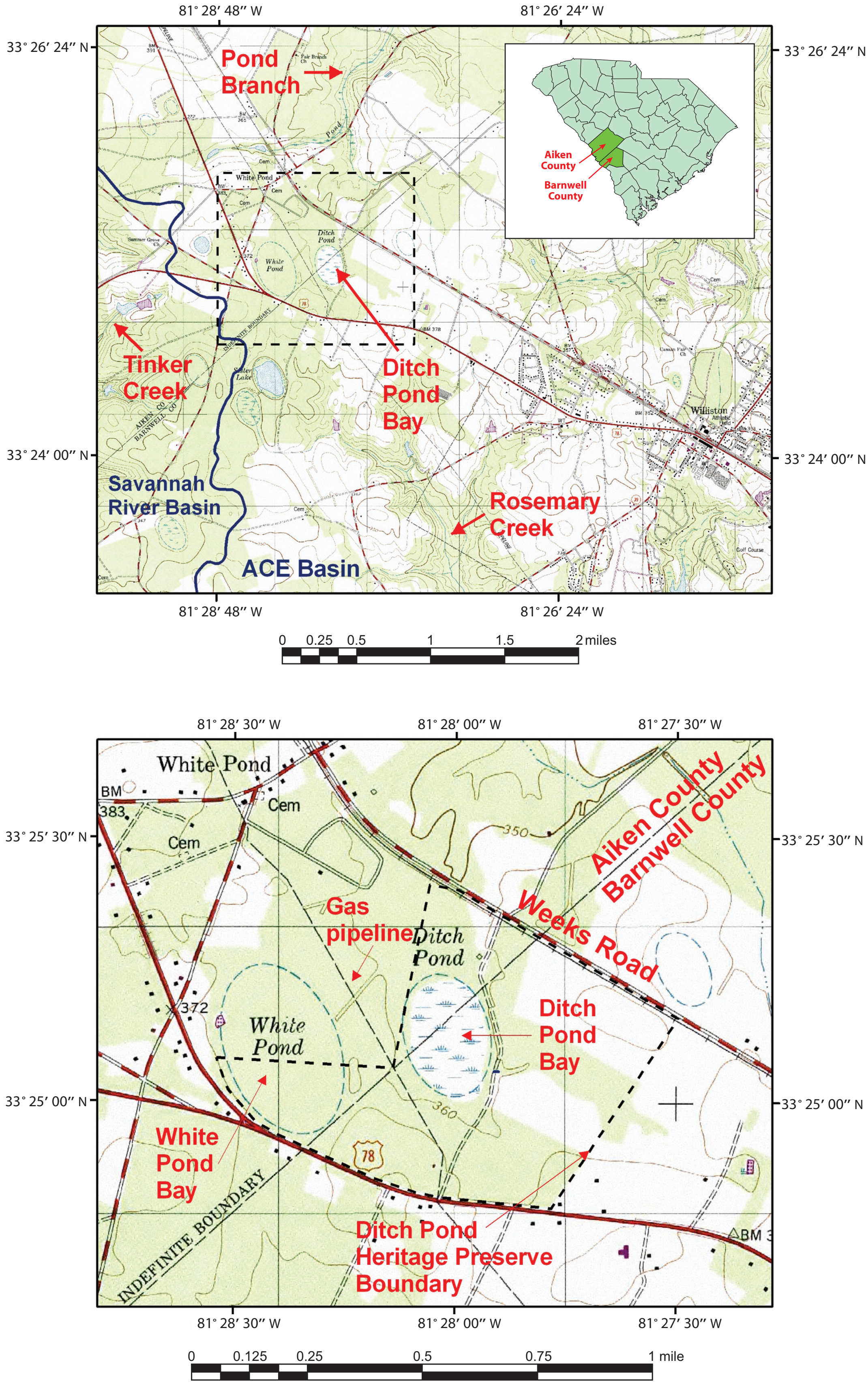


Figure 1. Location map and overview of DPB (map source: USGS, Williston 7.5′ quadrangle).

predatory fish, many of these systems can also support an abundance and diverse range of aquatic wildlife (Taylor and others, 1999). To date, most research on Carolina bays has focused on their ecological significance and few detailed studies have been done on the hydrology of these systems. However, the ecological dynamics of a Carolina bay are heavily controlled by its hydrologic regime (De Steven and Toner, 2004; Mitsch and Gosselink, 2000; Collins and Battaglia, 2001).

Undisturbed Carolina bays typically have no natural surface drainage into or out of them, and the amount of standing water in a bay depends heavily on climatic conditions, since hydrologic inputs to the bay are dominated by rainfall and outputs are dominated by evapotranspiration (ET) (Schalles and Shure, 1989; Lide and others, 1995; Sharitz, 2003; Pyzoha, 2003). Some bays will contain water permanently, even during drought periods, while others will remain dry for most of a year of normal rainfall. Water levels may fluctuate dramatically on a seasonal and annual basis due to variations in rainfall and ET patterns from season to season and from year to year (Sharitz, 2003). The occurrence of standing water in a bay is thought to be either a surface expression of the water table or the result of a perched system in which ponded water is held above the water table by a semi-impervious sediment layer (Lide and others, 1995).

Several studies have been done on the ground water-surface water interaction of Carolina bays. This interaction was first highlighted by Schalles and Shure (1989) on a 17-acre bay (Thunder Bay) in Bamberg County, S.C. These authors attributed the dilute water chemistry of the bay water and differences in surface gains and losses to ground water exchange. Newman and Schalles (1990) studied the water chemistry of 49 Carolina bays and argued that excess sulfate in some bays was due to surface-water enrichment from subsurface water beneath the bays.

More recently, several detailed hydrologic studies of ground water-surface water interactions have been done on Carolina bays (Lide and others, 1995; Sun and others, 2006). Lide and others, in a detailed hydrologic study of Thunder Bay, concluded that, although rainfall and ET were the dominating hydrologic factors, important interactions exist between surface and ground water. Ground-water outflow from the bay was dominant, but they found that ground-water inputs were possible during unusually high water-table conditions. They further observed that the water in Thunder Bay was a surface expression of the water table as opposed to a perched system and that no unsaturated conditions occurred beneath the bay during their study period. Their results were based on data collected from 34 piezometers across the bay-upland system (the bay and surrounding upgradient lands) as well as from a basic water budget for the bay.

Callahan highlighted four distinct hydrologic phases in his study of a 20-acre Carolina bay (Chapel Bay) using data collected from a series of 20 monitoring wells and 23 piezometers over a 6-year period from 1997–2003 in Bamberg County (T.J. Callahan, College of Charleston, written commun., 2006). Lateral ground-water discharges into the bay occurred during wetting, wet and drying seasonal phases, while ground-water inflow was nearly nonexistent during a dry seasonal phase. A hydrologic modeling study on this same bay, using the FLATWOODS model (Sun and others, 1998a, b), showed that Chapel Bay is a flow-through wetland that receives ground-water inputs on one side while recharging ground water on the other side of the bay (Sun and others, 2006). The direction of ground-water flow at Chapel Bay appeared to follow the topographic gradient across the bay-upland system. Hypothetical simulations also suggested that ground-water flow direction was dependent on the gradient of underlying semiconfining layers and not just the topographic gradient.

OBJECTIVES

The objectives of the this study were to (1) describe the current hydrologic regime of DPB; (2) assess the degree of disturbance and evaluate the need for restoration; and (3) provide recommendations on potential restoration approaches.

Phase I of the DPB restoration study involved the installation of nine monitoring wells, a staff gage, and an automatic rain gage. The purpose of Phase I was to provide preliminary baseline information on rainfall, bay-water levels, and water-table levels surrounding the bay. Details of Phase I can be found in South Carolina Department of Natural Resources Open-File Report 11 (Harder and others, 2006).

This report describes Phase II of the DPB hydrologic study and provides information on the installation of additional monitoring equipment at the site and a summary of hydrologic data collected since the beginning of the study in March 2006. Additional data are also presented on the drainage ditches and the sedimentology of the bay-upland system to facilitate interpretation of the hydrologic data collected at the site.

Hydrologic studies of wetland systems must capture a wide range of weather conditions to completely describe their hydrology. The data presented herein were collected primarily during a dry period with below-normal rainfall, and this report contains findings and tentative conclusions based on these dry conditions. Additional data will be collected over the next 1–2 years to evaluate the hydrology of the bay for a wider range of climatic conditions.

SITE DESCRIPTION

The location and overview of DPB is shown in Figure 1. DPB (centered at latitude 33º 25′ 7″ N, longitude 81º 28′ 1″ W) is located in the upper Coastal Plain between the towns of White Pond and Williston along the Aiken-Barnwell County line. The bay has an approximate length of 1,400 ft (feet) and an approximate width of 900 ft. The rim of the bay has an elevation of approximately 355 ft while the lowest elevation within the bay is approximately 348.5 ft.

Hydrology

The bay is on a highland, or plateau, that forms a drainage divide between Tinker Creek on the southwest, Rosemary Creek on the south, and Pond Branch Creek on the northeast. These streams drain into the Savannah, Combahee, and Edisto Rivers, respectively. The White Pond Bay (WPB) and DPB ditches converge near an outlet culvert beneath Weeks Road (State Road 215) and drain into Pond Branch Creek, which ultimately drains to the South Fork Edisto River. DPB is part of a small, localized drainage basin (160 acres) on the Williston-to-Windsor highland, and the basin extends nearly 5,000 ft across a broad upland valley to the east-southeast (Willoughby, 2002). This localized basin is part of a 35.3 square mile sub-basin that drains to the South Fork Edisto River (Hydrologic Unit Code 03050204030040) (Bower and others, 1999).

DPB is classified as an open-water bay and appears to hold water on a semi-permanent basis despite the presence of the shallow ditch. DPB and WPB were cited in maps as early as 1818 on the Barnwell sheet by Anderson (Anderson, 1818), and the maps were improved for inclusion in the atlas of Mills (1825). A Williston 15-minute topographic map (U.S. Geological Survey, 1927) also shows standing water. Aerial photographs taken between 1938 and 1999 show highly variable standing-water conditions that ranged from almost completely dry in 1955 (after a severe drought in 1954) to full or nearly full in 1966 and 1999. Several photographs (1951 and 1971) show water declines similar to those observed during 2006. SCDNR personnel observed completely dry conditions in the spring of 2002 following the severe drought from 1998–2002 (R.H. Willoughby, SCDNR, oral commun., 2006). The bay levels observed in these records generally followed rainfall patterns. A dry bay corresponded to 1–3 years of below average rainfall, whereas a full bay corresponded to a 1–3 years of above average rainfall. The aerial photographs suggest that the DPB ditch has not been effective in completely draining the bay and that hydrologic conditions are heavily dependent on rainfall patterns.

Ditch network

There are three ditches that may be affecting the water levels in DPB (Fig. 2). A shallow ditch, approximately 2 ft in depth, extends from the center of DPB northward to an outlet culvert underneath Weeks Road (State Road 215). This culvert, shown in Figure 3, drains to Pond Branch Creek, which flows into the South Fork Edisto River. Owing to the presence of several earthen dams or plugs within the ditch, surface-water outflow from the bay may occur only during extremely wet periods when water levels in the bay are higher than the tops of these plugs. The largest plug, approximately 150 ft from the edge of the bay, has a ground surface elevation of 354.0 ft. The water in the bay must first reach this elevation before any water will spill over the plug. Depressions in the ditch were observed immediately upstream and downstream of this plug, suggesting that this plug or earthen dam was created by excavating soil from the bed of the ditch. Soil samples were taken to a depth of approximately 8 ft below the surface of this plug and were consistent with the loamy sand encountered in several well boreholes in the northern section of the system (DP3 and DP5). A picture of the DPB ditch immediately upstream of this plug is found in Figure 4. The part of the ditch that extends into DPB (Fig. 5) is only about 1 ft deep and appears to have been naturally backfilled with soil from the bay. Aerial photographs over the past 65 years that show the presence of water even during relatively dry periods, and the presence of these artificial plugs suggests that the ditch has had little effect in draining the bay.

A second ditch, approximately 4 ft in depth, extends across WPB to the main culvert underneath Weeks Road (Fig. 2) and has almost completely drained WPB. A picture of the WPB ditch is found in Figure 6. Though some areas of the ditch appear to be partially filled in by fallen debris, no artificial plugs similar to those observed in the DPB ditch have been observed. The remnants of what appears to have been a beaver dam just upstream from the outlet culvert may slow or impede surface outflow from this ditch, but are not currently preventing drainage to the outlet culvert. The WPB ditch can be seen in aerial photographs as early as 1938, and very little water has been observed in the bay from photographs taken over the past 65 years. A surface elevation was measured in the WPB ditch at approximately its least distance (450 ft) from the edge of DPB. Elevation data will be used to assess the potential of the ditch to affect water levels in DPB by changing the local water table.

A third ditch (upland ditch), 2–3 ft in depth, is located on the east-southeast side of DPB (Fig. 2). The length of this ditch is currently uncertain, but it may have originally extended as much as 1,000 ft along the upland flat on the east side of the bay. Aerial photographs suggest that this ditch may have been created to drain two small depressions along this upland flat. Both of these depressions are located on private agricultural land, and the current effectiveness of this ditch for drainage is uncertain. This ditch would contribute surface inflow to DPB, as opposed to surface outflow. The ditch appears to be too shallow to significantly affect the water table in this area of the DPB study site. In addition, an access road that surrounds much of the bay may serve to plug this ditch. Additional information on this ditch (length, existence of plugs, and presence of standing water) will be needed to assess its impact on the hydrology of DPB.

Land Use

The dominant land uses around DPB are agriculture and timber production. Forested vegetation from the northern lip of the bay to Weeks Road and along a thin buffer surrounding the bay appears to have remained intact since at least 1938. Prior to 1955, land in the eastern and southern quadrants around the bay was predominantly agricultural, as observed from aerial photographs. Beginning in 1959, some of these

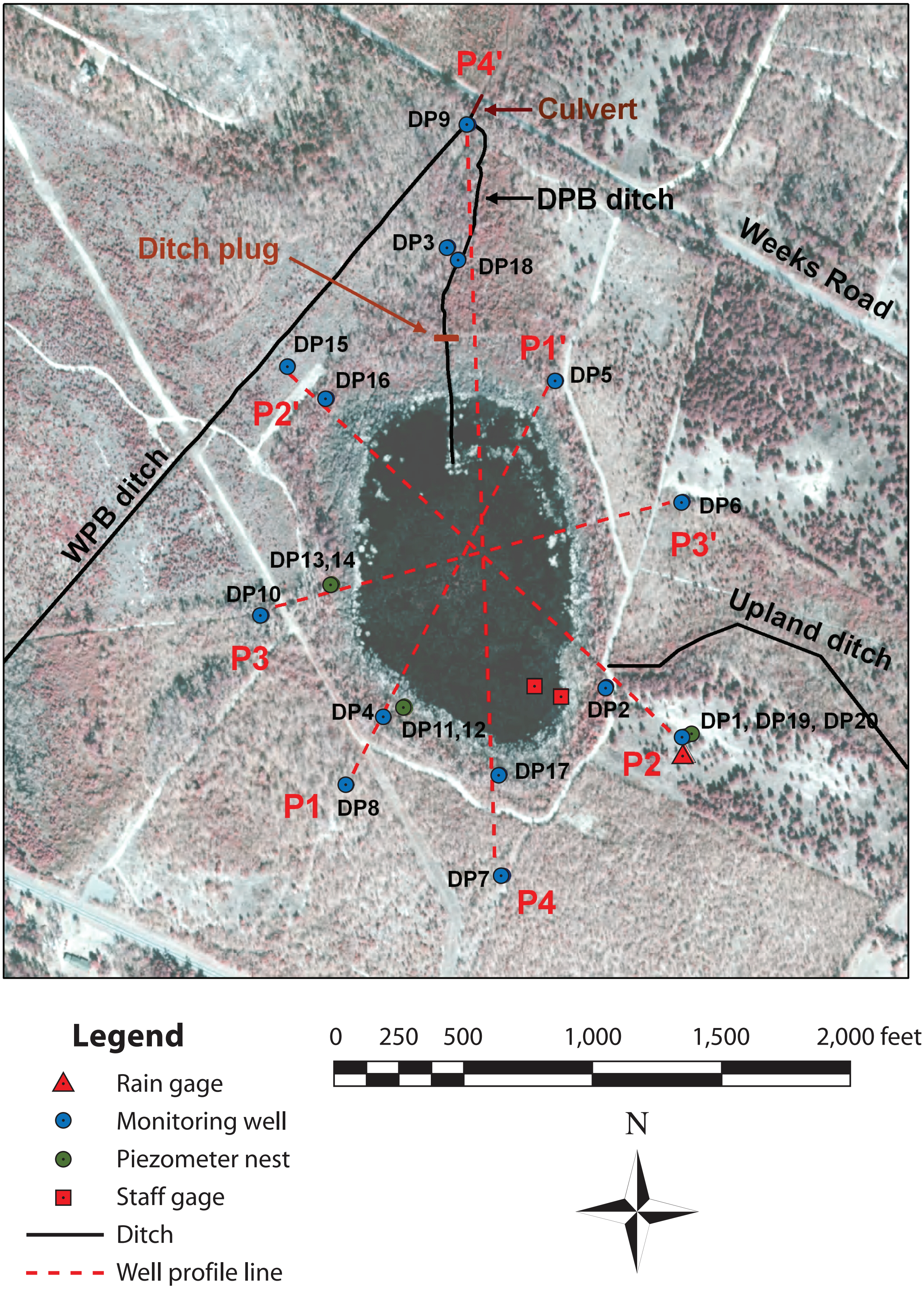


Figure 2. Instrument sites and well profiles.

Figure 3. Outlet culvert draining the WPB and DPB ditches.

Figure 4. DPB ditch, upstream of main plug.

Figure 5. Section of the DPB ditch extending into the bay.

Figure 6. WPB ditch.

plots appear to have been converted to forested vegetation. Forested areas in the southeast, southwest, and northeast uplands appear to have been clear cut in the late 1990's, and the 1999 aerial photograph shows very little forested vegetation in these areas. Vegetation has undergone a natural recovery on much of the preserve since its acquisition by SCDNR in 2002.

The quadrant northwest of DPB, including approximately one-half of WPB, is private property, and dominant tree species include several varieties of pine, including Long Leaf. The land is managed for timber production and recreational use. Comparing aerial photographs from 1999 and 2006, much of the property appears to have been logged between these years.

Vegetation/Rare Flora

Although there are no up-to-date vegetative surveys of the DPB Heritage Preserve, several rare or endangered plant species have been identified in the area during the past 35 years. In 1973, Dr. Al Radford of the University of North Carolina (UNC) first documented the significance of the bay and identified three rare plant species: Piedmont bladderwort (*Ultricularia olivaceae*), Florida bladderwort (*Utricularia floridana*), and Robbin's spikerush (*Eleocharis robbinsii*) (B.M. Moule, SCDNR, written commun., 2007). A Heritage Program botanist, Chick Gaddy, documented an additional rare species, awned meadowbeauty (*Rhexia aristosa*) in 1975 (B.M. Moule, SCDNR, written commun., 2007). A botany class from UNC documented another rare species, slender arrowhead (*Sagittaria isoetiformis*), in 1976 (B.M. Moule, SCDNR, written commun., 2007). Another rare species, blue maidencane (*Amphicarpum muehlenbergianum*), was identified during the late 1980's and early 1990's (B.M. Moule, SCDNR, written commun., 2007).

Stratigraphy

The higher elevations of the Williston-to-Windsor highland are underlain by the Tobacco Road Sand and the Upland unit (Willoughby and others, 2006). The Tobacco Road Sand is of nearshore marine origin and is of late Eocene age (approximately 34 to 37 million years old). The thickness of the unit is 40 to 50 ft on this highland. The Tobacco Road Sand outcrops near the outlet culvert north of DPB.

The overlying Upland unit is of fluvial origin and is of the late middle to early upper Miocene age (approximately 10 to 12 million years old). This unit may be as thick as 25 ft in parts of the highland but is much thinner at DPB. The Upland unit surrounds DPB (and WPB), but the Tobacco Road Sand probably underlies the base and center of DPB (Willoughby, 2002). The interiors of DPB, WPB, and several small oval-shaped depressions in the east-southeast upland area are mapped as Carolina bay sediments. Descriptions of the units (from Willoughby and others, 1994) are as follows:

Carolina bay sediments and associated sand deposits (Upper Pleistocene to Holocene) – The sediment inside Carolina bay outlines commonly is gray to black clayey sand or sandy clay and has noticeable to considerable organic material. The gray clayey material rich in organic matter is characteristic, although content of organic matter and darkness decrease toward the peripheries of the bays.

A veneer of white to tan, loose, fine to coarse grained quartz sand that has minor dark heavy mineral grains and little or no sand coating or interstitial clay covers hills and low areas outside and adjoining some Carolina Bays. Sand ridges are best developed on the east side of the bays.

Upland unit (upper middle Miocene to lower upper Miocene) – Composed largely of pink, orange, yellow, gray, tan, and brown, poorly sorted, medium to very coarse grained quartz sand, abundant quartz granules, and abundant interstitial clay. Scattered rounded quartz pebbles to 5 cm were noted in a few drill holes in Williston quadrangle, but they are not abundant and do not constitute a distinct facies as in some other areas. The upland unit is well cohesive and is tough to drill at most localities. Clay lenses were not noted.

Tobacco Road Sand (upper Eocene) – The characteristic lithology of the Tobacco Road Sand is predominantly medium to very coarse grained quartz sand with abundant quartz granules, with some very fine to very coarse grained sand throughout, and with minor to abundant interstitial clay. White clay flecks the size of coarse sand and granules are prominent locally and are interpreted as weathered feldspar grains. Rare to scattered clay laminae include quartz silt and very fine quartz sand. Dark heavy mineral grains are scattered to common, and muscovite flakes are rare to abundant. Muscovite is very abundant locally and imparts a characteristic sheen to the sediment. Part of the Tobacco Road Sand in the Williston quadrangle is variegated, very fine to medium grained quartz sand and has moderate interstitial clay, scattered tiny dark heavy mineral grains and minor to abundant muscovite flakes. Clay laminae and thin clay beds are scattered to common and were noted in some power-auger logs as "swirls".

Soils

Published soil surveys

The following soil descriptions were taken from the *Soil Survey of Aiken County Area, South Carolina* (Rogers, 1985).

Soils in DPB are classified as a Rembert series (Rogers, 1985), which is a poorly drained, slowly permeable soil that is characteristic of many Carolina bays in the upper Coastal Plain. Generally, the top 7 inches of a Rembert series is a dark gray loam enriched in organic matter. The subsoil typically consists of grayish sandy clay from 7 to 42 inches and sand and loamy sand from 42 to 60 inches.

Soils immediately surrounding DPB are classified as an Ogeechee sandy loam (Rogers, 1985), which is a poorly drained, moderately permeable soil. This soil series also extends from the north lip of the bay to just south of the outlet culvert. Typically, the top 8 inches of an Ogeechee soil is a dark grayish-brown sandy loam and the subsurface, from 8 to 15 inches, is light-gray loamy sand. The subsoil is a mottled, light-gray and gray sandy clay loam from 15 to 45 inches and a gray sandy clay loam from 45 to 65 inches.

The Troup sand (0 to 6 percent slopes) occupies much of the southern upland areas and has rapid permeability in the surface and subsurface layers and moderate permeability in the subsoil (Rogers, 1985). The surface layer typically is a grayish-brown sand about 2 inches thick, and the subsurface layer extends from 2 to 60 inches and consists of a brownish-yellow, brown, and reddish-yellow sand. The subsoil is a mottled yellow and red sandy clay loam that extends from 60 to 80 inches below ground surface.

The east-northeast upland areas are occupied by a Fuquay sand (2 to 6 percent slopes), which is a well-drained, gently sloping soil that has moderate permeability in the upper part of the subsoil and slow permeability in the lower part (Rogers, 1985). The surface is an 8-inch thick, grayish-brown sand with a yellowish-brown, loamy sand subsurface extending from 8 to 26 inches. The subsoil is a brownish-yellow sandy loam from 26 to 35 inches and a brownish-yellow sandy clay loam from 35 to 70 inches.

Much of the northwest area of the bay is classified as a Lakeland sand (0 to 6 percent slopes) and is described as an excessively drained, nearly level to gently sloping sandy soil that has rapid permeability (Rogers, 1985). The surface layer typically is 8 inches thick and consists of dark-gray and grayish-brown sand. The substratum from 8 to 80 inches is yellow, brownish-yellow, and reddish-yellow sand.

Soil descriptions from well boreholes

Soil samples were collected approximately every 0.5 to 1 ft from boreholes created at each well site (well sites are designated DP1, DP2, …DP20). Additional soil samples were taken from two boreholes in the bay (depths of 2 and 10 feet) and from another borehole along the bay's perimeter (depth of 6 feet). A description of each sample was made in the laboratory to characterize sediment content and distribution. Details of each soil profile for wells DP10–DP20 and for the two boreholes in the bay can be found in Appendix I, while profiles for DP1–DP9 and the perimeter borehole can be found in SCDNR Open-File Report 11 (Harder and others, 2006). Data from the Soil Survey described above are generally limited to depths of 6 to 8 ft below ground surface, and samples from many of the boreholes allow for soil descriptions to much greater depths. Many of the profiles (DP2, 3, 4, 5, 10, 12, 13) classified as an Ogeechee soil in the Aiken Soil Survey differed significantly from data reported in the Soil Survey for this series, at least for the top 6 to 8 ft of the soil profile.

The top 10 to 20 ft of sediment around the bay can generally be divided into two distinct zones, a sand to loamy sand surficial layer, and an underlying sandy clay loam layer. The thickness of the surficial layer varies from 3 to 7 ft to the south and east (DP1, 2, 4, 6, 7, 8, 11, 17), and from 6 to 12 ft to the north and west (DP3, 9, 10, 14, 15,16). The sandy clay loam underlying the loamy sand in the southern and eastern areas is consistent with the Upland geologic unit previously described. Coarse sand and gravel are common in this sandy clay loam. Many of the boreholes (DP1, 2, 4, 6, 7, 8, 17) also encountered a zone (1 to 4 ft in thickness) of somewhat higher clay content (designated a sandy clay or clay); however, the continuity of this layer is uncertain. These zones of higher clay content may produce locally perched water tables intermittently along the southern and eastern uplands. The sandy clay loam underlying the sandy surface and subsurface layers in the northern and western sections lack the coarse sand and gravel of the southern and eastern sections and may be correlated with the Tobacco Road Sand geologic unit.

Bay sediments

A 10-ft borehole was used to analyze sediments in the northwest interior of the bay. The uppermost 5 inches consists of black loam with high organic content underlain by 5 to 6 ft of loamy sand. This zone of loamy sand was also observed in a 6-ft borehole on the southeast edge of the bay (Harder and others, 2006). Clay content begins to increase about 7 ft below ground surface, and the loamy sand transitions into a sandy clay with much less permeability. The high clay content typically found within the top 3.5 ft of the Rembert soil series was not observed at this borehole.

Additional samples indicate that the thickness of the loamy, organic-rich surface layer varies across the bay. In the southeast edge, the loamy surficial layer is as much as 1.3 ft thick and is described as a silty loam to silty clay loam. A more peat-like organic layer, typically more than 8 inches thick, characterizes the east-northeast edge of the bay. Organic content is probably highest in the middle of the bay where ponded conditions occur nearly all of the time, and decreases outward, where the occurrence of standing water is more variable. Owing to its clay and silt content, the surficial sediments of the bay may form a semiconfining layer that impedes lateral and vertical seepage into the surrounding sediments.

HYDROLOGIC METHODS

A hydrologic study typically includes the identification of possible hydrologic inputs and outputs to a system. In most undisturbed Carolina bays, the dominant input is precipitation and the dominant output is evapotranspiration. Carolina bays may also have significant interactions with the local ground water, but the influence of ground water on the water level in a Carolina bay is not well understood. Inputs to DPB include precipitation and potential ground-water discharge to the bay (vertical and lateral) and outputs include evapotranspiration, potential ground-water recharge from the bay (vertical and lateral), and surface flow through the ditch to the drainage culvert located north of the bay. There is believed to be no significant surface inflow to the bay. The hydrology of DPB is being analyzed by using two approaches. The first approach is the long-term monitoring and analysis of bay levels and surrounding ground-water levels. The second approach is to conduct a water balance on the bay by measuring or estimating the hydrologic components of DPB.

Water-Level Monitoring

To assess the interaction of water in the bay with the surrounding ground water, a series of monitoring wells have been installed around the bay-upland system. Water-level measurements, from these wells and the bay itself, will be used to determine the direction and magnitude of any lateral hydraulic gradients, which are defined as the change in water-level elevation between two locations divided by their distance apart. The gradients indicate the general direction of ground-water flow between the two locations and are used to identify areas of possible ground-water recharge or discharge.

These gradients across the bay-upland system may have a spatial and/or temporal dependence. Certain margins of the bay may serve as consistent ground-water recharge areas while other margins may serve as consistent discharge areas. The nature of ground-water recharge and discharge may also vary seasonally or with climatic conditions at the site. Ground-water discharge into the bay may occur only during relatively wet periods and ground-water recharge from the bay may dominate during drier periods. Long-term monitoring of water levels will be used to characterize the interaction between the water in the bay and the surrounding ground water. Data should also be collected for a range of climatic conditions to gain a complete description of the bay's hydrology.

Several piezometer nests, consisting of two adjacent wells screened at different depths, have been installed at selected sites. These nests provide information on vertical hydraulic gradients, defined as the difference in water-level elevations between the two wells divided by the distance between their screened depths. The distance between the screened depths is measured from the midpoint of one well screen to the midpoint of the second well screen. A difference in water levels between two adjacent wells, which are screened in different sediment layers, indicates a potential for ground water to move vertically between the layers.

Water Balance

A water-balance equation is a useful tool in hydrologic studies, and for DPB, it can generally be expressed as

$$P - ET - Q \pm GW = \Delta WL_{Bay} \qquad (1)$$

where P is precipitation, ET is evapotranspiration, Q is surface outflow, GW is lateral and/or vertical ground-water recharge/discharge, and ΔWL_{Bay} is the change in water level of the bay. This water-balance equation is usually solved using a weekly or monthly time step, and quantities typically are represented as volume of water (ft^3) or as a depth (ft or inches). However, using linear units of depth can be misleading since an inch of decline when the bay is full represents a larger volume of water than an inch of decline when the bay is, for example, only half full. In order to estimate volumetric fluxes between surface water and ground water, a function relating the volume of water to surface area of water must be developed as well as a function relating the bay water elevation to the surface area of the bay. This report computes a water budget on a monthly time step using linear units, and the budget will be used to determine whether the net monthly movement of ground water is into or out of the bay for each month. Future work may include the collection of bathymetric data for the bay, which will allow for the estimation of volumetric fluxes between surface water and ground water.

Precipitation is measured by a rain gage on site, and potential evapotranspiration (PET) is estimated by the temperature-based Hamon method (Hamon, 1963). If the water balance is calculated during periods when standing water occurs in the bay, then ET is expected to occur at the maximum rate, since water is not limited in the system. The ΔWL_{Bay} is measured by a staff gage and an automatic water-level recorder installed in the bay. Due to the shallow nature of the DPB ditch and existence of several dams or plugs within the ditch, surface flow through the ditch is thought to be small to nonexistent except during very wet climatic conditions.

Assuming negligible surface flow out of the bay, Equation 1 can be simplified to

$$P - ET \pm GW = \Delta WL_{Bay} . \qquad (2)$$

This equation suggests a condition of ground-water outflow if $P\text{-}ET > \Delta WL_{Bay}$ and ground-water inflow if $P\text{-}ET < \Delta WL_{Bay}$. Data collected from the monitoring-well network can help to verify these conditions and also specify which sides of the bay may most likely be serving as ground-water recharge or discharge areas.

MONITORING NETWORK

Rainfall

Rainfall is monitored by a tipping-bucket rain gage, which was installed on March 17, 2006 in an open area approximately 500 ft southeast of the bay (Fig. 2). Each tip corresponds to 0.01 inch of rain. The gage is connected to a data logger (Unidata Starlogger 6004C) and originally recorded the total number of tips in 15-minute intervals. As of January 17, 2007, the data logger has been recording the number of tips in 60-minute intervals. The data logger is downloaded typically every 2 to 3 weeks, and the number of tips per 15- or 60-minute interval is converted to rainfall in inches. Daily, monthly, and annual rainfall totals are then computed from the 15- or 60-minute rainfall totals.

Long-term historic and current rainfall data are available from a weather station (Blackville 3W) near Elko, S.C., located approximately 9 miles from the study site. The Edisto

Research Station is owned by Clemson University, which currently operates this station. Data from this station will be used to compare current rainfall totals at DPB to long-term patterns in the area.

Bay Water Level

Bay water levels are measured with a staff gage installed and surveyed in March 2006 in the southwest corner of DPB (Fig. 2) to obtain water-level elevations in feet above sea level. A second staff gage was installed closer to the center of the bay in November 2006 after water-level declines in the bay caused the original gage site to dry out. Staff-gage measurements are taken approximately biweekly.

In July 2006 an automatic water-level recorder (Solinst Levelogger Gold) was installed adjacent to the original staff gage to record water levels on an hourly basis. This water level recorder is downloaded every 2 to 3 weeks, and measurements are converted to elevations above sea level.

Potential Evapotranspiration (PET)

Potential evapotranspiration (PET) is the maximum evapotranspiration (ET) rate that will occur if site conditions are not limited by available water. Since DPB typically holds water throughout the year, available water is rarely limited, and ET within the bay is assumed to correspond to the maximum PET rate. Monthly PET values for the period from April 2006 through March 2007 were estimated using the temperature-based Hamon method (Hamon, 1963) and a set of monthly correction factors developed from long-term pan-evaporation data.

The use of pan-evaporation data produces a more reliable estimate of PET than the Hamon method, but is less practical because it requires the use of an evaporation pan, whereas the Hamon method requires only temperature data. If available, pan-evaporation data can be used to develop correction factors to adjust Hamon PET estimates to better match PET estimates made using pan-evaporation data. Data from the Blackville 3W weather station, which has both long-term temperature and pan-evaporation data for the period 1963–1992 (Purvis, 1993), were used to determine monthly Hamon PET correction factors. The procedure used to make these monthly Hamon correction factors is as follows:

1) Evaporation pans typically overestimate actual ET, and pan coefficients are commonly used to adjust evaporation data to reflect actual ET. These coefficients depend on the pan environment and, therefore, are site specific. A coefficient of 0.75 was chosen based on information in a Weather Bureau Technical Report (Kohler and others, 1959). Average monthly pan-evaporation values from the Blackville 3W station were thus multiplied by a pan coefficient of 0.75.

2) Average monthly PET values were computed from average monthly temperature data from the Blackville 3W weather station using the Hamon method.

3) A correction factor was determined for each month by dividing the adjusted pan-evaporation data by the Hamon PET.

Table 1 lists the computed correction factors, average monthly Hamon PET, average pan evaporation, and adjusted average pan evaporation calculated from the Blackville 3W station using data collected from 1963 through 1992. For example, the average evaporation recorded for the month of January was 1.87 inches. After applying a pan coefficient of 0.75, the adjusted evaporation for January is 1.40 inches (0.75 x 1.87). Using the Hamon method and January's average temperature, the computed PET value was 1.37 inches. The value from the pan-evaporation data (1.40

Table 1. Monthly correction factors developed from monthly temperature and pan-evaporation data (1963-1992) at the Blackville 3W weather station

Month	Average pan evaporation (inches)	Adjusted pan evaporation (inches)	Hamon PET (inches)	Correction factor
January	1.87	1.40	1.37	1.03
February	2.63	1.97	1.65	1.20
March	4.42	3.32	2.38	1.39
April	5.93	4.45	3.33	1.34
May	6.86	5.15	4.44	1.16
June	7.41	5.56	5.56	1.00
July	7.52	5.64	5.97	0.95
August	6.45	4.84	5.47	0.88
September	5.21	3.91	4.39	0.89
October	4.06	3.05	2.93	1.04
November	2.65	1.99	2.03	0.98
December	2.00	1.50	1.50	1.00
Annual	57.01	42.76	41.02	1.04

inches) is then divided by the Hamon value (1.37 inches) to produce a correction factor of 1.03.

Average daily temperature data from the Blackville 3W weather station from April 2006 through March 2007 were used to calculate monthly Hamon PET values for this period. Each of these monthly Hamon PET values was multiplied by its respective monthly correction factor (Table 1) to estimate the final monthly PET values. The corrected PET values were used in the monthly water-budget computations to estimate the ground-water component in the hydrology of DPB. PET estimates, similar to changes in the water level of the bay, are computed in linear units, and the volume of water lost to ET (assumed equal to the PET rate) at one bay water level will not be same volume of water lost to ET at another level.

To collect onsite temperature data, a temperature sensor (Unidata model 6501) was installed on January 17, 2007 and connected to a data logger (Unidata Starlogger 6004C). The data logger records average hourly temperature and hourly maximum and minimum temperatures, and data are downloaded typically every 2 to 3 weeks. A manual measurement with a thermometer is taken during each download as a check on the accuracy of the temperature sensor. Data from the temperature sensor will be used to estimate daily, monthly, and annual PET values, using the temperature-based Hamon method (with the correction factor described above) for future measurement periods.

Ground-Water Levels

Well network

Eleven new wells (DP10–20) were drilled during this phase of the study, and there are now 20 wells at the site (Fig. 2). Schematic diagrams of wells DP10–DP20 can be found in Appendix II, while diagrams of wells DP1–DP9 can be found in SCDNR Open-File Report 11 (Harder and others, 2006). All wells were constructed with 2-inch PVC casing, and screened sections have a #10-slot screen size. All wells are capped at the bottom, and wells were secured by inserting a 2-inch lockable well plug at the top of the standpipe. Gravel-pack material is #2 sand, and wells are sealed at the surface with either cement grout or bentonite clay. Each well has been surveyed to calculate water-level elevations in feet above sea level. Water levels have been measured on a weekly to biweekly basis since March 2006 with a Solinst water-level meter. General information for each new well is given in Table 2.

Automatic water-level recorders

Automatic water-level recorders were installed in several wells to provide continuous monitoring of ground-water levels. These recorders give detailed water-level data (on an hourly basis) that can provide information on water-table behavior in response to rainfall events that otherwise cannot be captured by biweekly well measurements. Solinst Leveloggers were installed inside wells DP1, DP4, and DP9 on June 28, 2006. On October 18, 2006, the recorder from well DP9 was moved to well DP3 to obtain detailed water-table data near the DPB ditch at a location approximately halfway between DPB and the outlet culvert (Fig. 2). The water-level recorder from DP4 was removed on October 18, 2006, and installed in well DP15 on November 2, 2006, in order to collect detailed water-table data along the profile extending from the WPB ditch to DPB (Fig. 2). Metal enclosures with padlocks were also installed around wells DP1, DP3, and DP15 to protect the loggers from theft or vandalism.

The Leveloggers record total pressure (water and atmospheric) on an hourly basis, and each measurement must be adjusted to correct for atmospheric pressure. Atmospheric compensation was provided by data collected from a Solinst Barologger, installed in the standpipe of DP1, which records atmospheric pressure on an hourly basis. The hourly data from the Barologger are subtracted from the corresponding hourly Levelogger measurements to obtain water levels above the Levelogger sensor. These water-level measurements are then converted to water-level elevations in feet above sea level. The Leveloggers and Barologger are typically downloaded every 2 to 3 weeks.

Well profiles

Most of the wells at the site are aligned along one of four profiles (or transects) across the bay-upland system as shown in Figure 2. These profiles provide cross-sectional views of ground-surface elevations, water elevations, and stratigraphy across the bay-upland system, which will be used to determine the direction and magnitude of lateral hydraulic gradients and will also help determine the influence of soil stratigraphy on the hydrology of the bay. Details of each profile are as follows:

P1-P1′

Profile P1-P1′ is oriented in a SW-NE direction and consists of wells DP8, DP4, and DP11 southwest of the bay and well DP5 northeast of the bay.

P2-P2′

Profile P2-P2′ is oriented in a SE-NW direction and contains wells DP1 and DP2 on the southeast side of the bay and wells DP16 and DP15 on the northwest side of the bay. DP15 and DP16 are located along a line representing approximately the closest distance between DPB and the WPB ditch.

P3-P3′

Profile P3-P3′ is oriented in an W-E direction and consists of wells DP10 and DP14 on the west side of the bay and well DP6 on the east side.

P4-P4′

Profile P4-P4′ is oriented in a S-N direction and consists of wells DP7 and DP17 on the south side of the bay and wells DP3 and DP9 on the north side.

Table 2. Summary of wells constructed during Phase II of this study

Well	Well county number	Installation date	Elevation of land surface (ft)*	Well depth (ft)	Screened interval (ft bls**)	Latitude*** (deg min sec)	Longitude*** (deg min sec)	Gravel pack (ft bls**)	Seal material	Seal thickness (ft)	Distance from bay (ft)
DP10	AIK-2616	6/20/06	361.8	18.8	3.8–18.8	33 25 05	81 28 10	2.0–18.8	cement	2.0	340
DP11	BRN-997	8/29/06	352.9	4.5	3.5–4.5	33 25 02	81 28 04	3.0–4.5	bentonite	3.0	30
DP12	BRN-998	8/29/06	352.9	10.2	9.2–10.2	33 25 02	81 28 04	8.0–10.2	bentonite	8.0	30
DP13	AIK-2619	9/8/06	353.2	10.3	9.3–10.3	33 25 06	81 28 07	8.0–10.3	bentonite	8.0	50
DP14	AIK-2620	9/8/06	353.1	5.2	4.2–5.2	33 25 06	81 28 07	2.7–5.2	bentonite	2.7	50
DP15	AIK-2621	9/21/06	356.1	14.3	4.3–14.3	33 25 15	81 28 09	1.5–14.3	cement	1.5	350
DP16	AIK-2622	9/21/06	354.0	11.0	2.0–11.0	33 25 14	81 28 07	2.0–11.0	cement	2.0	160
DP17	BRN-999	9/29/06	354.5	13.3	3.3–13.3	33 24 55	81 27 59	2.0–13.3	cement	2.0	140
DP18	AIK-2623	10/5/06	349.9	5.5	4.0–5.5	33 25 19	81 28 01	2.0–5.5	bentonite	2.0	460
DP19	BRN-1000	11/11/06	360.8	18.2	16.3–18.2	33 25 01	81 27 51	15.0–18.2	bentonite	15.0	500
DP20	BRN-1001	12/13/06	361.0	9.0	8.3–9.0	33 25 01	81 27 51	7.0–9.0	bentonite	7.0	500

* North American Vertical Datum of 1988
** bls, below land surface
*** North American Datum of 1927

Piezometer nests

DP11 and DP12 make up a piezometer nest located at the southwest edge of the bay (Fig. 2). DP11 is only 4.5 ft deep and is screened in the loamy sand that extends from the surface to approximately 5 ft below ground surface. DP12, located several feet from DP11, has a 10-ft depth and is screened in a more clayey material that underlies the sandier surficial layer. Similarly, wells DP13 and DP14 form a second piezometer nest on the west edge of the bay.

Soil and water-table data from Phase I of the study indicated the existence of a semi-impermeable layer at DP1, the top of which is approximately 10 ft below land surface. This semiconfining layer consists of a sandy clay soil approximately 3 ft thick at DP1 and may contribute to a localized and temporary perched water-table system. To further investigate the water table at DP1 and the potential vertical movement of ground water in this upland area, a piezometer nest was installed near DP1 and includes wells DP19 and DP20. DP19 is screened below this semi-impermeable layer, while DP20 is screened above this layer.

RESULTS

Rainfall

In September 2006, a moderate drought was declared for the Savannah River basin, which includes sections of Aiken and Barnwell Counties, and the status was maintained through January 2007. The closest weather station with historic and current rainfall data is the Blackville 3W station approximately 9 miles from DPB. The 2006 rainfall total at this station (37.9 inches) was approximately 8 inches below the long-term (1894–2002) average (45.9 inches), representing a 17 percent deficit.

The rainfall total for the DPB gage from April through December 2006 was 29.4 inches, which is the same as the Blackville 3W total for the same period. The long-term average at the Blackville 3W station for these nine months is 34.2 inches. Despite the spatial variation in rainfall that may occur between the Blackville Station and DPB site, it is likely that DPB is experiencing below-normal rainfall on the order of 5 inches for this 9-month period. A monthly comparison between the Blackville 3W 2006 and long-term rainfall is shown in Figure 7. The 2006 monthly rainfall can generally be described as substantially below-normal for the winter and spring periods, moderately below-normal for the summer and early fall periods (except for June), and near to above-normal for the late fall period. Substantial deficits occurred for the months of March, May, and July, which were below normal by 2.0, 2.7, and 2.1 inches, respectively. June had the highest monthly total in 2006 and was more than 2 inches above normal. Rainfall was below normal for each of the first three months of 2007 (Fig. 7), with March having the highest deficit (2.2 inches).

Monthly rainfall totals for 2006 and early 2007 at the DPB gage are also depicted in Figure 7. Data were unavailable or incomplete for the first three months of 2006. DPB's rainfall total for April 2006 through March 2007 was approximately 9.1 inches below the long-term average measured at the Blackville 3W station. Monthly patterns at

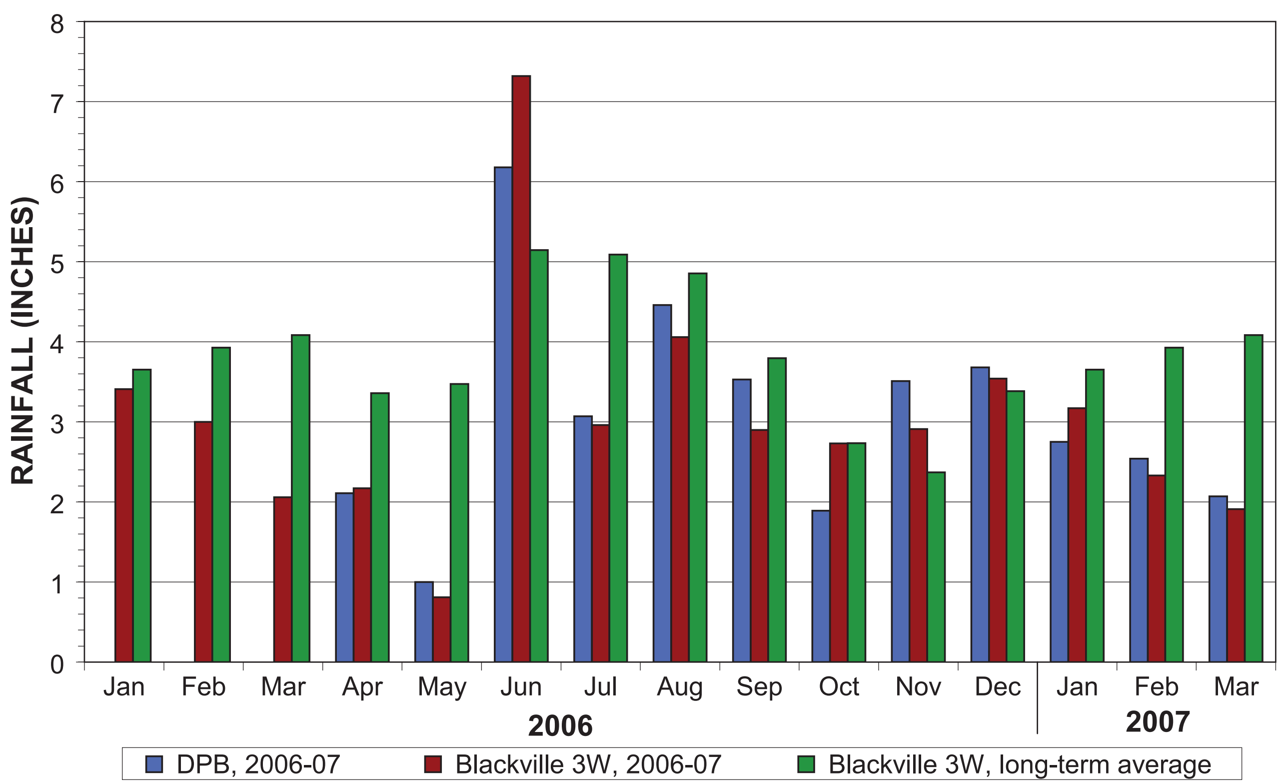


Figure 7. Monthly rainfall totals at DPB and Blackville 3W, S.C.

DPB generally follow those at Blackville 3W from April to September. Rainfall was substantially below normal in the late spring and moderately below normal for the summer and early fall (except for June). Rainfall was above normal for the late fall period. Substantial deficits at the DPB gage were seen for the months of May and July, which were 2.5 and 2.0 inches below normal, respectively. June and November were above normal by 1.0 and 1.1 inches, respectively. Rainfall for each of the first three months of 2007, similar to that at the Blackville site, was below normal. March had the highest deficit (2.0 inches), and the bay is, thus far, experiencing a 2007 deficit of more than 4 inches.

Bay Water Levels

Water levels in the bay are shown in Figure 8, along with daily rainfall totals since the beginning of the study period. Periodic storm events have caused temporary increases in water levels, but the overall trend shows a steady decline through the late spring, summer, and fall of 2006. Water levels began to level off during November and December at around 350.7 ft above sea level, and increased slightly through the first two and a half months of 2007. The highest recorded water-level elevation, which occurred in late March 2006, was 352.8 ft, and the lowest level, 350.6 ft, occurred in mid-December.

During an average climate year some Carolina bays and other wetland depressions will experience high water levels in the winter and early spring seasons, due to decreased ET and moderate rainfall, and lower water levels during the summer season when ET rates are much higher (Sharitz, 2003). Water-level decline over the spring, summer, and fall at DPB is most likely a result of both the deficit in rainfall described above and increased ET rates. The leveling off and subsequent small rise in water level from November 2006 to early January 2007 are probably due to above-average rainfall and decreased ET rates during November and December. Lower water levels may generally be expected at DPB during the summer season, but the overall amount of drawdown the bay experienced in 2006 may be atypically large due to the below-normal rainfall at the site.

Water levels continued to increase slightly from January through the beginning of March 2007 despite below-average rainfall for the first two months of 2007. The water-level behavior in January and February is consistent with low ET rates during these months; however, the water-level rise (approximately 0.2 ft) may be smaller than would be expected for a winter season with average rainfall. In addition, the water-table drawdown around the bay during 2006 may have limited ground-water influx to the bay (see "Well network" section below). To verify these hypotheses, long-term rainfall and water-level data are needed to describe the behavior of seasonal water levels in the bay. By the end of March the bay had again receded to levels similar to those in November 2006 due to the below-normal rainfall in this month.

The water-level decline of 2006 has greatly reduced the aerial coverage of standing water in the bay. The perimeter along the northern section of the bay, which is more

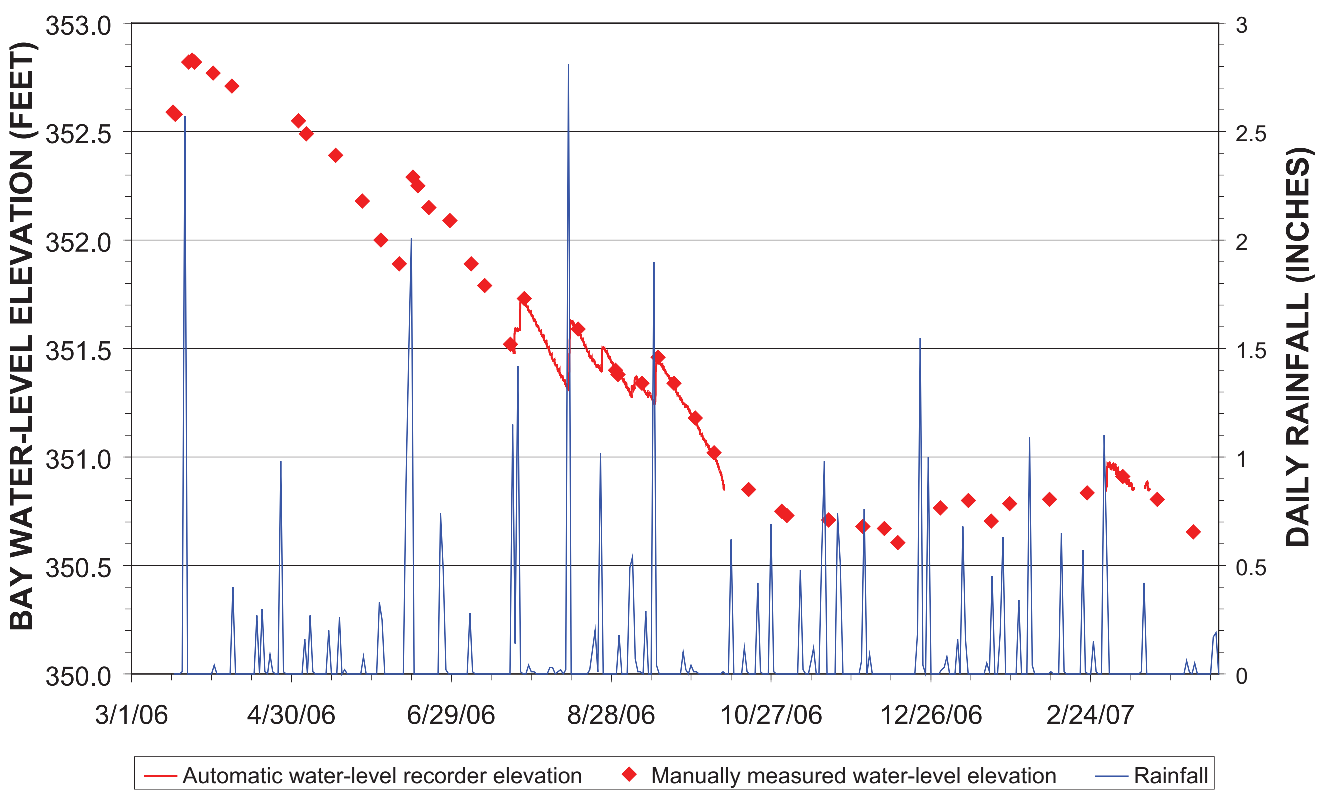


Figure 8. Ditch Pond Bay water-level elevations and daily rainfall totals from March 17, 2006 through March 2007.

topographically flat than the southern section, has greatly receded, exposing the organic, mucky sediments of the bay's bottom (Fig. 9). The area of ponded water in the bay was measured in mid-October and compared with the size of the bay estimated from a January 2006 aerial photograph. Because the average aerial coverage of ponded water in the bay is unknown, it was approximated by the open area of the bay (up to the tree line). This comparison is depicted in Figure 10. The area of standing water has been reduced to approximately 73 percent of the estimated open area of the bay. A view of the southeast section of DPB during the early spring of 2006, when bay level was near its maximum, is shown in Figure 11. A view of the same section of DPB (Fig. 12) during the spring of 2007 shows considerable water level drawdown over the twelve and a half month study period (approximately 2 feet).

Ground-Water Levels

Well network

Water-level elevations of the bay and the individual wells are presented in Figures 13–32. The wettest conditions (highest water-table elevations) measured during the study period occurred in late March 2006 after a large storm event (2.6 inches) on March 21. Only wells DP1–DP5 were installed during this event, and water levels in wells DP2, DP4, and DP5 were all slightly above the water level of the bay. These hydraulic gradients, though small (less than 1 percent), suggest that during a wet period, there may be shallow ground-water discharge into the bay in these areas. Long-term data are needed to determine the frequency and magnitude of these hydraulic gradients to better assess the occurrence of ground-water discharge into the bay during high water-table conditions.

Despite several storm events in the summer and early fall periods (June 13–14, July 25, August 11–12, September 14) that caused temporary increases, there has been a general decline from March to November in water levels surrounding the bay. Beginning in May, water levels began to decline more rapidly, which is consistent with increased ET rates and the effects of below average rainfall during the spring. By early June, water levels in all installed wells (DP1 through DP9) had dropped below or near the level of the bay. Water levels remained below bay levels for the rest of the summer and fall for all wells except DP1, DP6, DP15 and DP16, and most wells had their lowest water levels at the end of October. The data suggest that during dry conditions, the bay remains elevated above much of the surrounding water table. This may be a result of semi-impermeable sediments lining the bottom of the bay, the effect of a clayey unit found below much of the surficial sandy sediments in and around the bay, or a combination of both.

Generally, ground-water levels began to increase in mid-November 2006, probably because of decreased ET rates and above average-rainfall in November and December 2006 (similar to bay water levels). Substantial increases in water levels began by late December in response to two large

Figure 9. Exposed bed sediments along the north section of DPB.

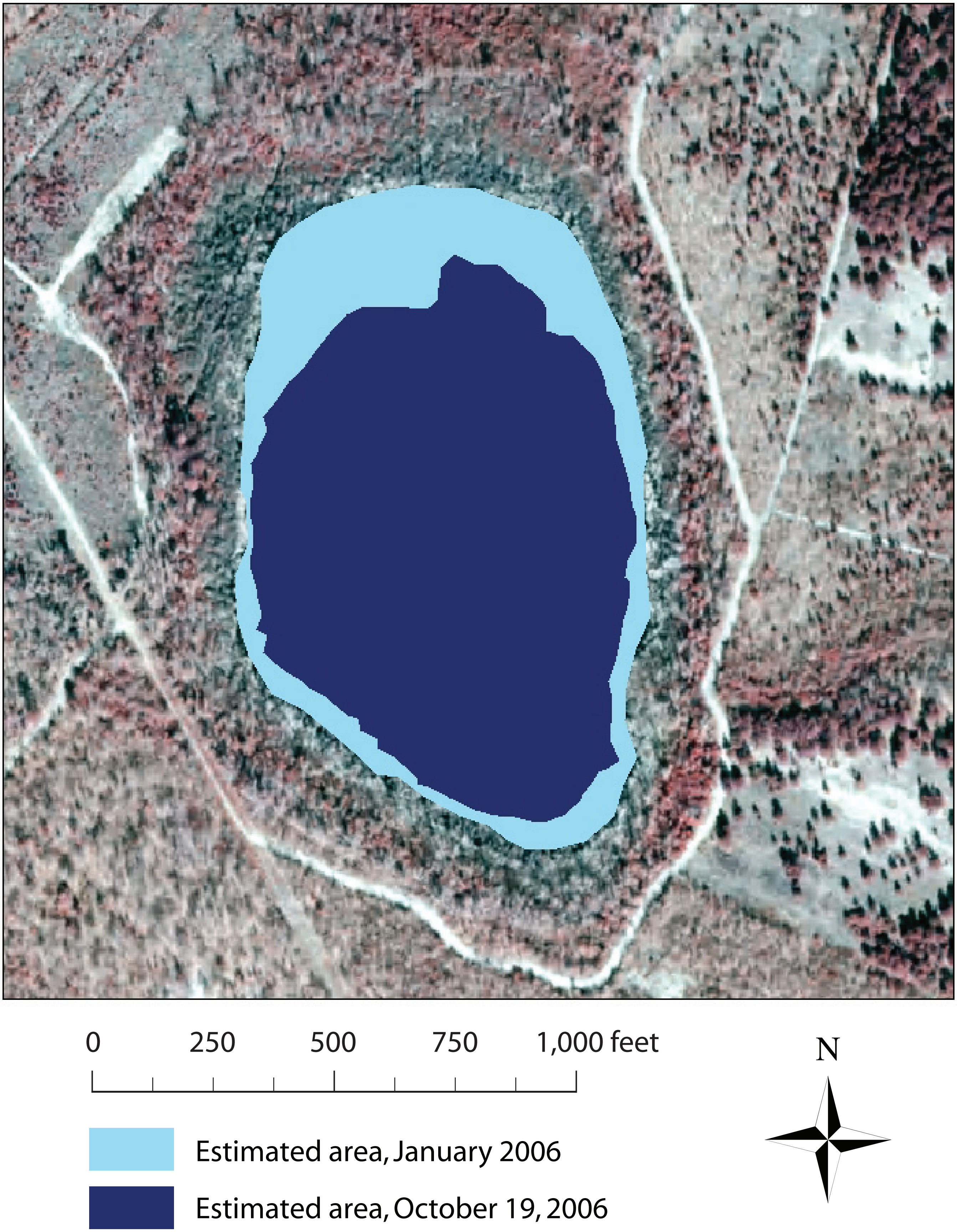


Figure 10. Estimated areas of ponded water at Ditch Pond Bay in January 2006 and on October 19, 2006.

Figure 11. View of the southeast section of DPB during the spring of 2006.

Figure 12. View of the southeast section of DPB during the spring of 2007.

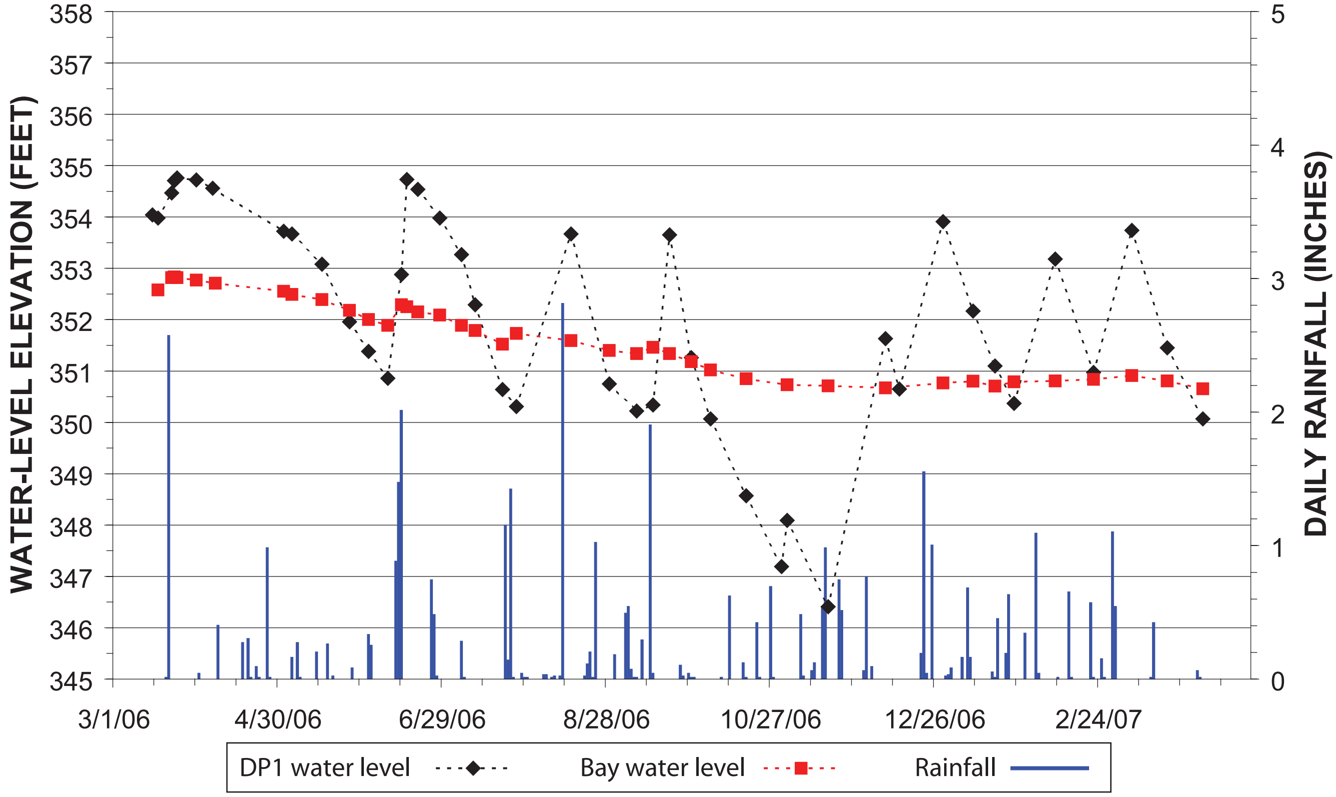


Figure 13. DP1 water-level elevations.

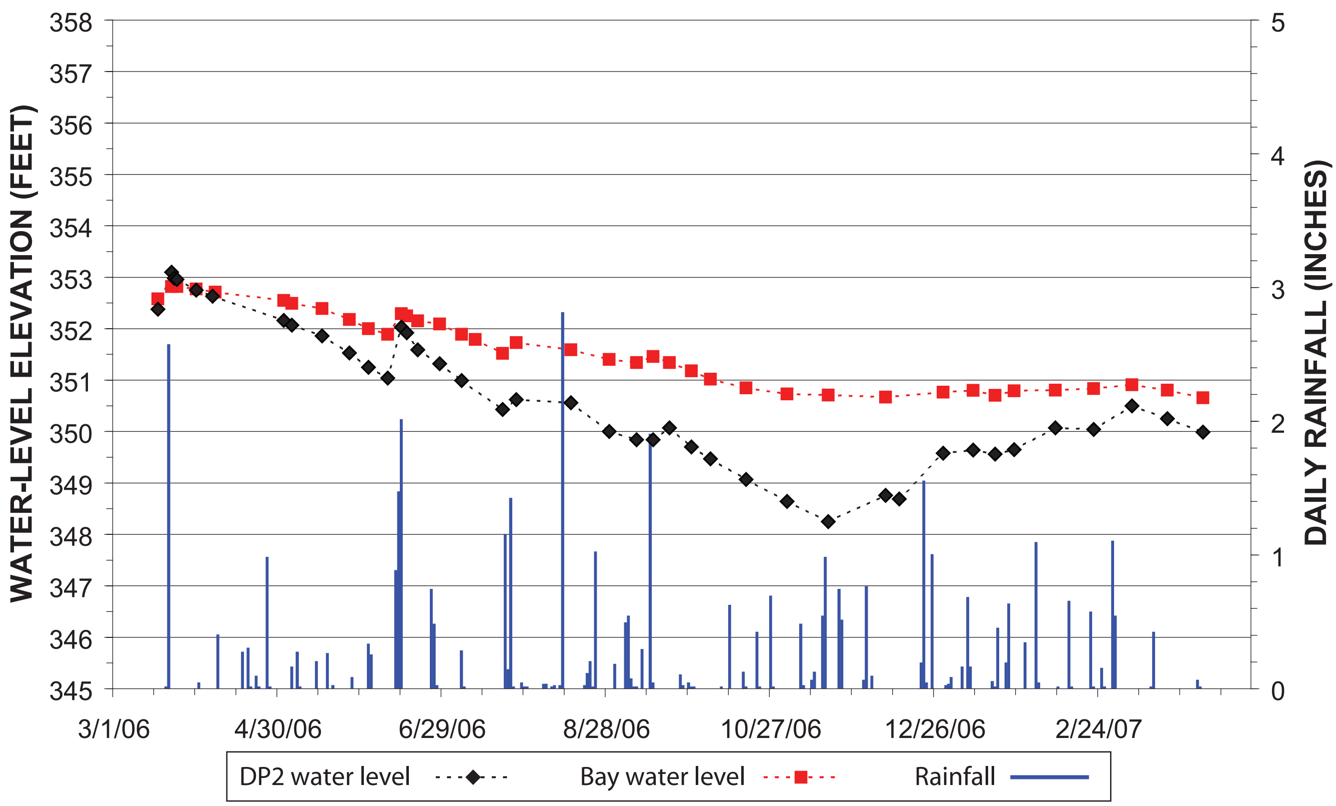


Figure 14. DP2 water-level elevations.

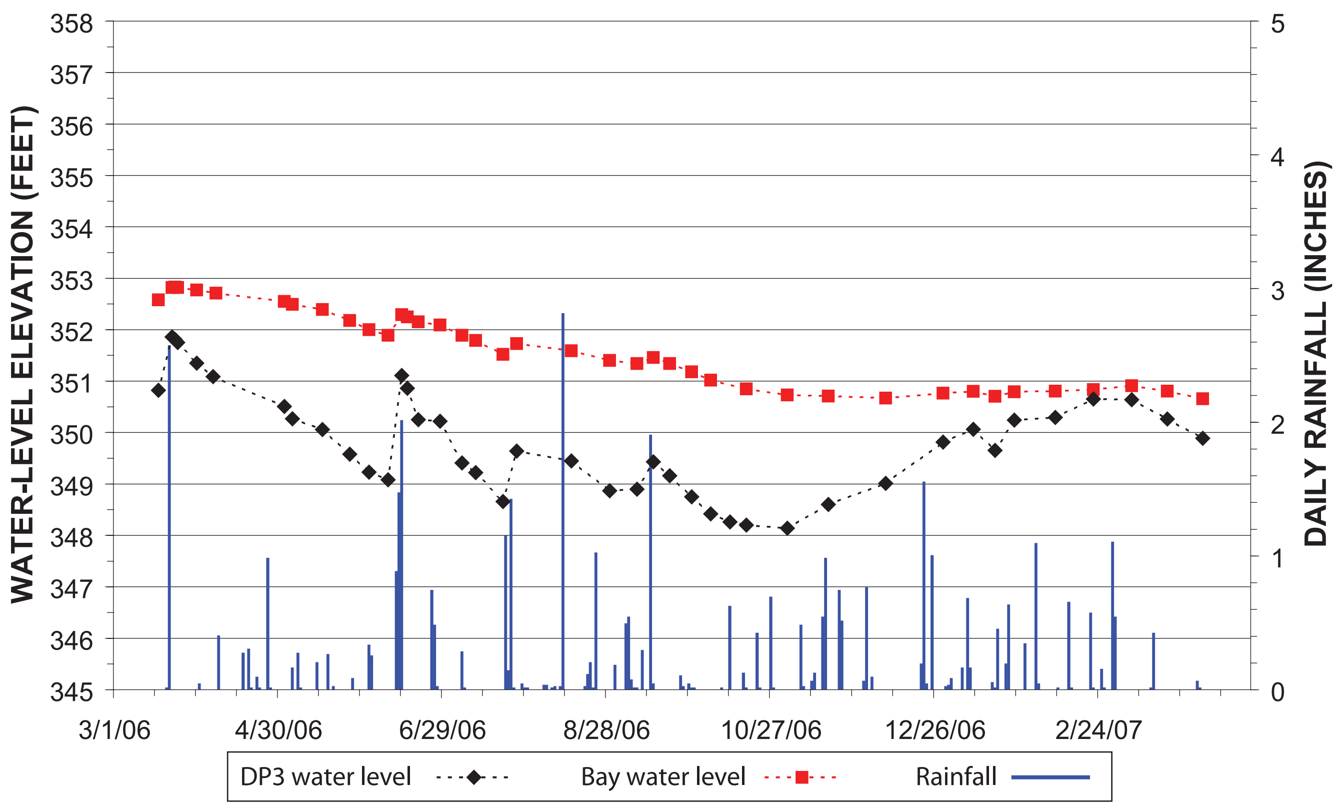


Figure 15. DP3 water-level elevations.

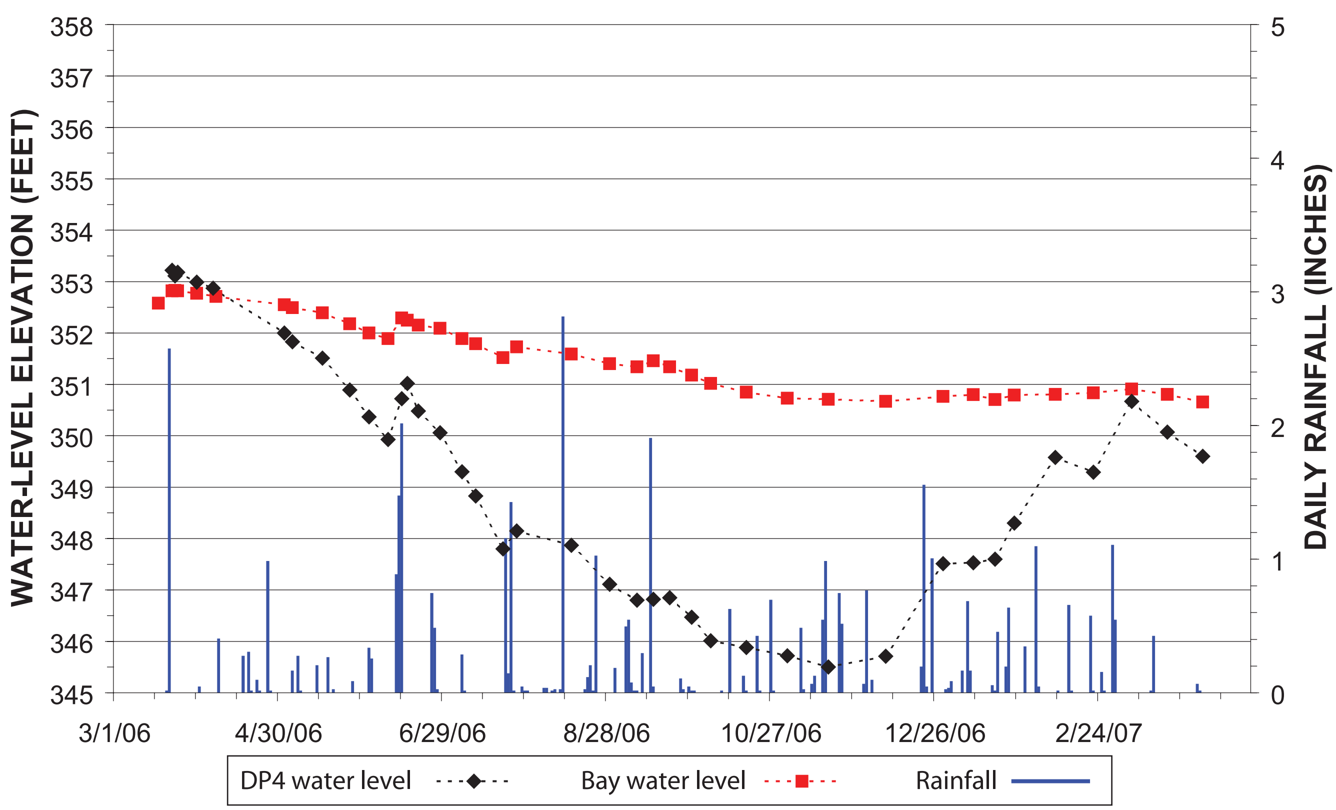


Figure 16. DP4 water-level elevations.

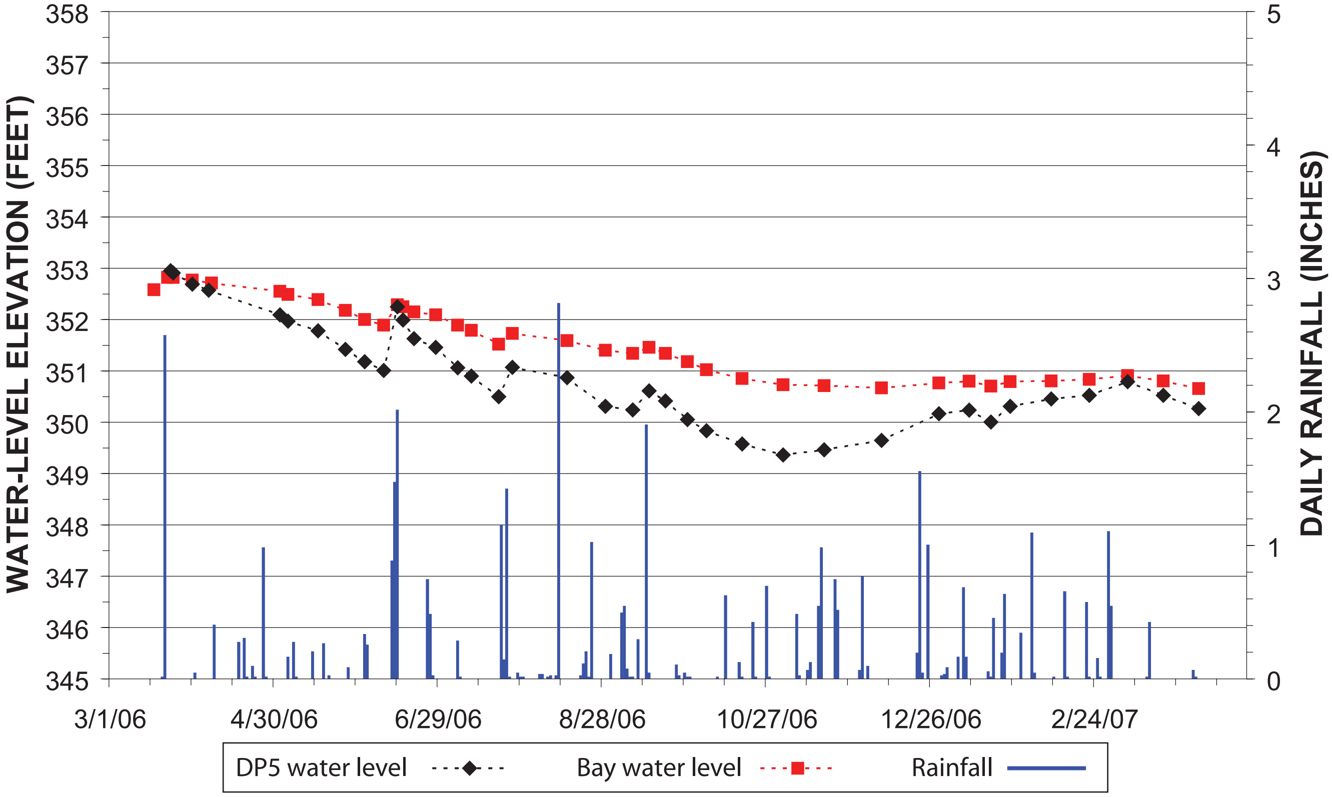


Figure 17. DP5 water-level elevations.

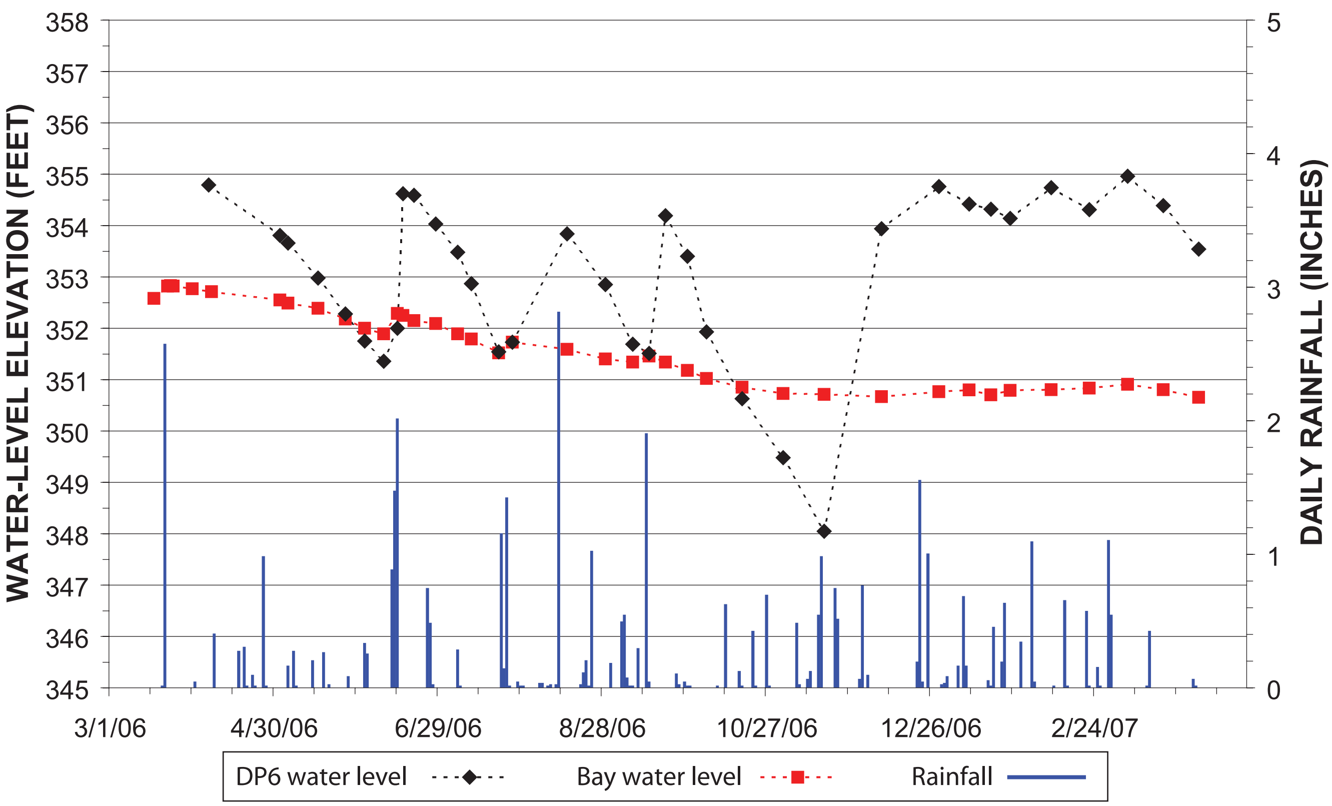


Figure 18. DP6 water-level elevations.

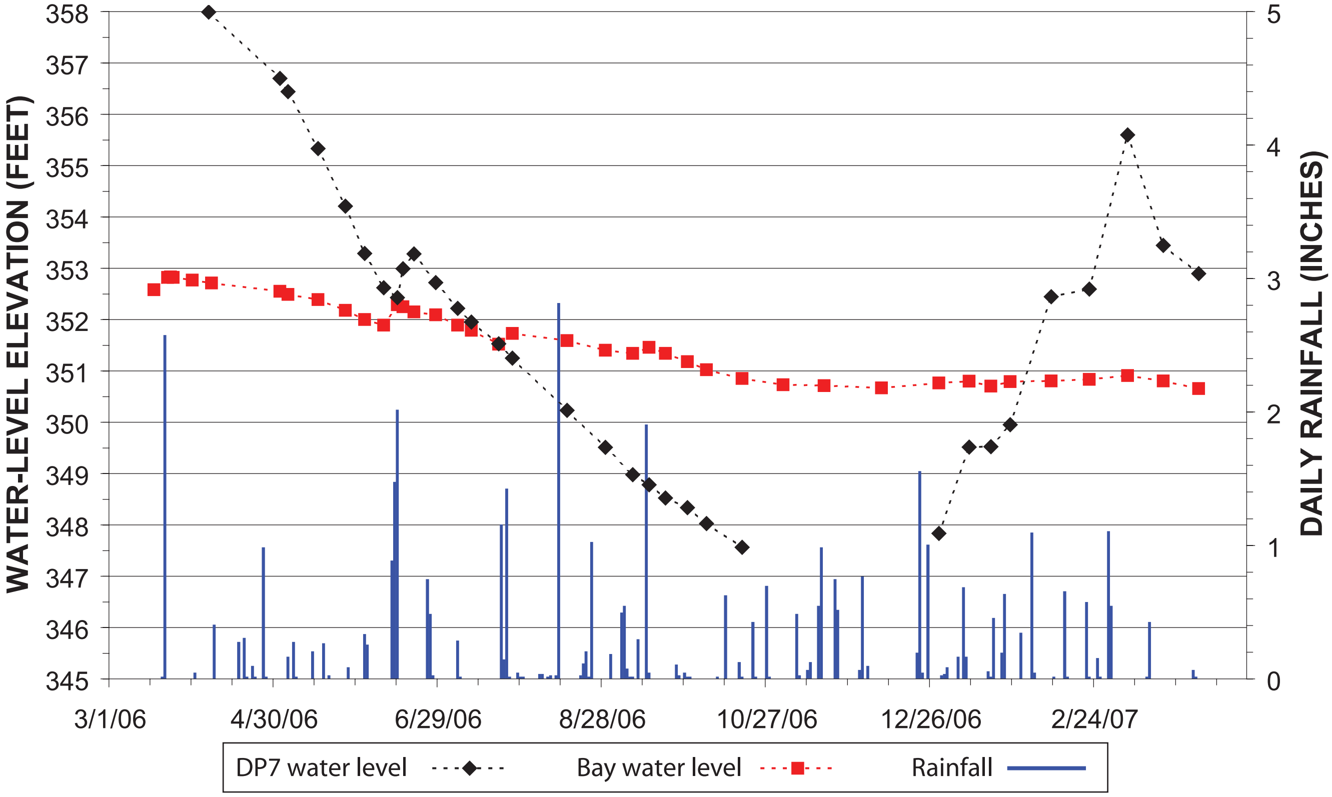


Figure 19. DP7 water-level elevations.

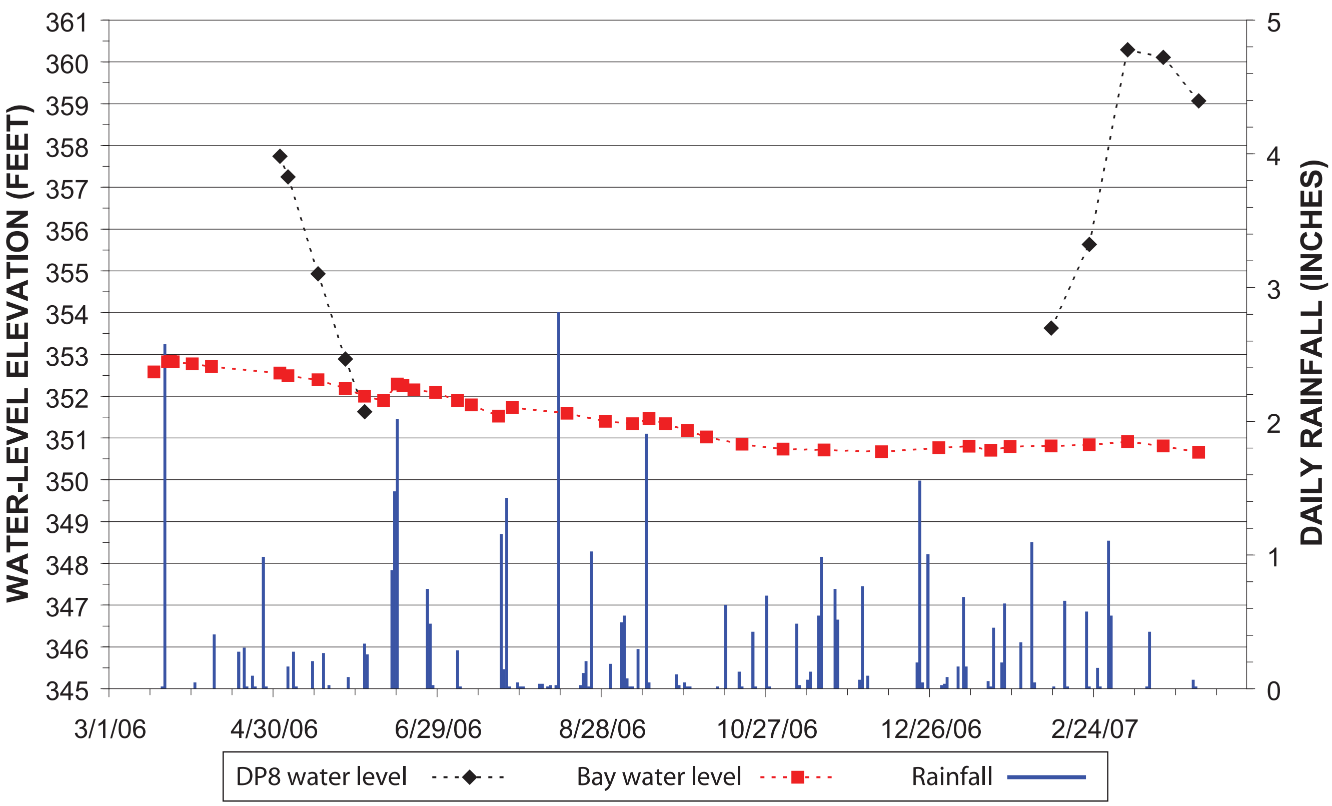


Figure 20. DP8 water-level elevations.

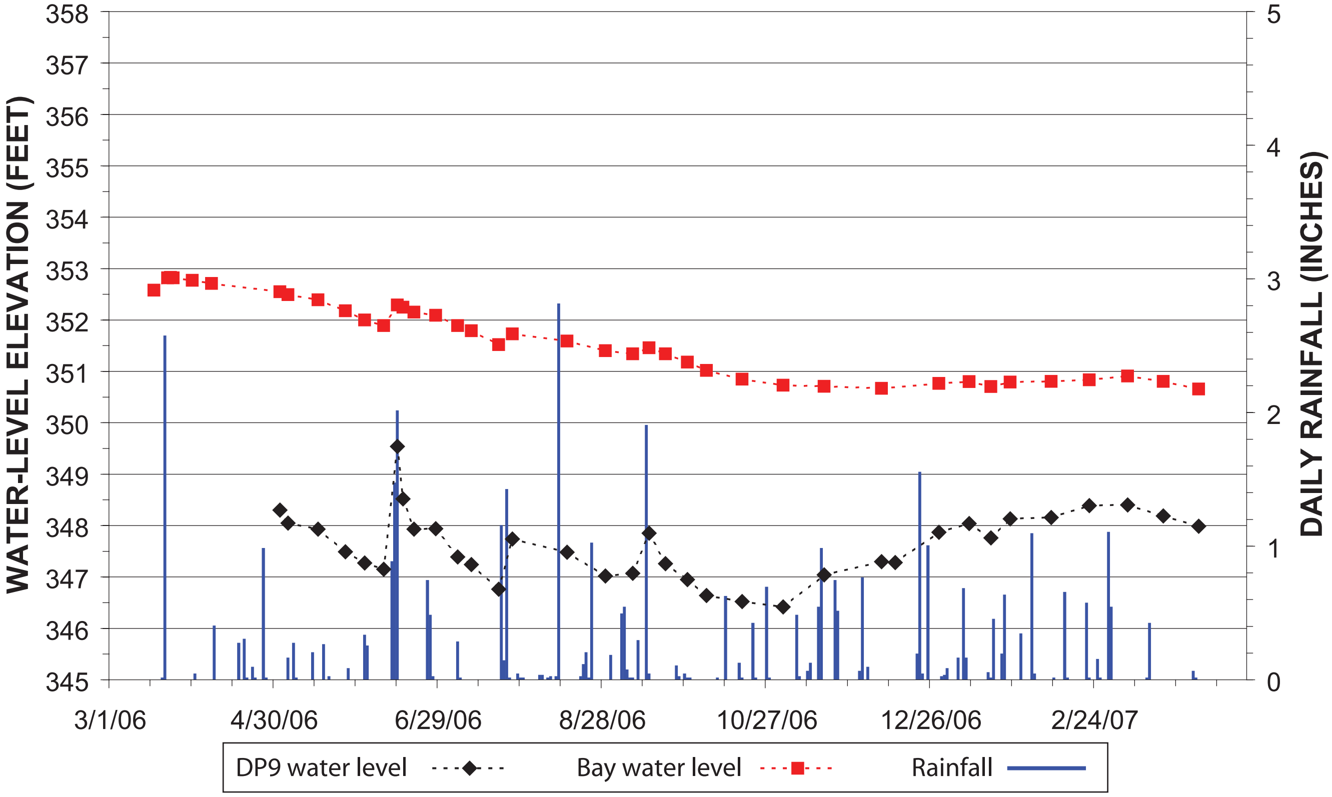


Figure 21. DP9 water-level elevations.

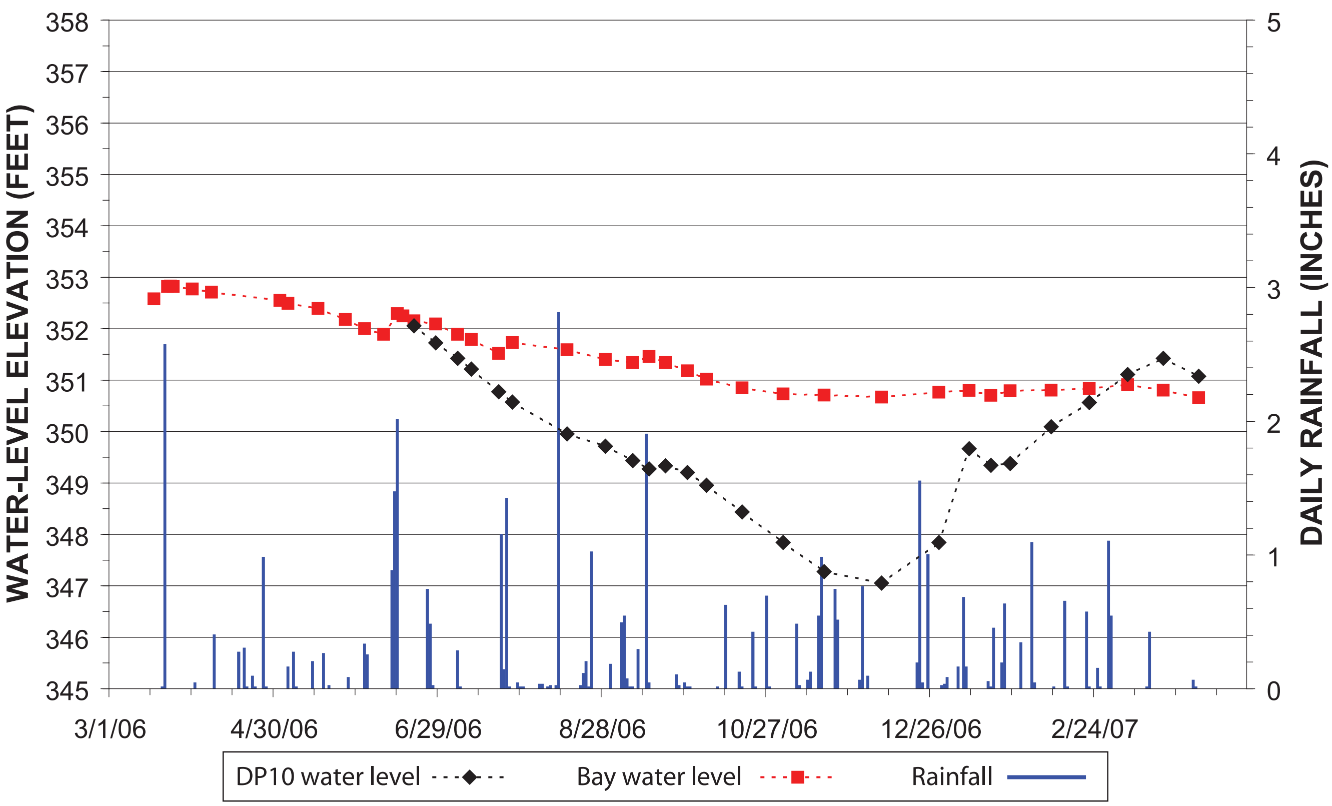


Figure 22. DP10 water-level elevations.

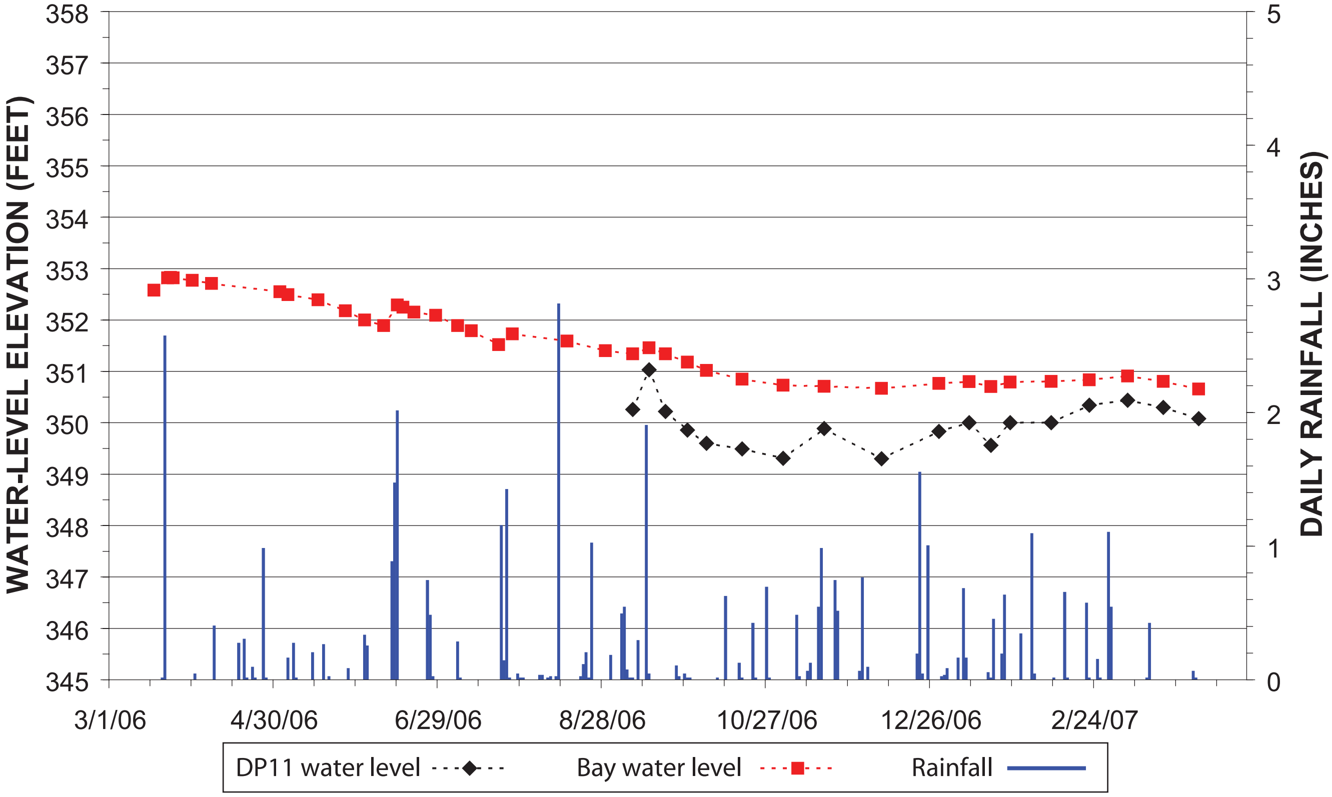


Figure 23. DP11 water-level elevations.

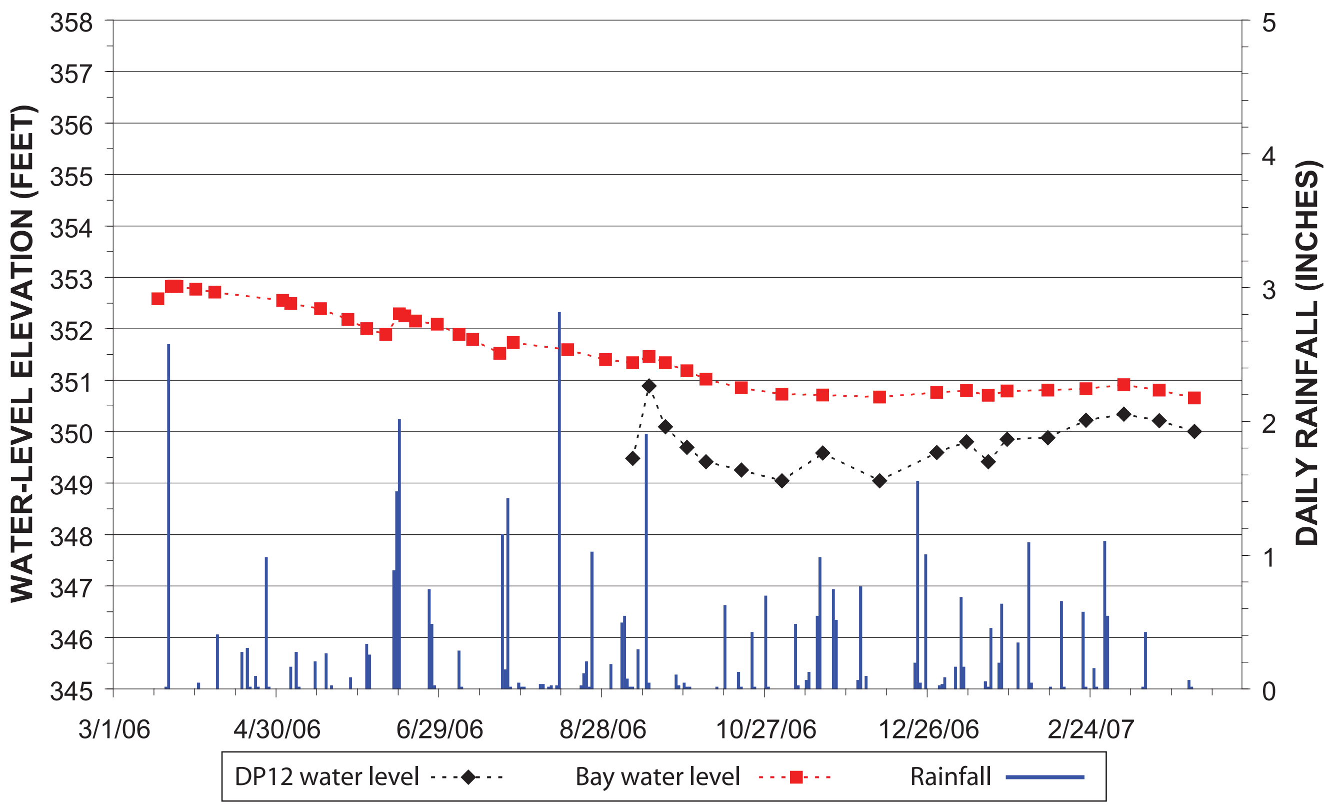


Figure 24. DP12 water-level elevations.

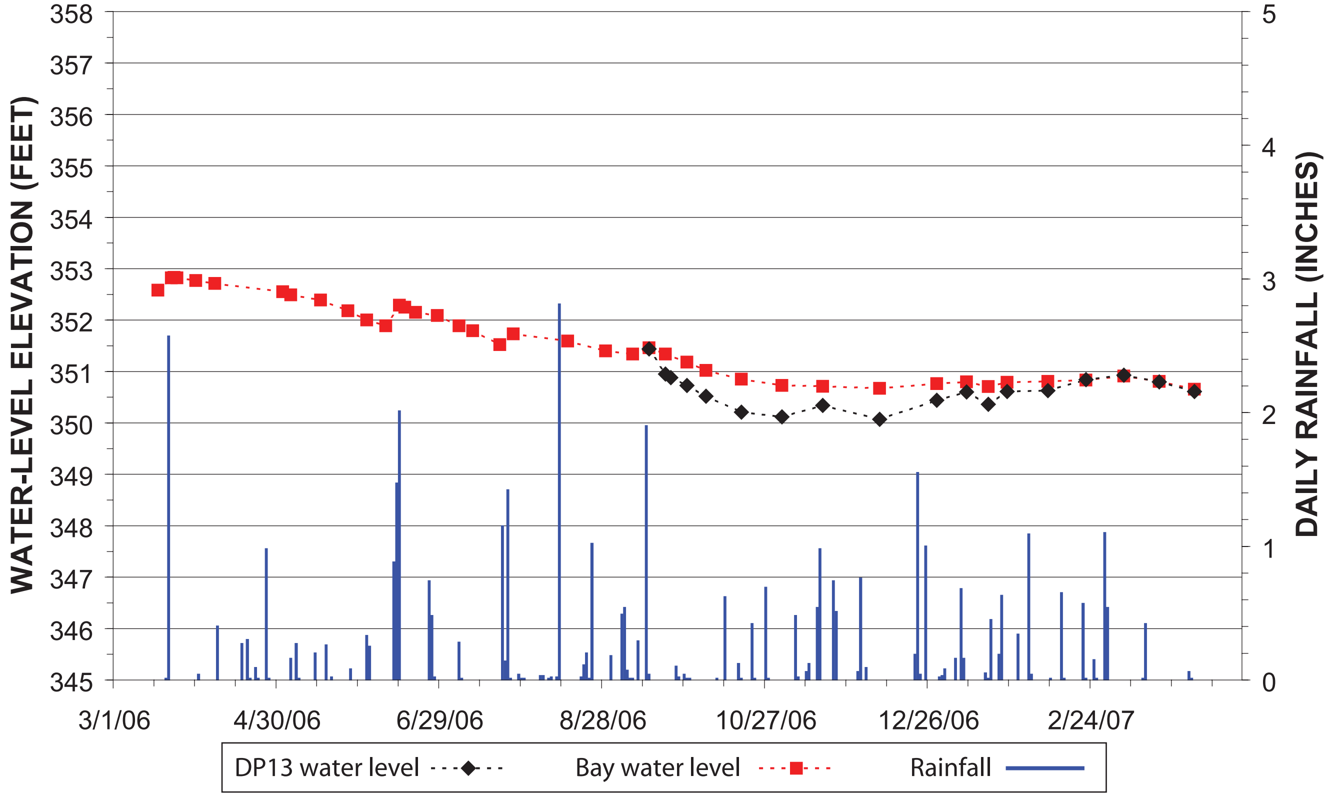


Figure 25. DP13 water-level elevations.

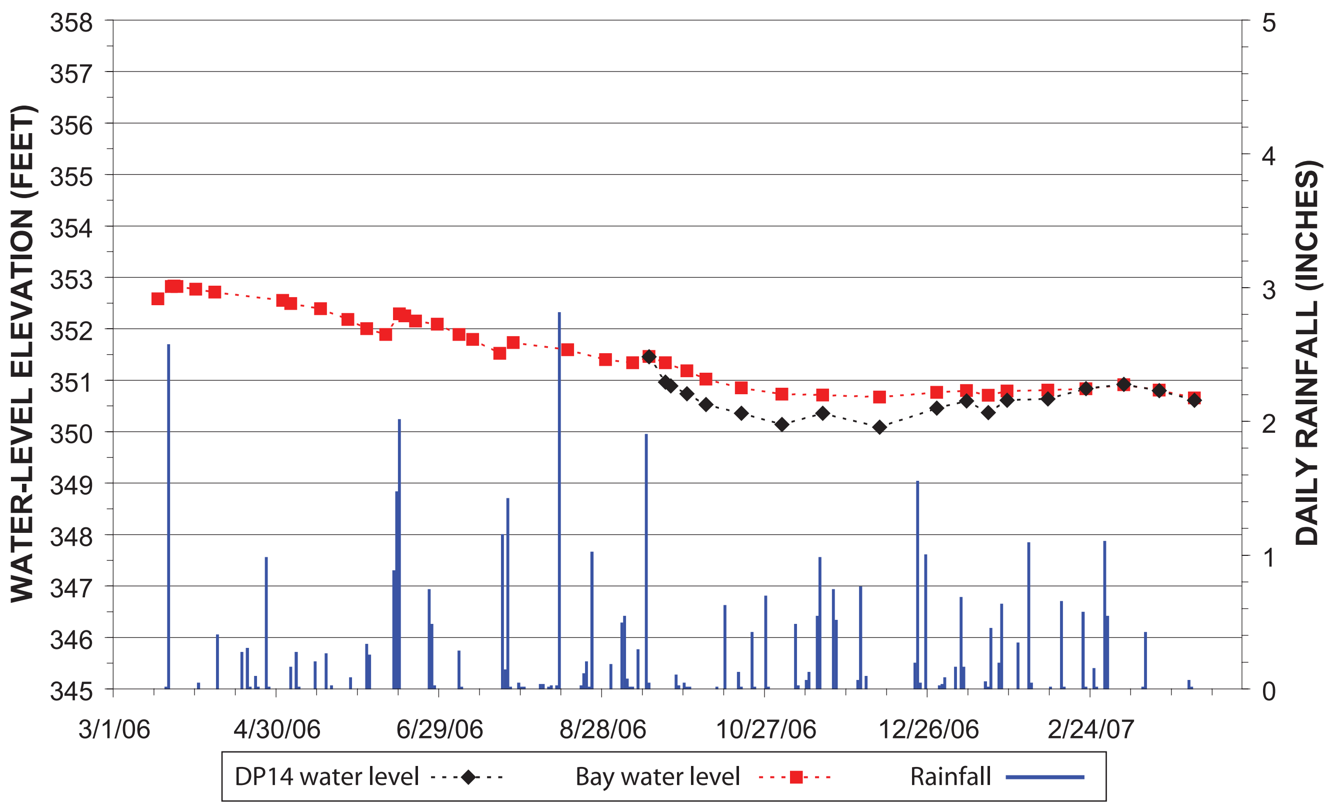


Figure 26. DP14 water-level elevations.

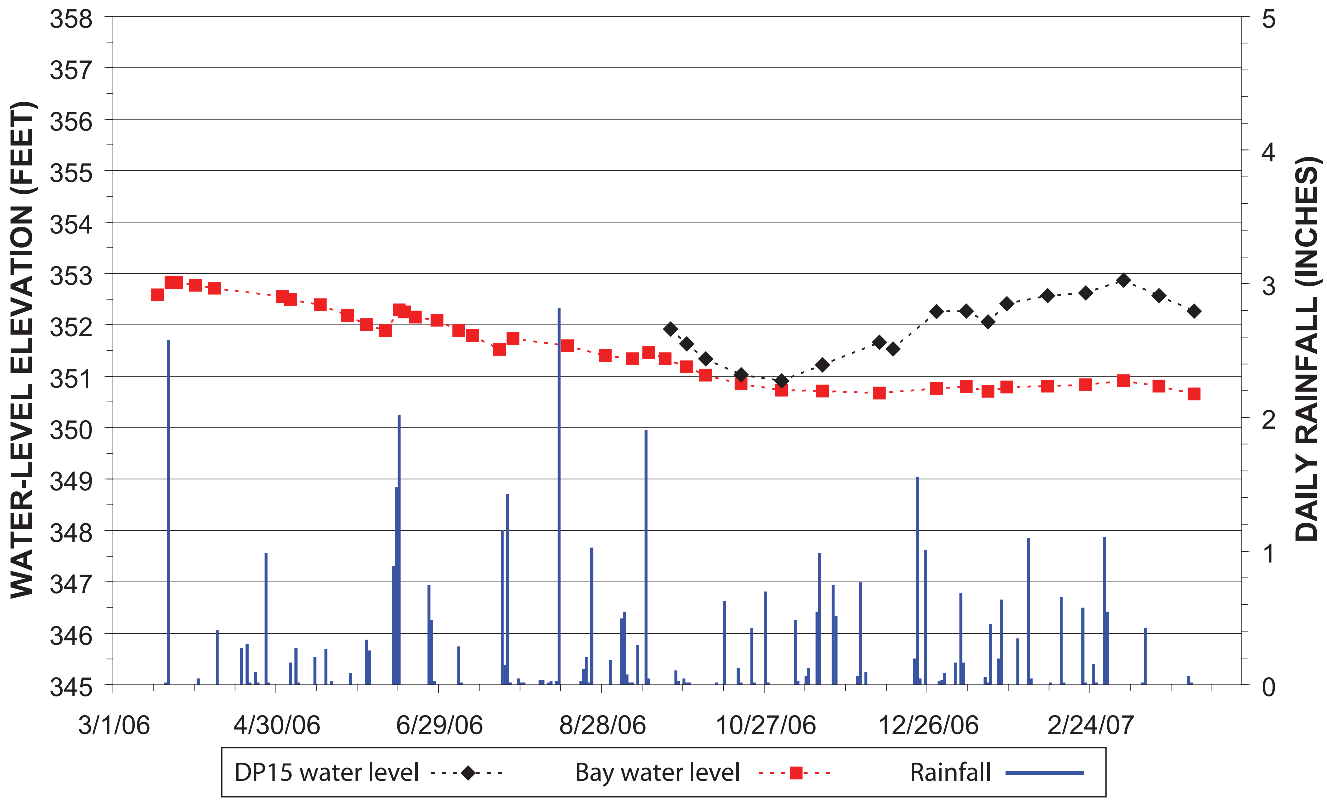


Figure 27. DP15 water-level elevations.

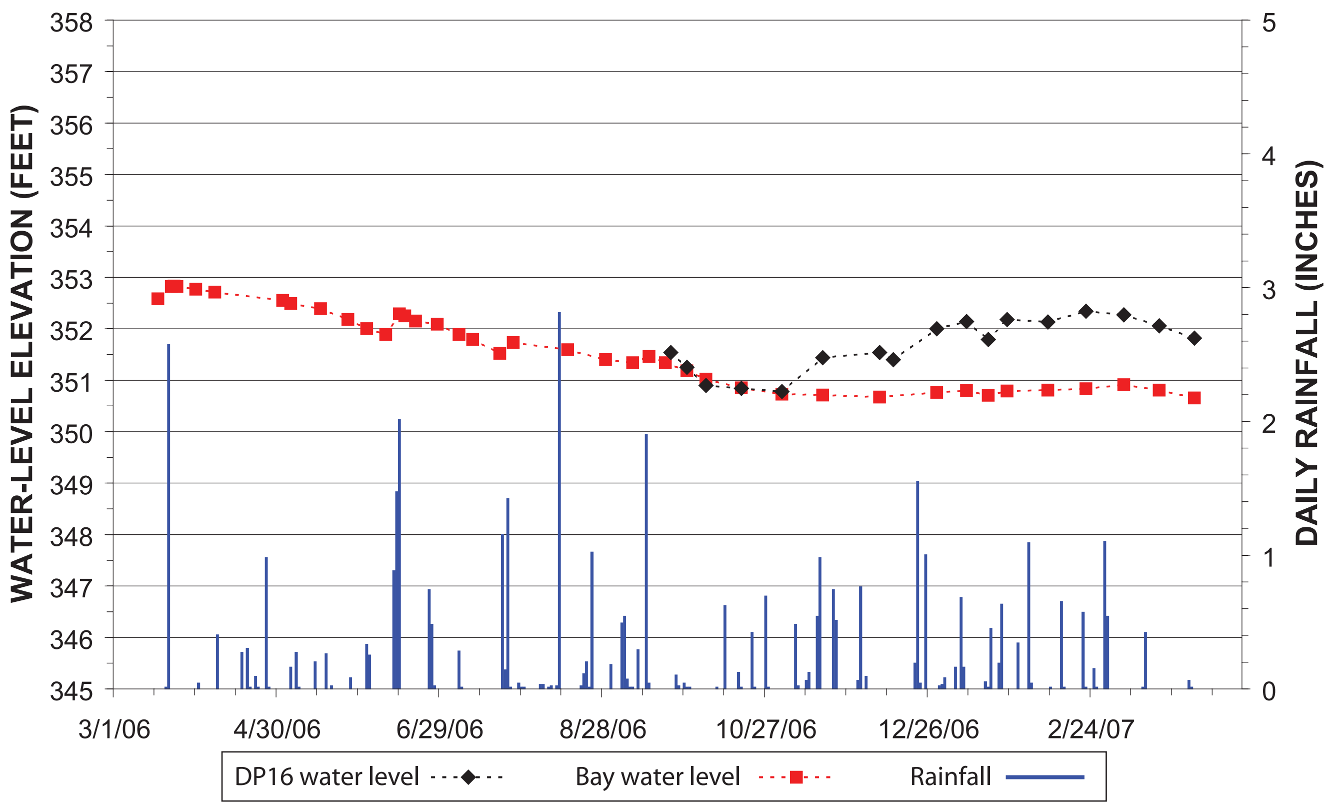


Figure 28. DP16 water-level elevations.

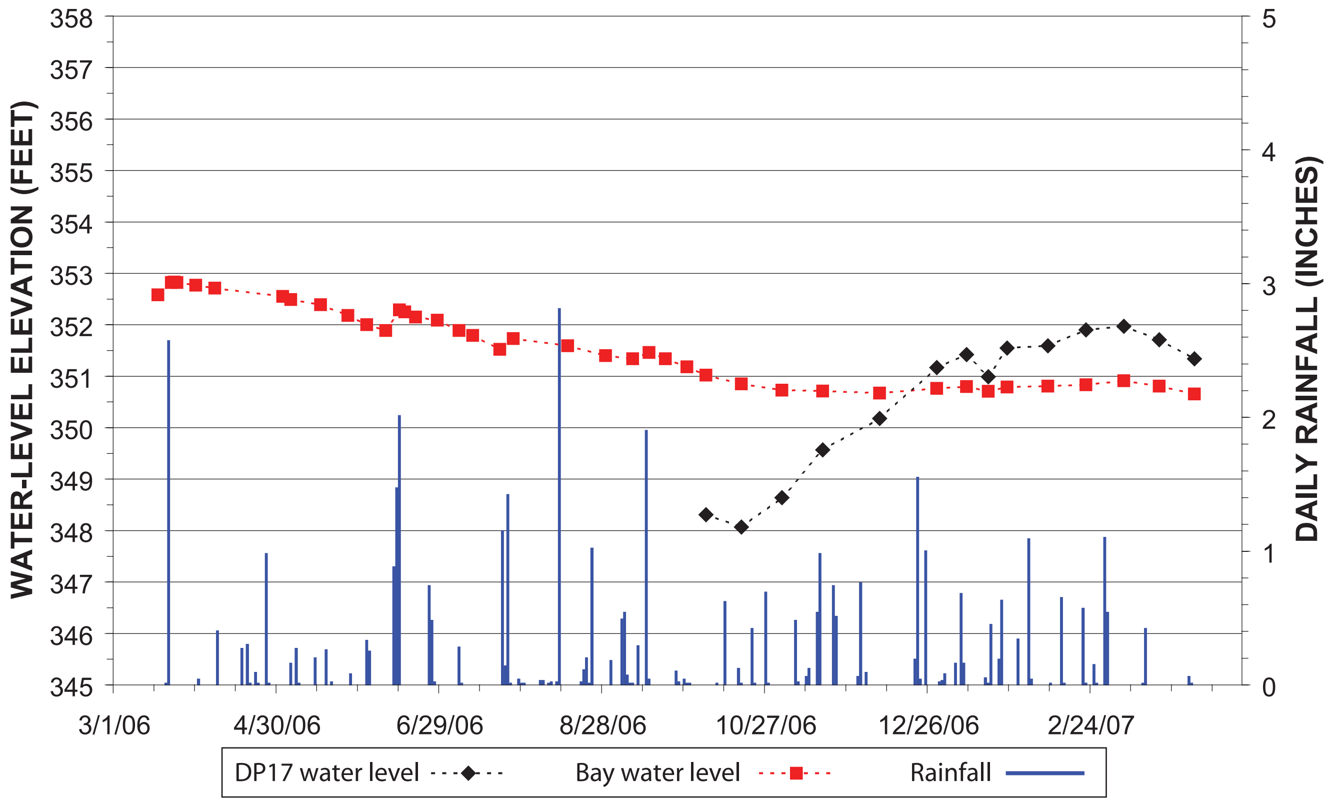


Figure 29. DP17 water-level elevations.

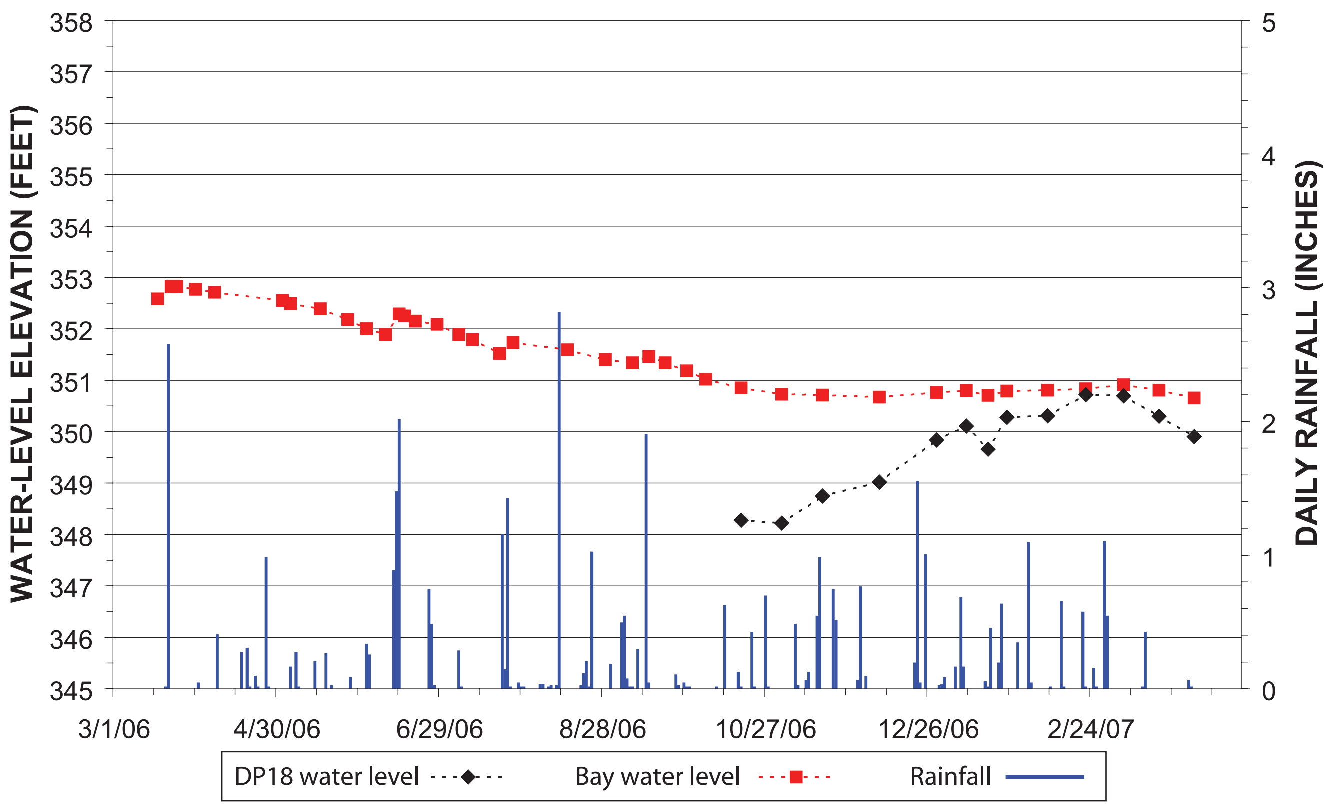


Figure 30. DP18 water-level elevations.

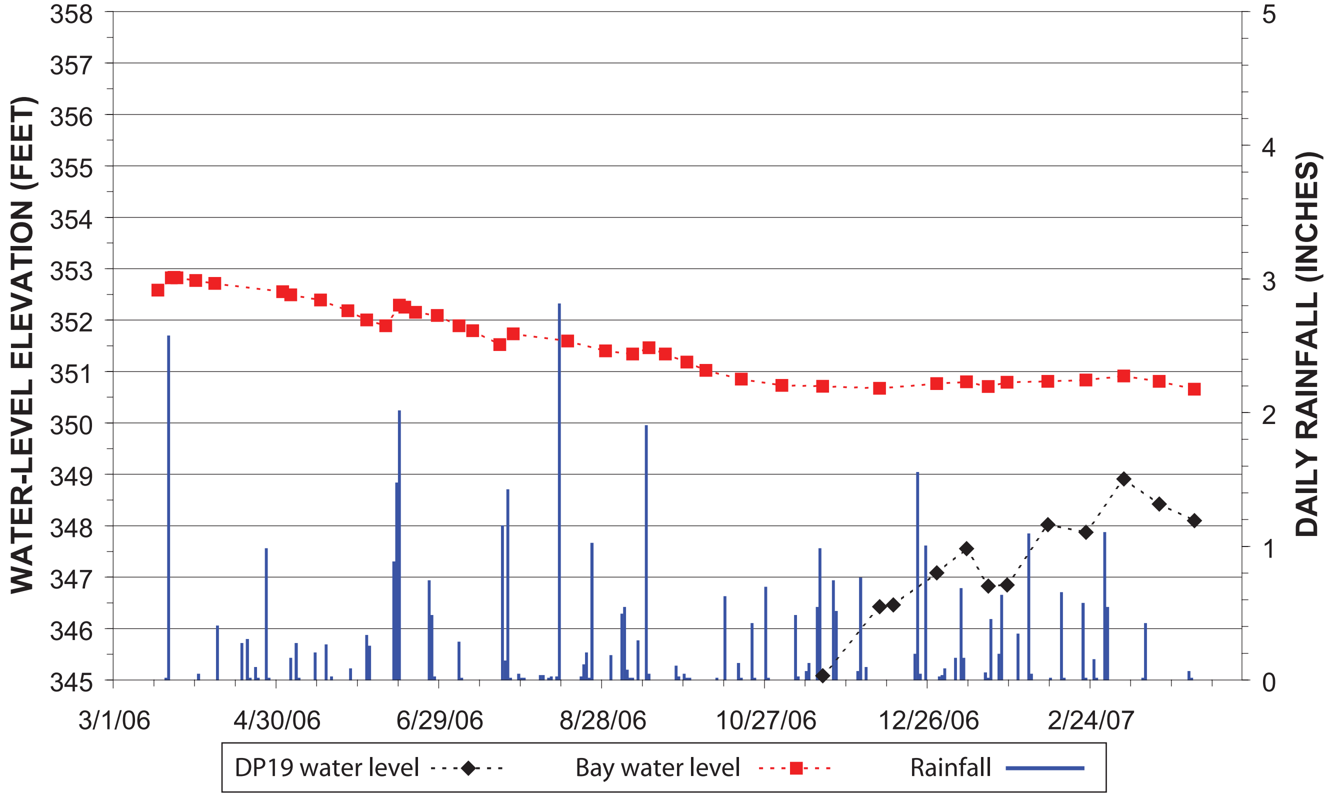


Figure 31. DP19 water-level elevations.

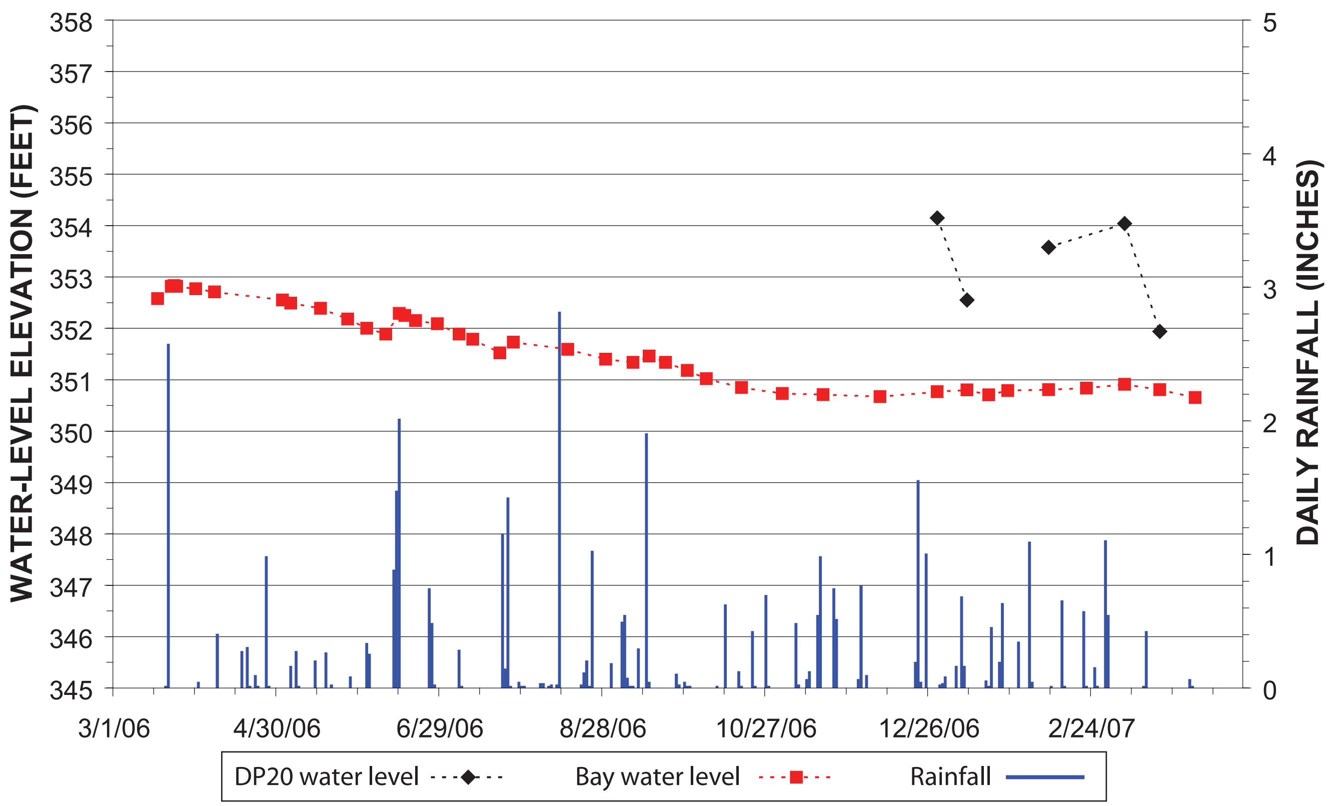


Figure 32. DP20 water-level elevations.

rain events (1.8 and 1.0 inches). After several rain events through January on the order of 0.5 to 1.0 inch, water levels in wells DP1, DP6, DP7, DP8, DP15, DP16, and DP17 had risen above the bay. Also in response to these rain events, wells DP2, DP4, DP5, DP11, and DP14 had levels at or approaching those in the bay. The overall rise in ground-water levels through the winter period continued despite below-average rainfall during January and February 2007. Although water levels in many of the wells rose substantially over this period, the bay rose by only 0.2 ft. Given the same amount of rainfall, ground-water levels generally will increase more than surface water levels due to soil porosity. For example, a rise of one inch in the bay would correspond to a rise of approximately 3 inches in a soil with an effective porosity of 0.33. By mid to late March 2007, water levels in most wells began to decline, probably due to the lack of rainfall in the remainder of that month.

Automatic water-level recorder data

Data from automatic water-level recorders installed in DP1, DP4, and DP9 for the period from June 28 through October 18, 2006 are presented in Figure 33, along with bay water-level elevations. Three distinct water-table fluctuations occurred during this period. DP1 shows the strongest response to large rainfall events on July 22–24 (2.8 inches), August 12 (2.8 inches), and September 13 (1.9 inches), and levels typically peak 4 to 6 days after the event. Two factors may explain this water-table behavior. First, DP1 is located in an open area with little to no vegetation, and local ET rates at this well site are greatly reduced. Second, the soil profile at DP1 contains a sandy clay layer approximately 10 ft below ground surface, which may cause a temporary perched water-table condition. These two factors are discussed in more detail in the "Piezometer nests" section (see below).

For these same rainfall events, the levels in DP4 responded only 0.5–1.0 ft and typically peaked 2 to 3 days after the event. DP4 also shows a water level decline of more than 4 ft during the summer through mid-fall period despite the temporary increases associated with these rainfall events. In contrast to well DP1, DP4 is located in a mature forest where ET rates are greater and, hence, less infiltrating rainfall reaches the water table. In addition, canopy interception may reduce the amount of rainfall reaching the ground for infiltration. These factors may explain why DP4 has a much smaller response to rainfall events than DP1.

Water levels typically increased by 1.0–1.5 ft at DP9 and peaked within a day for the large rainfall events discussed above. DP9, compared to DP4, also had noticeably greater fluctuations during the large rainfall events as well as during small events (August 28, September 4–5, and October 12). DP9 is located in a low-lying, forested area near the outlet culvert, where the water table typically remained 3.0–4.0 ft below ground surface. Water levels at DP4 typically were 6–9 ft deep at the onset of rainfall events, and thus, infiltrating water must travel a larger distance at DP4 than at DP9 before reaching the water table. Because the shallow water table at DP9 may help to maintain high soil-water content in the unsaturated zone, less infiltrating rainfall may be lost to ET or to the rewetting of the soil profile before it reaches the water table. Some of the infiltrating rainfall at DP4 is probably used to bring the soil-water content to its maximum value and, thus, less water is available to reach the water table. Differences in porosity between the soils at the two wells may also, in part, account for these differences in water table response.

Water levels at DP9 also have a noticeably distinct diurnal fluctuation for much of the summer period (Fig. 33). For example, the first several weeks of July show a general decline in the water table, but daily maximums typically occur between 8:00 and 10:00 in the morning, whereas daily minimums occur around 9:00 to 10:00 at night. Evapotranspiration (ET) and ground-water seepage, which occur simultaneously, are two processes that may be controlling these fluctuations. During the day, ET dominates, causing an overall daily decline in the water table; however, during the nighttime hours, when ET is nearly zero, ground-water seepage causes small rises in the water table (approximately 0.05–0.10 ft). ET is the overall dominating factor and causes a general decline in the water table.

Water-level data from the automatic recorders installed in wells DP1, DP3, and DP15 for the period from October 18, 2006, through April 3, 2007 are shown in Figure 34. Water-level behavior in DP1 is similar to that observed during the summer to mid-fall period and is discussed in more detail in the upcoming "Piezometer nest" section. Water levels in DP3 and DP15 behaved similarly during this period and showed similar water table rises in response to individual rainfall events. Water levels in both wells generally rose approximately 2 ft over the winter and early spring period when ET rates were greatly reduced. Well DP3, however, typically responds faster than DP15. Since both wells have similar soils, the difference in the temporal response probably is due to the somewhat deeper water table at DP15, where rainfall may take more time to reach the water table than at DP3.

A WPB ditch-bed elevation of 352.6 ft was measured at approximately the shortest distance between the ditch and DP15 (Fig. 2). DP15 water levels, except for a 2-week period in early March 2007, have remained below the bottom of the ditch during the November 2006 through March 2007 period (Fig. 34).

The ground-surface elevation of DP18, which is in the DPB ditch near DP3, is 349.9 ft. Well DP18, however, is located in a depression, and its elevation is not representative of the average bed elevation along this stretch of the DPB ditch. Figure 34 shows that water levels in DP3 were higher than the DP18 ground elevation from late January through March 2007. This is consistent with the ponded water observed at the DP18 well site during this period, and measured water elevations at DP18 were comparable to DP3, suggesting that the ponded water was simply a surface expression of the water table. The ponded water, however, was localized in the depression, and the rest of the ditch

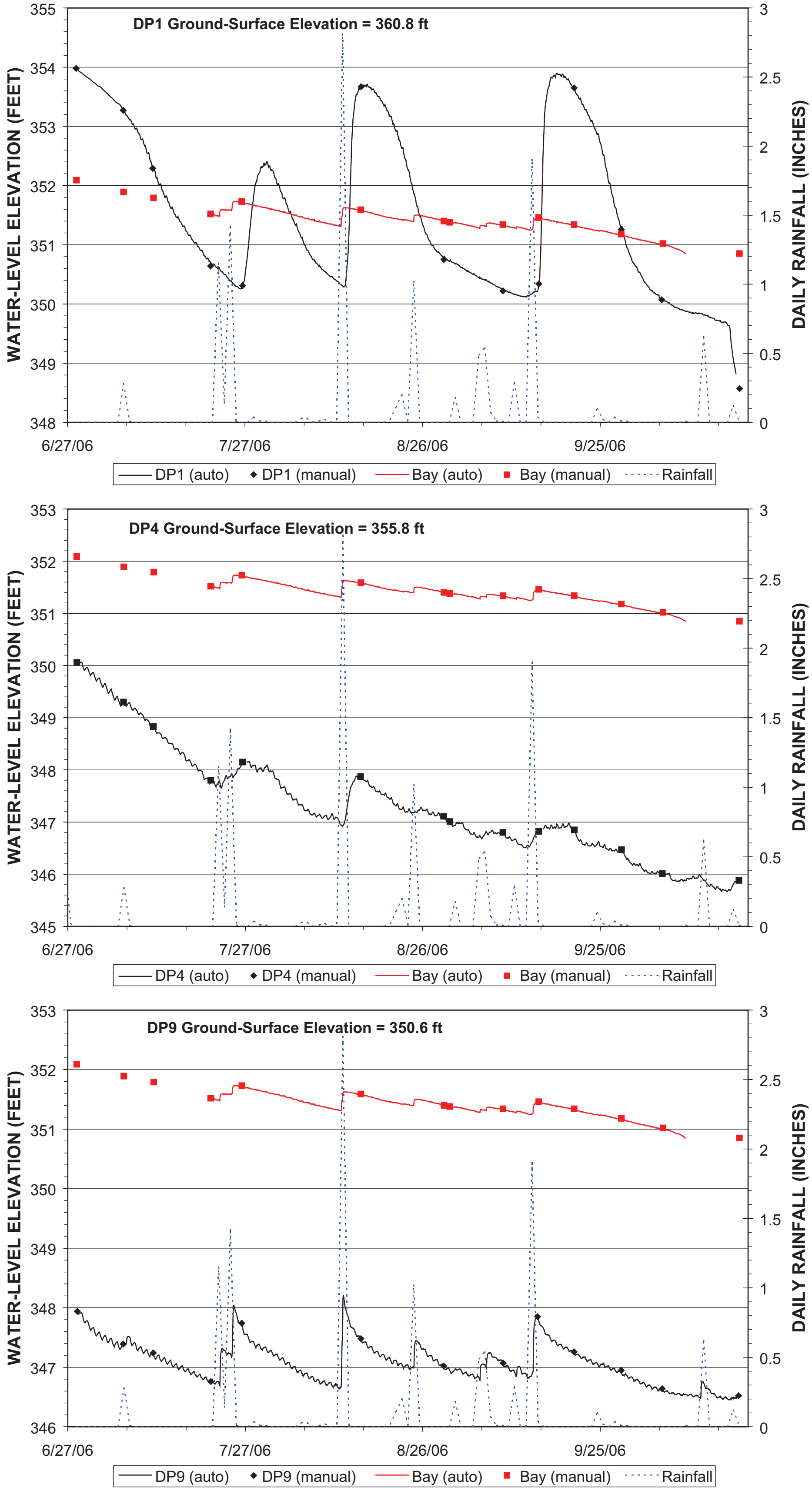


Figure 33. Water-level elevations for DP1 (top), DP4 (middle), and DP9 (bottom) continuously measured from June 28 to October 18, 2006.

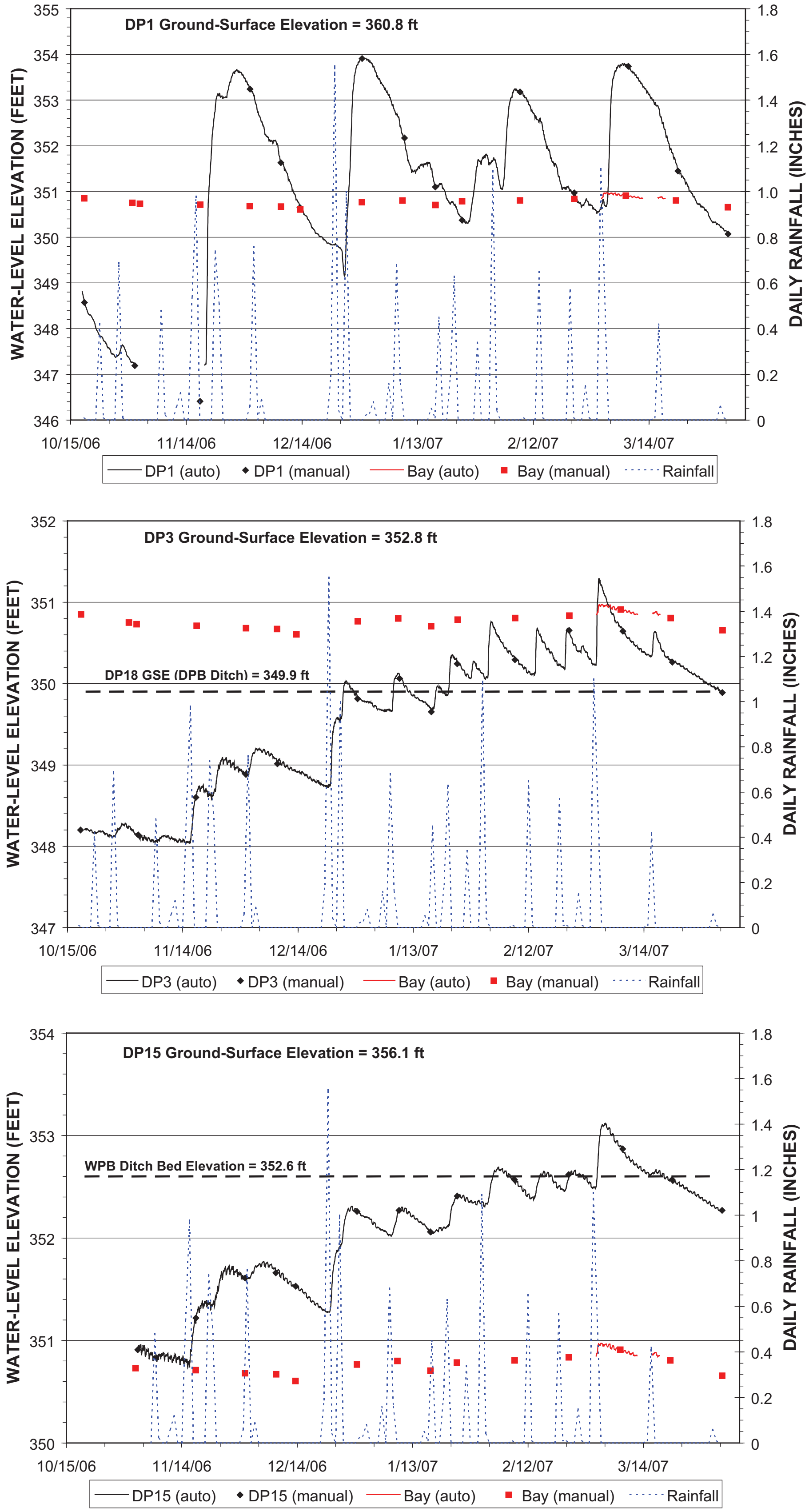


Figure 34. Water-level elevations for DP1 (top), DP3 (middle), and DP15 (bottom) continuously measured from October 18, 2006, to April 3, 2007.

in this area remained dry, at least for those days on which measurements were taken.

Figure 34 also shows a 3-day period following a rainfall event on March 1, 2007, in which water levels in DP3 were temporarily higher than the levels in the bay. These are the only recorded days throughout the entire study period in which water levels at DP3 were higher than the bay, and show that water-table mounding can temporarily occur between DPB and the outlet culvert.

Well profiles

The four cross-sectional profiles across the bay-upland system shown in Figure 2 are depicted in Figures 35–38 for selected dates. Hydraulic gradients are expressed as a percentage and are computed by dividing the difference in water levels between a well and the bay by their distance apart and then multiplying by 100. Positive lateral hydraulic gradients, which occur when well water-level elevations are higher than bay elevations, signify potential ground-water movement toward the bay (bay recharge). Negative gradients, which occur when bay elevations are higher than the well water-level elevations, signify potential ground-water movement away from the bay (bay discharge). Lateral hydraulic gradients can similarly be computed between two wells. Ground-water flow is also controlled by the hydraulic conductivity of the soil, which has not been measured for any of the well locations. Thus, while gradients may exist that suggest ground-water movement, the actual amount of ground-water flow cannot be determined without the hydraulic-conductivity measurements. In addition, the significance of the magnitude of these gradients is uncertain, but it is still instructive to compare the relative sizes of gradients in one area of the bay to another in order to highlight likely recharge and discharge areas.

P1-P1′

Water levels along profile P1-P1′ are presented in Figure 35 for selected dates. Water levels at DP4 have had the lowest water-level elevations measured during the study period. Ground-water levels in DP8 have been below the bottom of the well from early summer until early February 2007 and a limited amount of data were available from which to analyze hydraulic gradients.

Water levels at DP4 were temporarily above the bay in late March, creating a slight positive hydraulic gradient (much less than 1 percent); however, during the late spring, summer, and fall periods negative gradients on the order of 1–2 percent were observed (May 26, July 21, September 28, and November 2, 2006). In mid-September, well DP11 was installed between the bay and DP4. Negative gradients greater than 1 percent were observed between the bay and DP11 for most of the fall and early winter period, while steeper gradients of 2–3 percent were observed between DP11 and DP4 (September 28 and November 2, 2006). The lateral hydraulic gradients along the southwest portion of this profile have consistently been the largest gradients measured at the site. These data suggest that the southwest quadrant of the bay was a bay discharge area for much of the 12-month study period. Lateral gradients began to decrease in this quadrant during December 2006 as ground-water levels began to rise substantially, and by February 8, 2007, the gradients were less than 1 percent.

The water-level profile for May 26 in Figure 35 shows the occurrence of a trough or dip in the water table where water levels in DP4 have decreased below the bay and DP8. This trough is believed to be due, in part, to the increased ET rates in the late spring season. DP4 is in a heavily vegetated area with mature trees that, through ET, cause a greater degree of water-table drawdown compared to DP8, which is in an area of less mature vegetation. Canopy interception and evaporation may also play a role in the water-table drawdown at DP4, which limits the amount of rainfall that can infiltrate the soil and raise the water table.

DP5 is the only well on the northeast side of the bay along profile P1-P1′. Water levels at DP5 were slightly above bay levels in late March; however, hydraulic gradients were much less than 1 percent (see March 24). Water levels generally declined from late spring to late fall, but negative hydraulic gradients never exceeded about 0.5 percent during this time (May 26, July 21, September 28, and November 2, 2006). During the rewetting phase from December 2006 through early March 2007, measured gradients were nearly negligible as water levels in DP5 increased (December 29, 2006, and February 8, 2007). The data show that negative hydraulic gradients in the northeast quadrant of the bay-upland system are consistently much smaller than those in the southeast (see below) and southwest quadrants for this 12-month study period.

P2-P2′

Cross-sectional views of profile P2-P2′ are shown in Figure 36 for selected dates. Water levels in wells DP15 and DP16 (northwest of the bay) have shown a different behavior compared to those around other sides of the bay. No data were available for DP15 and DP16 until the end of September 2006, but their water levels have remained above or near the level in the bay through March 2007 (September 28, November 2, and December 29, 2006, and February 8, 2007). The levels in DP15 and DP16 consistently were some of the highest water-level elevations across the entire site, suggesting that the northwest margin of the bay may be a source of ground-water contribution to the bay even during dry conditions (see September 28 and November 2, 2006). Measured lateral hydraulic gradients, however, are well below 1 percent. Water levels at these two wells have been consistently higher compared to water levels at DP10, DP14, DP3, and DP9 and suggest the presence of a mounded water table to the northwest of the bay. The cause for this mounding is uncertain.

Consistent negative gradients have been observed between DP2 and the bay along the southeast end of the profile (May 26, July 21, September 28, and November 2, 2006). These gradients were small for much of the spring

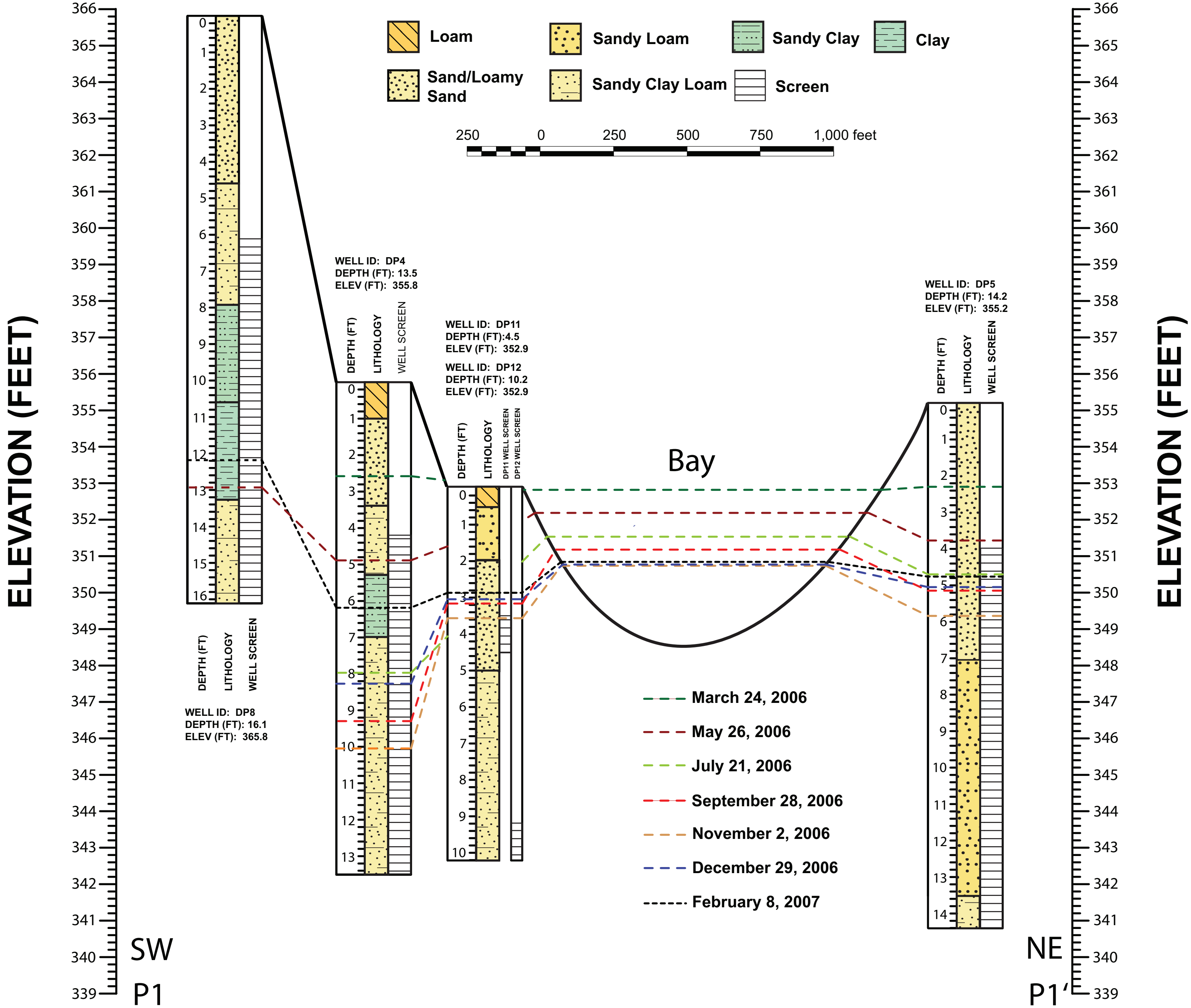


Figure 35. Soil profiles, ground-surface elevations, and water-level elevations for wells along profile P1-P1′.

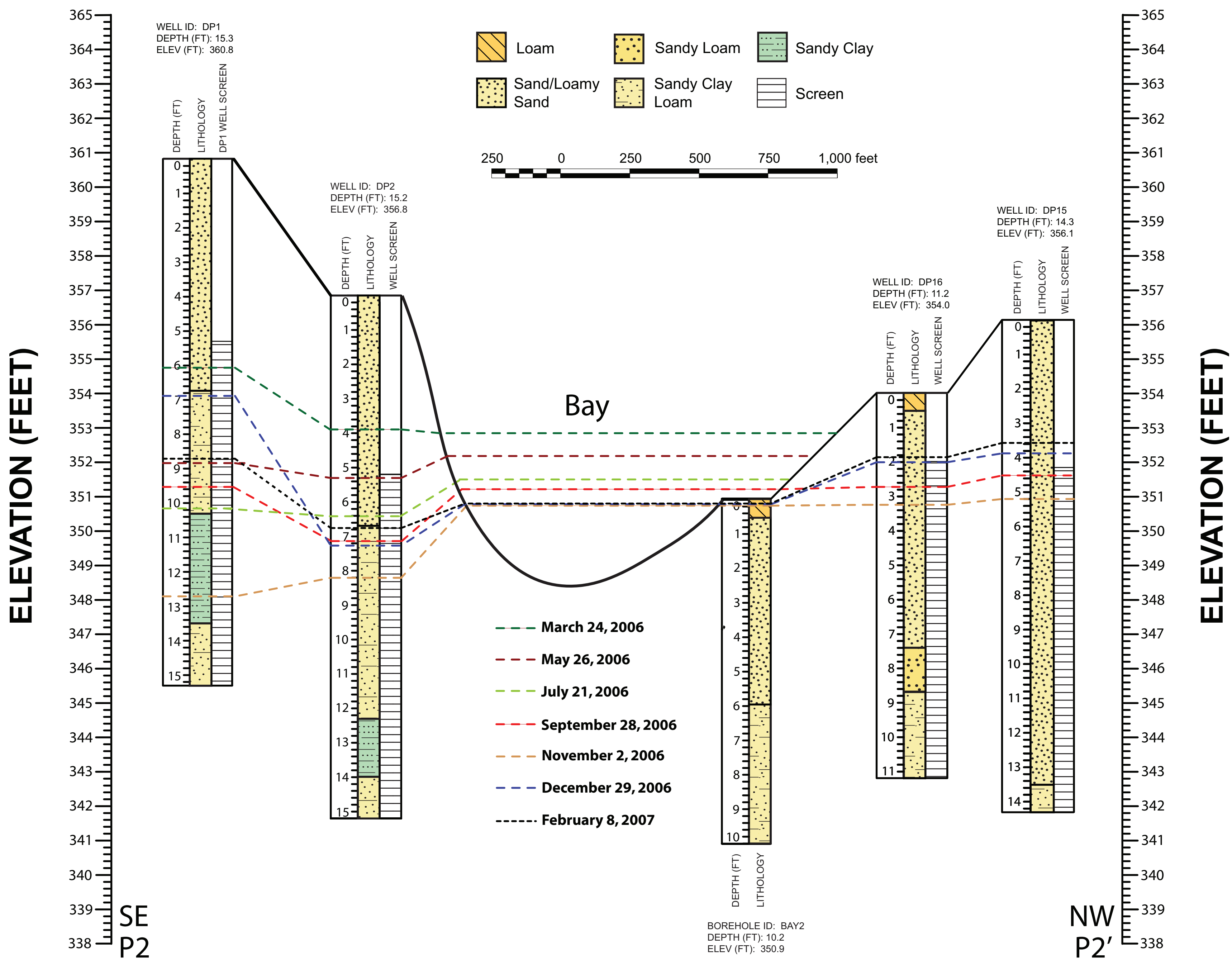


Figure 36. Soil profiles, ground-surface elevations, and water-level elevations for wells along profile P2-P2′.

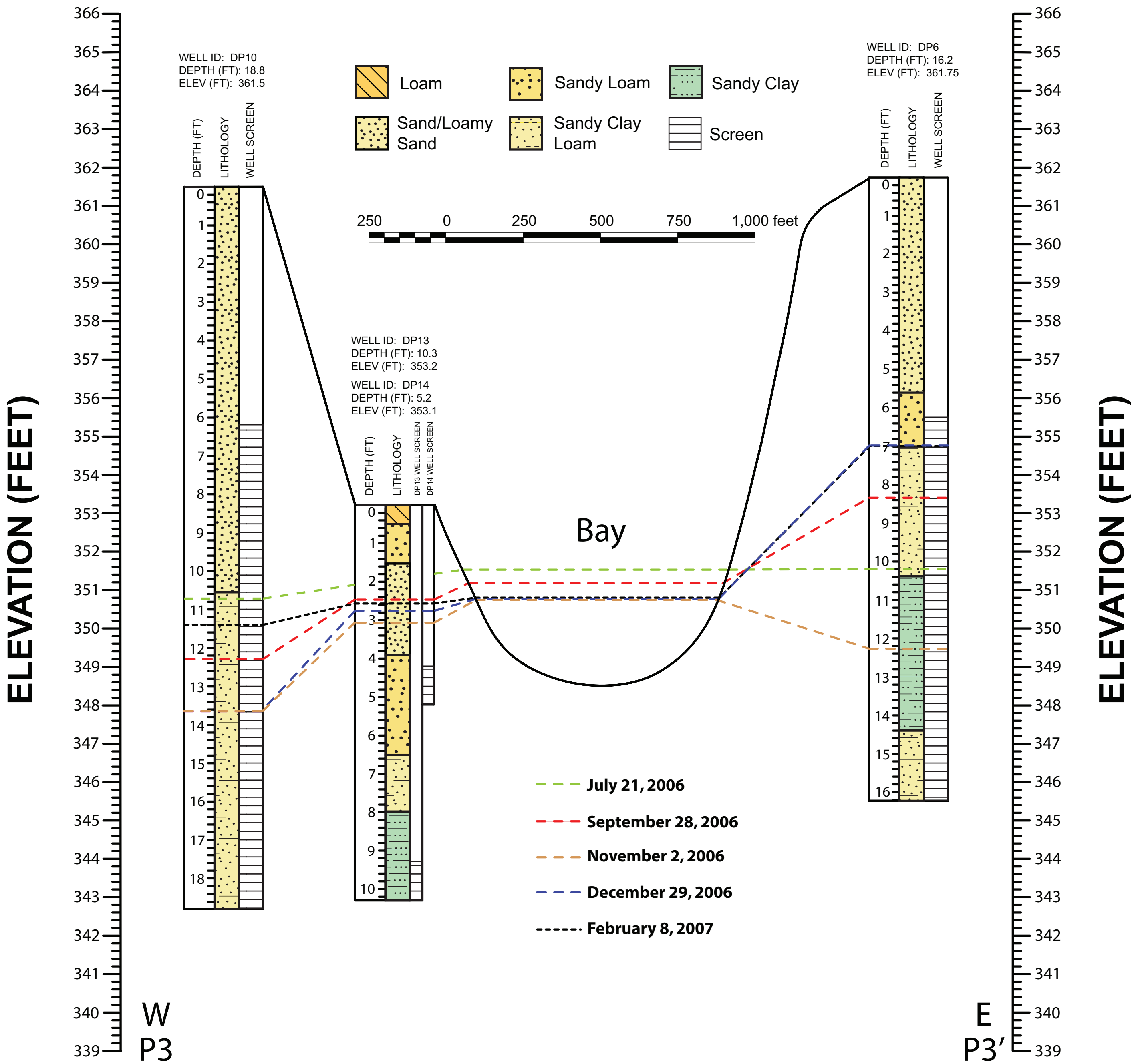


Figure 37. Soil profiles, ground-surface elevations, and water-level elevations for wells along profile P3-P3′.

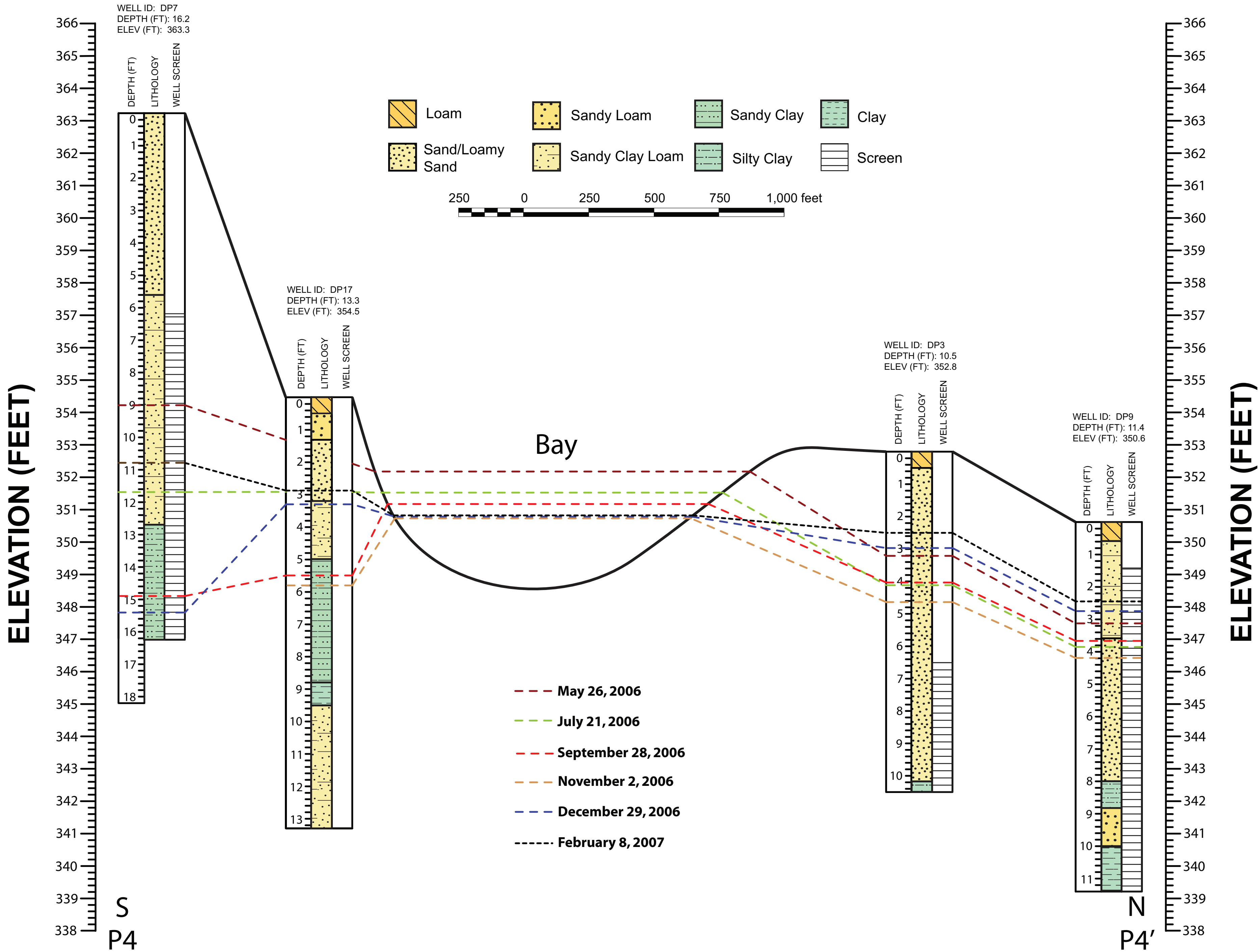


Figure 38. Soil profiles, ground-surface elevations, and water-level elevations for wells along profile P4-P4′.

and summer periods (less than 1 percent; May 26 and July 21, 2006), but typically were about 1 percent for the fall period (September 28 and November 2, 2006). During the rewetting phase from December 2006 through early March 2007, gradients declined below 1 percent as water levels in DP2 rose. Similar to profile P1-P1′, the data for P2-P2′ suggest that the southeast quadrant was a bay-discharge area for much of the 12-month study period. A positive gradient, though very small (much less than 1 percent), was observed on March 24, 2006, the only date with a recorded water level in DP2 above the level in the bay.

Well DP1 has shown highly variable water-table conditions. Water levels typically rise 3–4 ft in response to large rainfall events, and this behavior may reflect a localized perched water table due to a sandy clay zone approximately 10 ft below ground surface at this well (see the following section on "Piezometer nests").

The water levels in well DP2, similar to DP4, show a trough in the water table on July 21 and September 28 when water levels in DP2 were below both the bay and the upland well DP1. Because DP2 is in a heavily vegetated area and DP1 is in an open area with much less vegetation, these troughs may indicate the effects of increased ET in the late spring and early summer period along the perimeter of the bay. DP2 is also in a mature forest, where canopy interception and evaporation may reduce the amount of rainfall infiltrating the soil.

P3-P3′

Cross-sectional views of profile P3-P3′ are shown in Figure 37 for selected dates. Wells DP10 and DP14 were not installed until June and September, respectively, so no data were available during the wet period in late March 2006. Negative gradients have occurred between the bay and DP14 through the fall and winter period; however, these gradients have not exceeded more than 0.5 percent (see September 28, November 2, December 29, 2006, and February 8, 2007). Negative lateral hydraulic gradients between DP10 and DP14 have varied between 0.5 and 1.0 percent from September through December 2006 but were less than 0.5 percent from January through March 2007 as water levels in DP10 began to markedly rise.

Though gradients along the west side of this profile are somewhat less than gradients found along the southern sections of the bay, the data show that the west side of the bay may be a discharge area during relatively dry conditions at the site. In addition, water levels at DP10 and DP14 have remained at or below the bay since the date of their installations (no positive hydraulic gradients), and no trough in the water table has been observed during their measurement period. No data were available, however, at DP14 for late spring and summer periods during which water-table troughs are more likely to form.

Well DP6 is the only well on the east side of the bay along this profile and is in an upland area approximately 450 ft from the bay. Water levels, similar to those of DP1, have varied greatly compared to levels measured in most of the other wells. Water levels typically rise 2–5 ft after rainfall events of 1.0 inch or more, but they recede at a slower rate than those observed at DP1. The response of the water table may be due to a perched water table cause by a sandy clay layer approximately 10 ft below ground surface, similar to that observed at the DP1 site.

P4-P4′

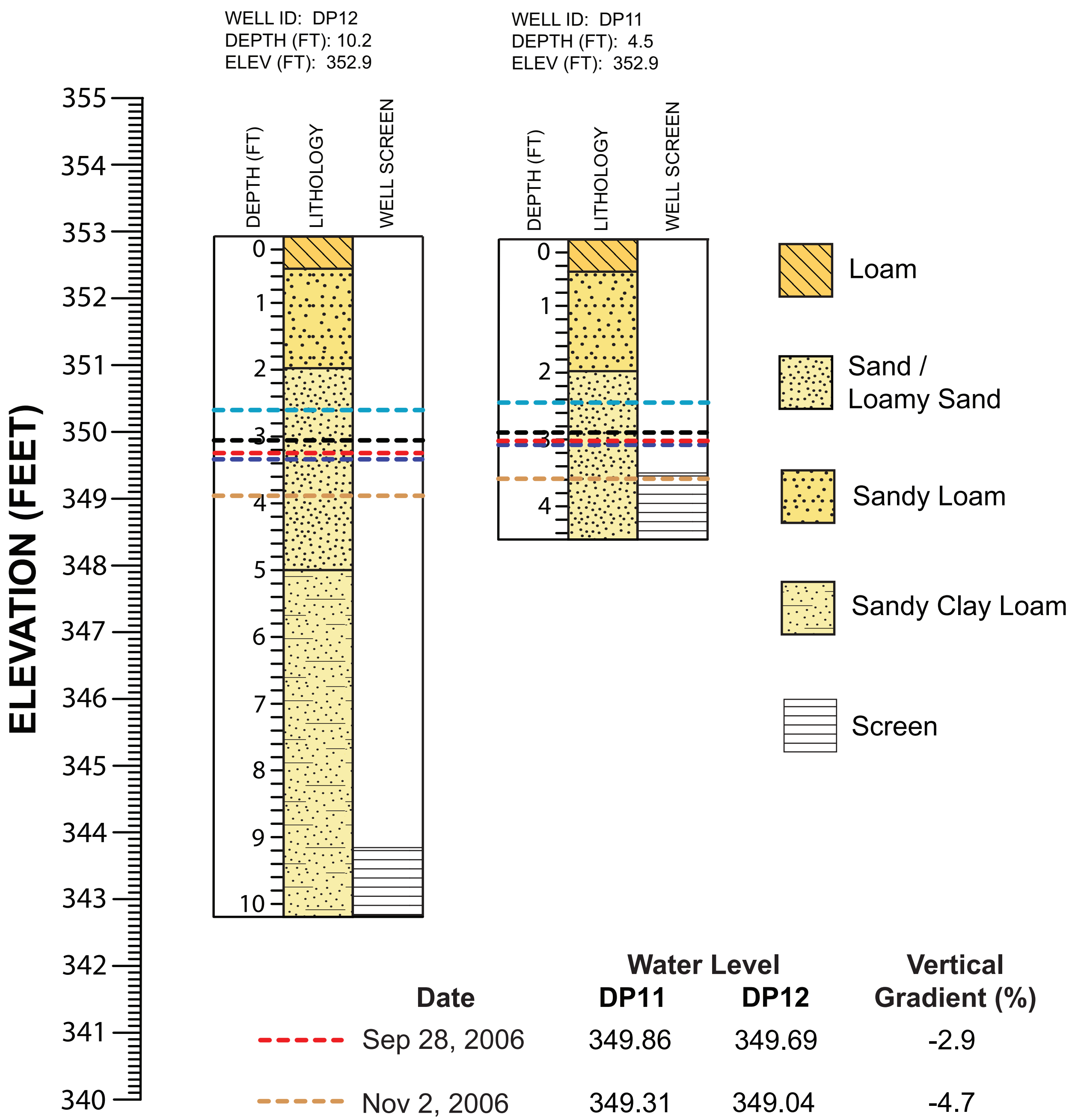
Cross-sectional views of profile P4-P4′ are shown in Figure 38 for selected dates. Measurements at DP3, DP9, and the bay have shown consistent negative hydraulic gradients from the bay toward the outlet culvert for almost the entire study period, including the wet period described above in late March. These gradients are small, typically less than 1.0 percent, but show that the northern section may consistently be a bay discharge area. Water levels in DP3 were temporarily higher than bay elevations for a 3-day period in March 2007; however, hydraulic gradients were much less than 1.0 percent.

Lateral hydraulic gradients are somewhat steeper and more variable at the south end of this profile. Negative gradients of 1.0–1.5 percent were measured on September 28 and November 2 between the bay and DP17, while small positive gradients (less than 1 percent) were measured on December 29, 2006, and February 8, 2007. These results show that the south end of the bay may serve at times as a bay recharge area and at other times as a bay discharge area.

The soil profile at DP17 contains a sandy clay layer approximately 5 ft below ground surface that may serve to create a perched water table condition after rainfall events. The water table at DP17 had consistently higher elevations than the bay throughout the months of January and February 2007. Well DP7's water levels remained below the levels of DP17 (since measurements began in late September) through January 2007, and lateral gradients between these wells are small (less than 1 percent). A water-table mound, possibly due to DP17's perched condition, was observed on December 29, 2006, between DP7 and the bay. Water levels in DP7 rose above levels in DP17 and the bay by the first week of February, but lateral gradients between DP7 and DP17 were small (much less than 1 percent on February 8, 2007).

Piezometer nests

Well diagrams of DP11 and DP12 and water levels for selected dates are presented in Figure 39. Water levels in DP11, screened from 3.5 to 4.5 ft below ground surface, have consistently remained higher than the levels in DP12, which is screened from 9.2 to 10.2 ft below ground surface. Measured vertical hydraulic gradients (i.e., the difference in water levels divided by the difference in screen depth) have ranged from 2–5 percent in a downward direction since the installation of these two wells in late August. These gradients, which are noticeably larger than most of the lateral hydraulic gradients discussed above, suggest that the southwest margin



Date	Water Level DP11	Water Level DP12	Vertical Gradient (%)
Sep 28, 2006	349.86	349.69	-2.9
Nov 2, 2006	349.31	349.04	-4.7
Dec 29, 2006	349.83	349.59	-4.1
Feb 8, 2007	350.00	349.88	-2.0
Mar 8, 2007	350.44	350.34	-1.7

Figure 39. Soil profiles and water-level elevations for piezometers DP11 and DP12.

of the bay-upland system may be an area where shallow ground water is moving downward to deeper layers.

Well diagrams for DP13 and DP14 and their associated water levels for selected dates are presented in Figure 40. Water levels in DP14, screened from 4.2 to 5.2 ft below ground surface, have consistently remained higher than the levels in DP13, which is screened from 9.3 to 10.3 ft below ground surface. The vertical hydraulic gradients at this site are much less than 1 percent, suggesting that there is little if any downward movement of shallow ground water in this area.

Water levels in DP1 and DP6 have been highly variable and typically rise 3–4 ft after large rainfall events of 1.0 inch or more. These responses contrast greatly with most of the other wells at the site, and although lower drainable porosity values at DP1 and DP6 may contribute to their large rises, the water-level data suggest a perched water-table system at these wells. The soil profiles determined from these wells contain a sandy clay layer beginning approximately 10 ft below ground surface. The thickness of this layer is about 3.0 ft in DP1 and 4.0 ft in DP6. The screened interval of DP1 extends from the less clayey sediments above the sandy clay, through the sandy clay itself, and into a less clayey layer below. To investigate the nature of this 3–4 ft sandy clay layer and its role as a semi-impermeable layer, two piezometers were installed adjacent to DP1. A schematic diagram of each well, along with water levels for selected dates, is shown in Figure 41. Well DP19 was installed to a depth of 18.2 ft and is screened in the sandy clay loam below the sandy clay zone. DP20 was installed to a depth of 9 ft and is screened in sandy clay loam above the sandy clay zone.

DP19 and DP20 were installed in mid-November and mid-December, respectively; therefore, a limited amount of data has been collected for this report. There are 4 days during the study period thus far in which water was measured in both DP19 and DP20. On December 29, 2006, after successive rainfall events of 1.0 and 1.6 inches on December 22 and 25, respectively, water elevations in DP20 were more than 7.0 ft above the elevations in DP19. On January 9, water levels in DP20 had declined by 1.6 ft and the water level in DP19 had risen nearly 0.5 ft. Downward vertical hydraulic gradients measured on December 29 and January 9 were 82 and 58 percent, respectively. By January 17, 2007, DP20 was dry. On February 8, 2007, water was again observed in both DP19 and DP20 one week after a 1.1-inch rain event. Water-level elevations in DP20 were 5.6 ft above those in DP19; however, by February 22, 2007, the well again was dry. After a 1.6-inch rain event on March 1–2, 2007, water was again observed in DP20, and the well had water-level elevations nearly 5.1 ft above those in DP19. Vertical hydraulic gradients of 65 and 60 percent in a downward direction were measured on February 8 and March 8, 2007, respectively. The large gradients suggest that the sandy clay layer is a semi-impermeable layer that creates a localized perched water-table system at DP1. The perched water table may also be a temporary condition as evidenced by the drying out of DP20 between successive rain events.

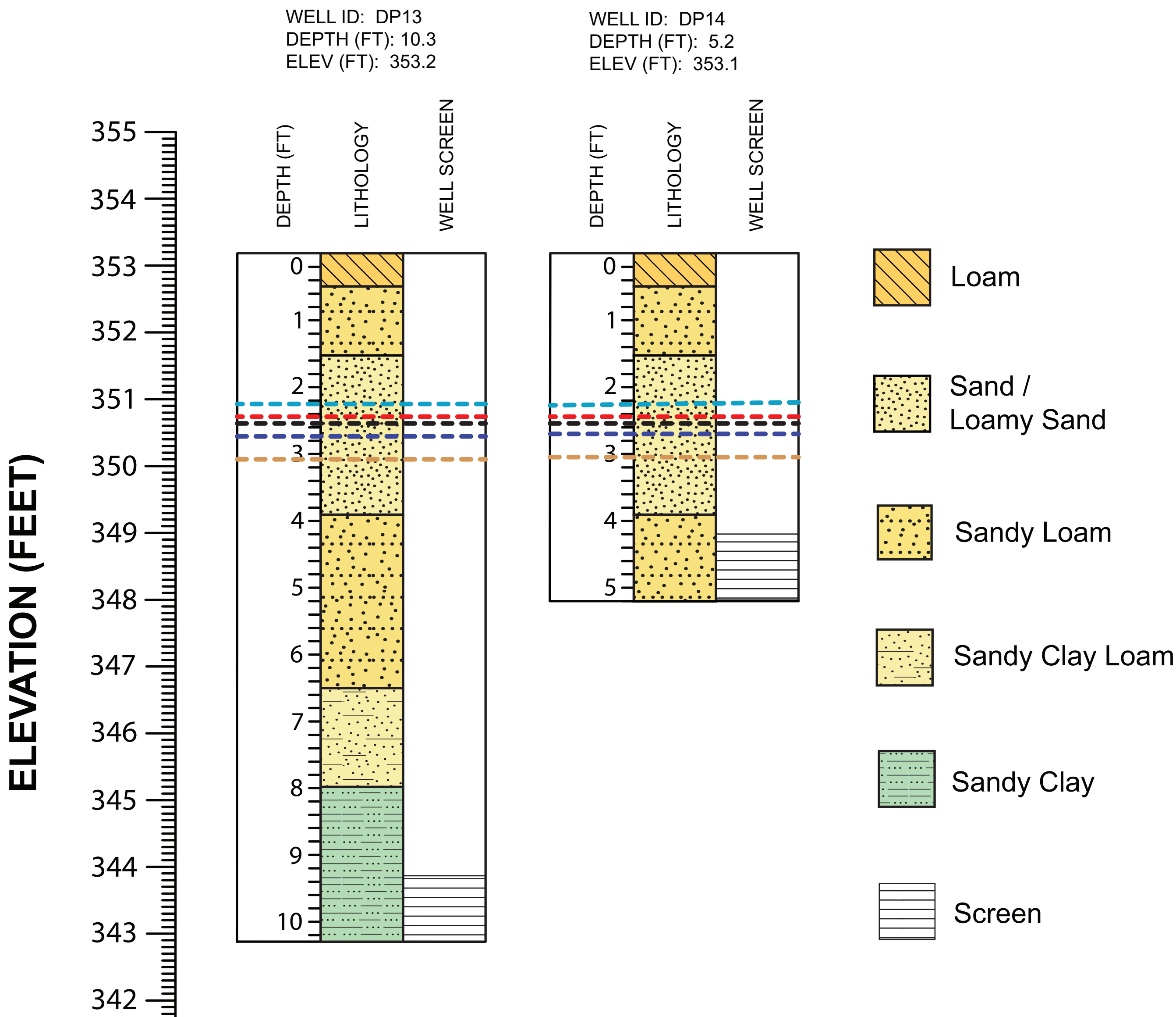
Water levels in DP1 were 0.2, 0.4, 0.4, and 0.3 ft below the levels in DP20 on December 29, January 9, February 8, and March 8, respectively. Differences in water-level elevations in DP1 and DP20 may result from the screened interval in DP1 extending through the lower sandy clay layer. The screened interval of DP1 expedites the movement of water to the more permeable sediments below the sandy clay layer and may form a small cone of depression in the water table at DP1. Additional data are needed to better assess the nature of the water table at this well site.

Upland wells

The water-level behavior at DP6 is similar to that of well DP1 (Pearson correlation coefficient = 0.89). These two wells have similar soil profiles and their screen intervals are nearly identical. Hence, the variations in DP6, like DP1, are believed to be due a perched water-table system as well.

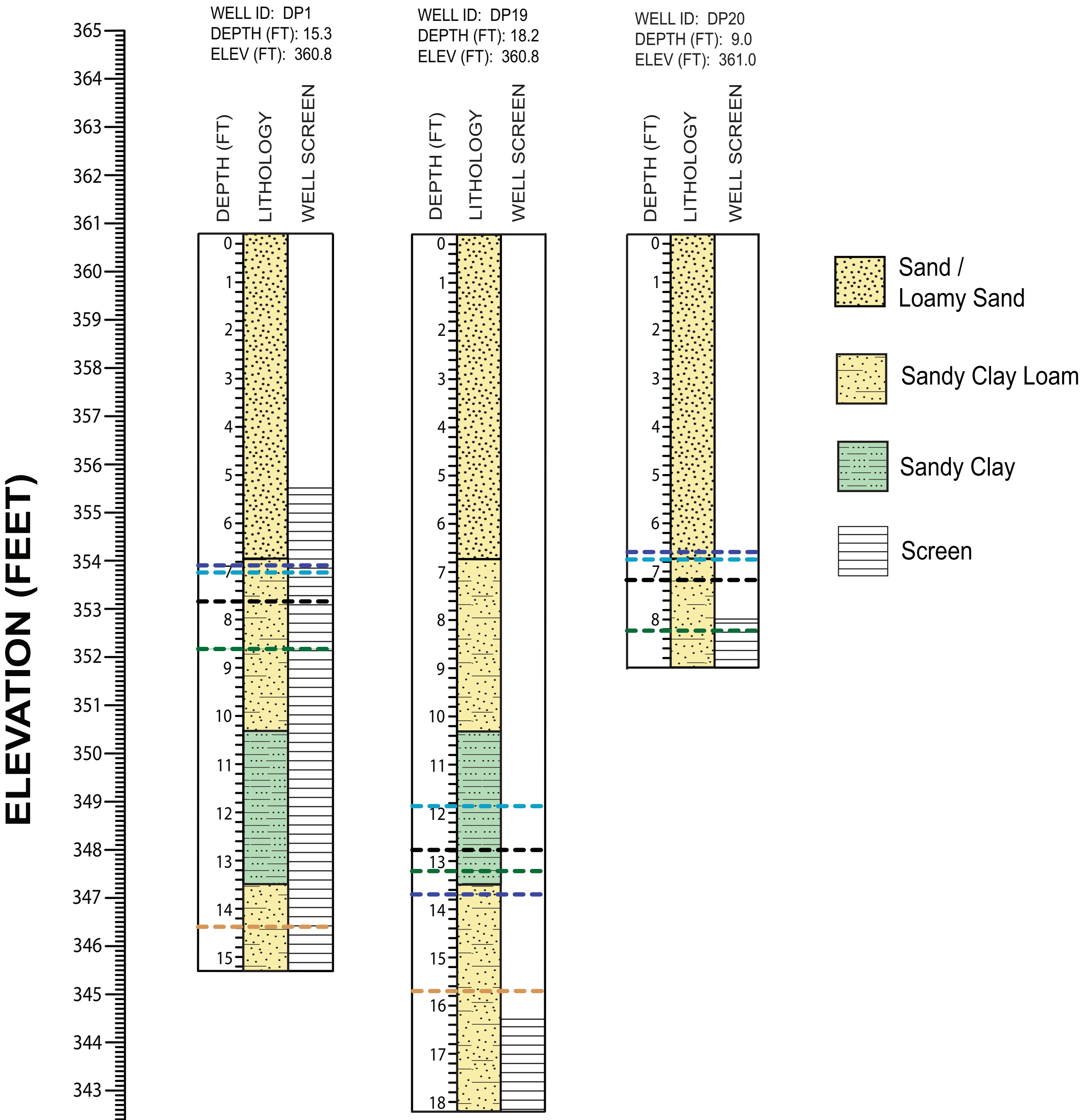
The soil profile at well DP7 is also similar to the profile at DP1; however, the water-level behavior at DP7 contrasts greatly with that of DP1 (and DP6). Figure 42 compares water-level elevations for DP1, DP6, and DP7 for the entire study period. Water levels in DP7 steadily declined through the summer and fall of 2006, and the well had only one observable response to a large rainfall event (June 14) during this period. The variable or fluctuating water levels measured at DP1 and DP6 were not observed at DP7, and water levels at DP7 declined more than 10 ft from early April to mid-December 2006. There are at least two possible reasons for this difference in behavior during this period. First, DP1 and DP6 are in open areas with little to no vegetation, and the surficial soil is highly permeable sand. Most of the rainfall infiltrates the soil rapidly and evaporative losses at the surface are small. After the water infiltrates the soil, little water is lost to ET (due to the lack of roots) as it moves downward through the unsaturated zone to the water table. DP7, on the other hand, is in a forested area, and though the tree stands at DP7 are relatively young (approximately 10 years old), the forest floor may slow infiltration and increase evaporative losses at the surface. After water infiltrates the soil, more water is lost to ET through the root system, and less water is reaches the water table. Second, at DP1 and DP6, there is little to no canopy interception, so nearly all of the rainfall reaches the ground surface, whereas at DP7, canopy interception decreases the amount of rainfall reaching the forest floor, and subsequently, the amount of water available to infiltrate the soil.

The water-level behavior at DP7 during the latter half of December 2006 through March 2007 also supports these explanations. Water levels at DP7 began to noticeably increase in mid-December 2006 and continued to rise substantially from January through March 2007 (Fig. 42). During this period, ET rates and canopy interception were greatly reduced, allowing for greater infiltration of rainfall into the soil and decreased losses through ET. In a study by Hubbard (1986) at the Savannah River Site, S.C. (located approximately 30 miles southwest of DPB), ET and recharge



Date	Water Level DP13	Water Level DP14	Vertical Gradient (%)
Sep 28, 2006 (red dashed line)	350.73	350.74	-0.2
Nov 2, 2006 (tan dashed line)	350.12	350.14	-0.4
Dec 29, 2006 (blue dashed line)	350.44	350.46	-0.4
Feb 8, 2007 (black dashed line)	350.63	350.64	-0.2
Mar 8, 2007 (light blue dashed line)	350.93	350.92	0.1

Figure 40. Soil profiles and water-level elevations for piezometers DP13 and DP14.



	Date	Water Level DP1	Water Level DP19	Water Level DP20	Vertical Gradient (%) (DP19–DP20)
orange dashed line	Nov 17, 2006	346.41	345.09	——	——
blue dashed line	Dec 29, 2006	353.91	347.09	354.15	-82.2
green dashed line	Jan 9, 2007	352.17	347.56	352.55	-58.1
black dashed line	Feb 8, 2007	353.18	348.02	353.58	-64.4
light blue dashed line	Mar 8, 2007	353.74	348.91	354.04	-59.6

Figure 41. Soil profiles and water-level elevations for piezometers DP1, DP19, and DP20.

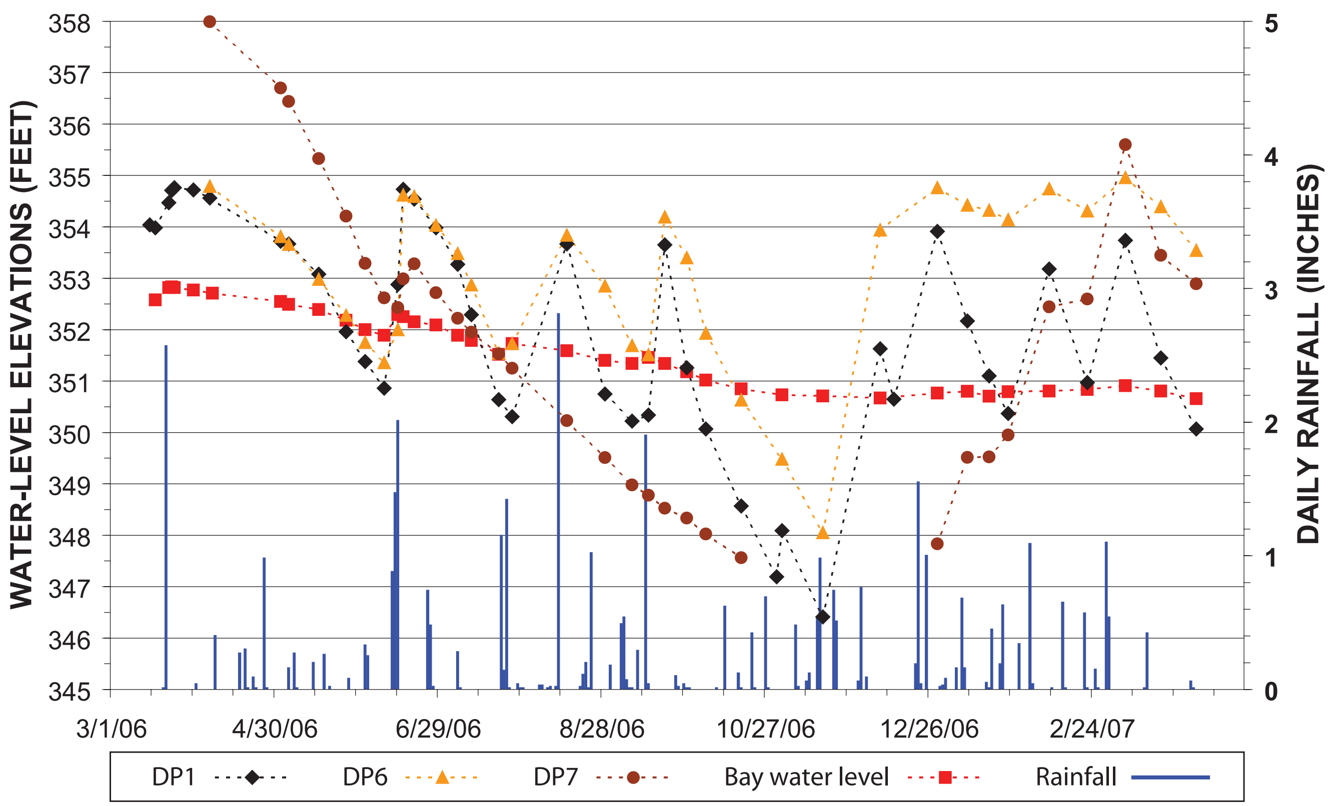


Figure 42. DP1, DP6, and DP7 water-level elevations.

rates were shown to vary substantially between heavily forested areas and areas with exposed soil or grass. In heavily forested areas, annual ET and recharge rates were 40 inches/yr and 6 inches/yr, respectively, whereas in the open areas ET and recharge rates were 30 inches/yr and 16 inches/yr, respectively. The differences in water-table behavior observed between wells in forested areas and open areas at DPB appear consistent with Hubbard's results on ET and recharge rates in forested and nonforested areas. Hubbard's annual ET value of 40 inches/yr measured in the heavily forested area is similar to the annual ET value estimated for DPB during the April 2006 through March 2007 period (40.9 inches).

Water levels at DP10 behave similarly to DP7 (Pearson correlation coefficient = 0.98), and DP10 is also in a forested area where the effects of increased ET and greater canopy interception may have contributed to the water-table drawdown observed at this well during the summer and fall of 2006. The water table at DP10 rose substantially through the winter of 2006–2007, which is also consistent with both reduced ET and canopy interception. The limited amount of data available for the study period at DP8 suggest that its water-level behavior is probably similar to that of DP7 and DP10. Water levels in DP8 were below the bottom of the well from mid-June 2006 to early February 2007; however, water levels have risen dramatically through February and March 2007. Like DP7 and DP10, DP8 is in a more heavily forested area than wells DP1 and DP6. Additional long-term data covering a greater range of climatic conditions are needed to assess whether the differences in water-table patterns among these wells can be explained by their location in forested or nonforested areas.

Water Balance

Average monthly pan-evaporation data and average monthly rainfall for the period 1963–1992 at the Blackville 3W weather station are presented in Figure 43, and cumulative totals are given in Figure 44. Since this station is located less than 10 miles from DPB and because we are considering monthly averages over a 30-year period, these data offer a reasonable representation of the general climatic conditions at the bay. Average annual ET for this 30-year period was 42.8 inches after a 0.75 pan correction coefficient was applied, compared to an average annual rainfall of 47.3 inches for the same period. Thus, on an annual basis, rainfall typically exceeds ET by 4.5 inches. Assuming negligible surface inflow or outflow and that the long-term change in water level (the ΔWL_{Bay} term in Equation 1) is approximately zero, the data suggest that 4.5 inches of water is lost from the bay as ground water seepage in a typical year. Figure 44 shows that cumulative rainfall totals consistently exceed cumulative ET totals for a year with average climatic conditions.

Monthly rainfall values exceed their corresponding ET values for the period November–March, with the greatest

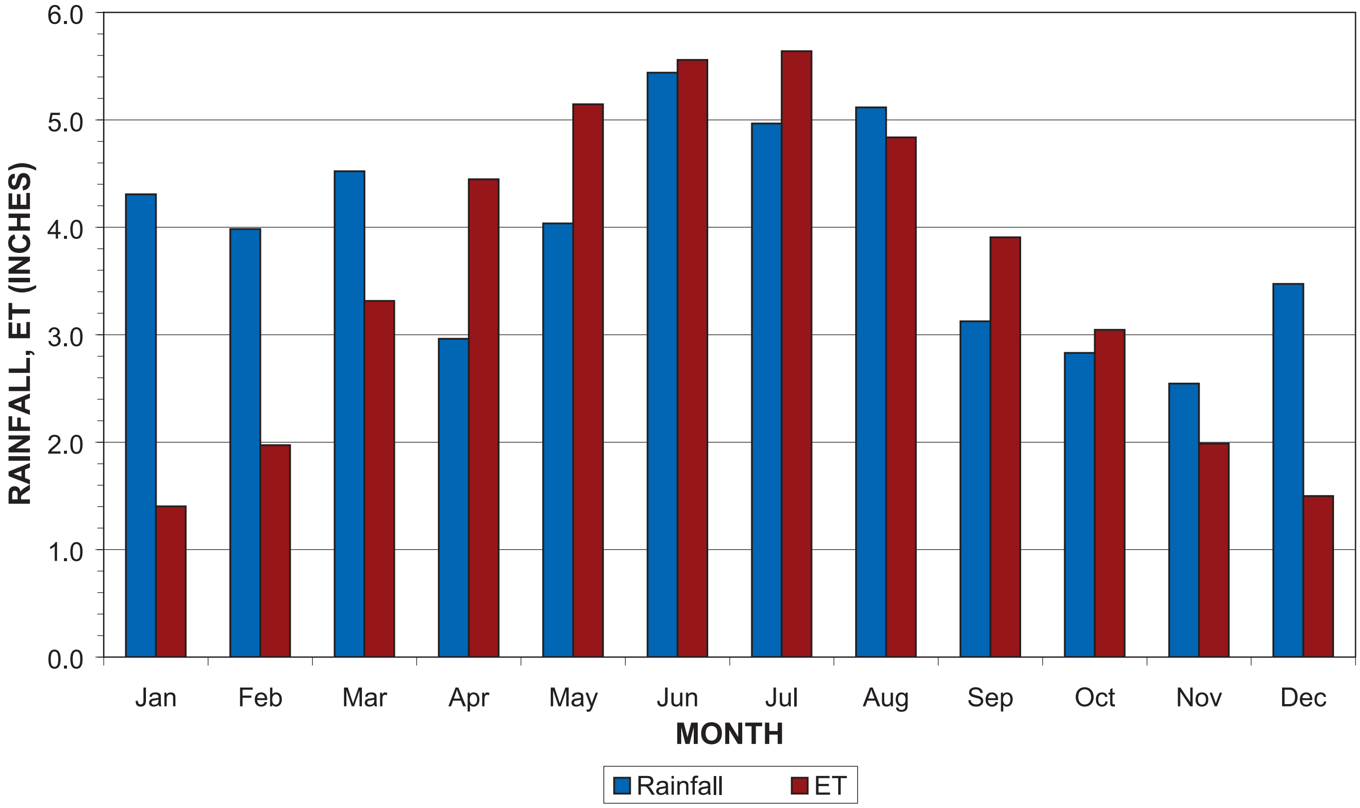


Figure 43. Average monthly rainfall and ET at the Blackville 3W weather station for the period from 1963 through 1992.

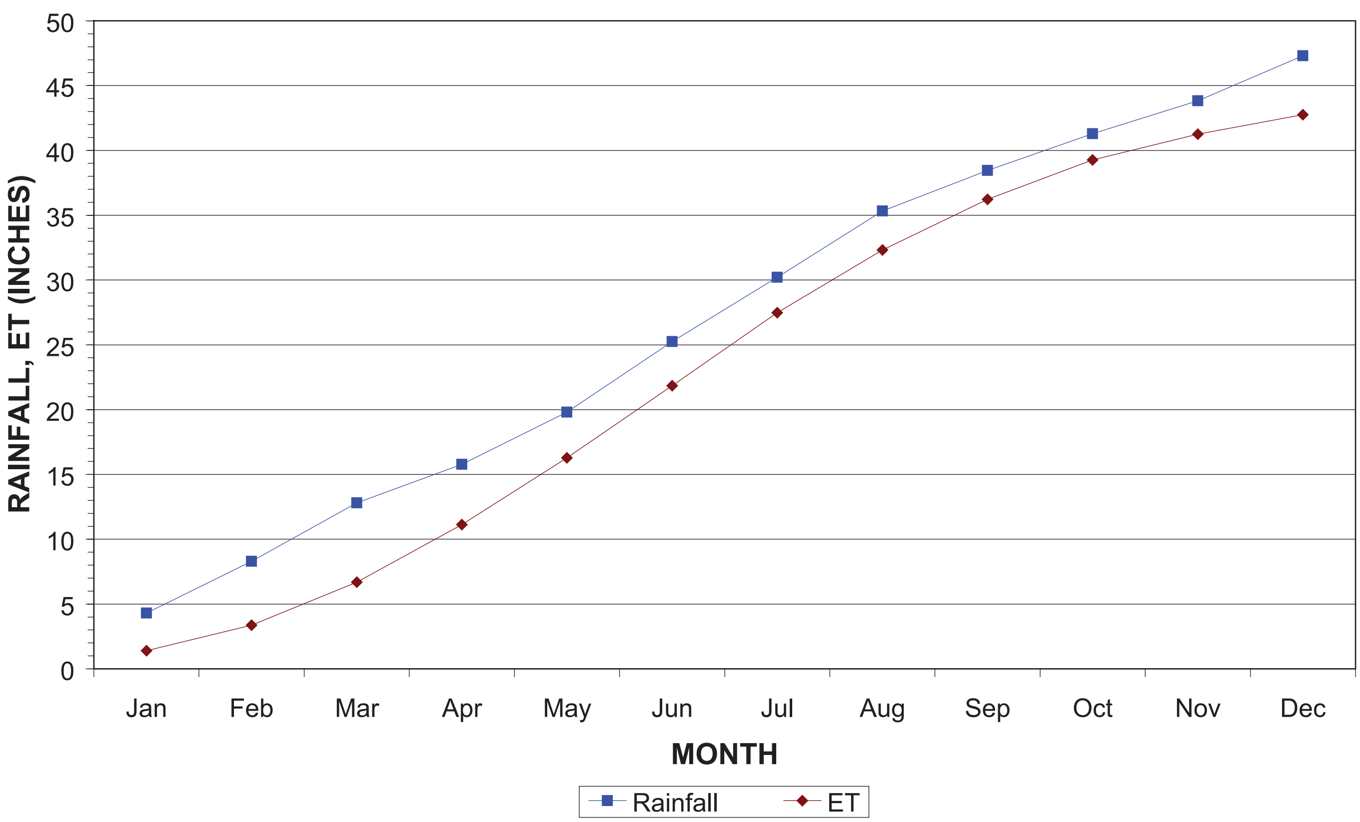


Figure 44. Cumulative monthly rainfall and ET at the Blackville 3W weather station for the period from 1963 through 1992.

differences (about 2 inches or more) occurring in December, January, and February. ET exceeds rainfall for the months of April through October (except for August) with the largest differences (more than 1 inch) observed in April and May. These data suggest that water levels at DPB would generally rise during the winter months, with the wettest conditions occurring in the late winter-early spring period. The data also show that water-level decline is expected throughout the growing season (spring and summer), with the lowest levels occurring in the late summer-fall period. This behavior is common in many wetland ecosystems where ponded conditions typically occur during the dormant or winter season and the driest conditions (little to no ponding) exist late in the growing season.

Monthly PET and rainfall values at DPB are presented in Figure 45 for the period from April 2006 to March 2007. Monthly PET values were computed using the Hamon method with correction factors developed from the historic pan-evaporation data as described earlier. Since the bay held ponded water for this entire 12-month period, ET is assumed equal to the PET rate.

The greatest differences in monthly PET and rainfall occurred in the months of April, May, and July, when PET exceeded rainfall by 2.4, 4.0, and 2.1 inches, respectively. Rainfall was comparable to PET for the months of August and September, and rainfall exceeded PET in June, November, and December 2006 and January and February 2007. November and December had the greatest differences, with rainfall exceeding PET by 1.7 and 2.0 inches, respectively. The rainfall total for the 12-month period was 36.8 inches, while the total PET was 40.9 inches.

Figure 46 shows cumulative rainfall and PET for the 12-month period along with cumulative changes in bay level (ΔWL_{Bay}). The plot shows that the cumulative PET was greater than the cumulative rainfall for the entire year. This behavior contrasts greatly with the 1963–1992 average monthly ET and rainfall data (Fig. 44) and suggests that this 12-month period is an atypical climate year. Large declines in the bay level from May through October 2006 (except June) are consistent with the greater slope of the cumulative PET curve over the rainfall curve during this period (Fig. 46). By November, the cumulative rainfall curve began to rise at a faster rate than PET, and correspondingly, water levels in the bay leveled off and rose slightly from October 2006 through February 2007. In March 2007, PET again was greater than the rainfall and the water level in the bay declined.

Monthly water budget components for the 12-month period are presented in Table 3. Estimated monthly PET values from the Hamon method, measured monthly rainfall (P), and measured monthly changes in bay level (ΔWL_{Bay}) were used in Equation 2 to calculate a residual component of the water budget. Since there were no apparent surface-water inputs to or outputs from the bay during this 12-month period, this residual provides information on the ground-water component of the water budget. Solving for the ground-water residual (GW) in Equation 2 gives

$$GW = \Delta WL_{Bay} - P + ET. \qquad (3)$$

Though Winter (1981) highlighted the need for caution when interpreting residuals as ground water, large monthly residuals, combined with information on lateral hydraulic gradients around the bay, suggest monthly net ground-water movement (Lide and others, 1995). Negative values in the ground water column of Table 3 denote that water is moving from the bay to the surrounding sediments. Changes in bay level, ΔWL_{Bay}, were determined by calculating the difference between the bay-level elevation at the beginning and end of each month. Several months did not have water-level measurements at the beginning and end days of each month,

Table 3. Monthly water budget components for DPB from April 2006 through March 2007

Month	PET (inches)	Rainfall (R) (inches)	R-PET (inches)	ΔWL_{Bay} (inches)	Ground water (GW) (inches)
April 2006	4.5	2.1	-2.4	-2.6	-0.2
May 2006	5.0	1.0	-4.0	-6.2	-2.2
June 2006	5.0	6.2	1.2	-0.2	-1.4
July 2006	5.2	3.1	-2.1	-5.0	-3.0
August 2006	4.6	4.5	-0.2	-2.6	-2.5
September 2006	3.5	3.5	0.1	-3.2	-3.3
October 2006	2.8	1.9	-0.9	-4.3	-3.4
November 2006	1.8	3.5	1.7	-0.7	-2.4
December 2006	1.7	3.7	2.0	1.1	-0.9
January 2007	1.6	2.8	1.1	0.4	-0.8
February 2007	1.7	2.5	0.9	0.5	-0.4
March 2007	3.6	2.1	-1.5	-1.9	-0.4
12-month total	40.9	36.8	-4.1	-25.1	-21.0

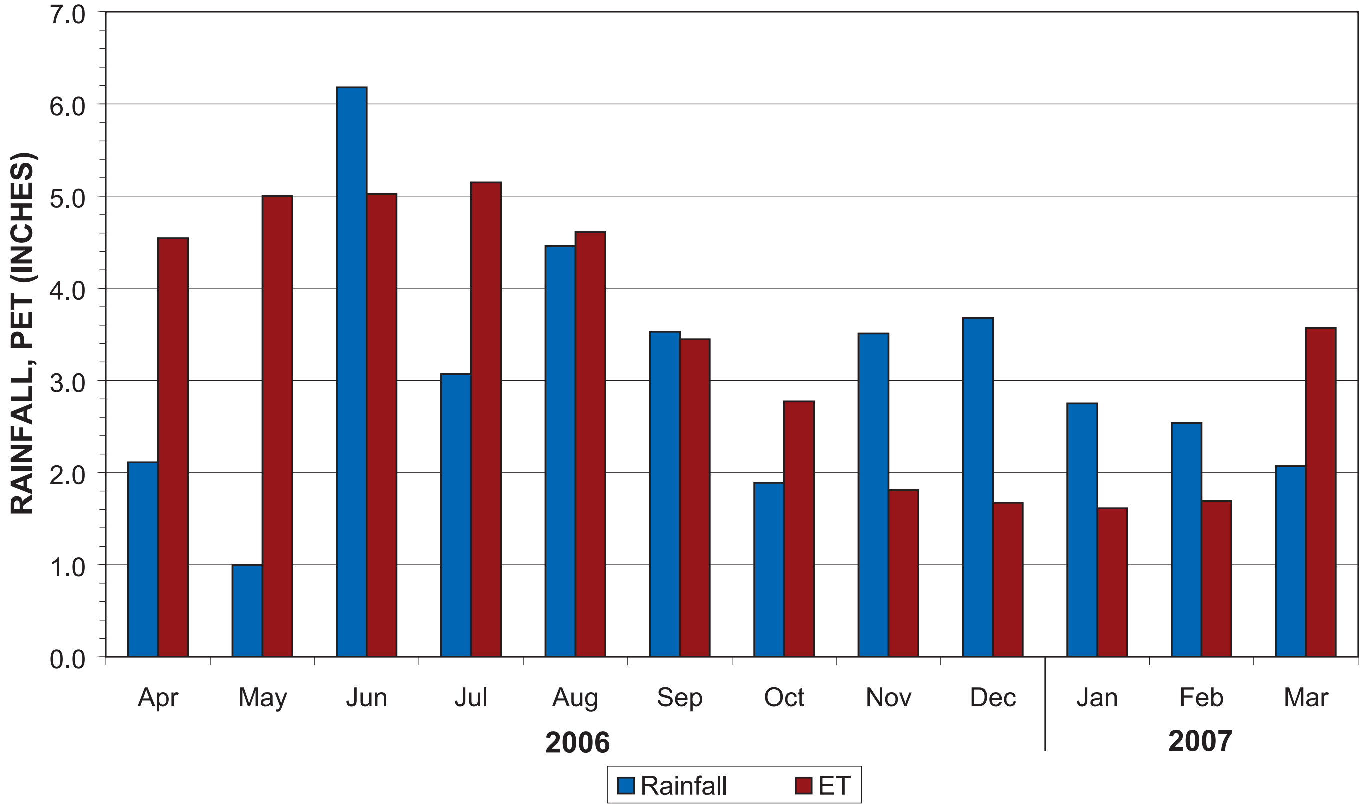


Figure 45. Monthly rainfall and PET at DPB for the period April 2006 through March 2007.

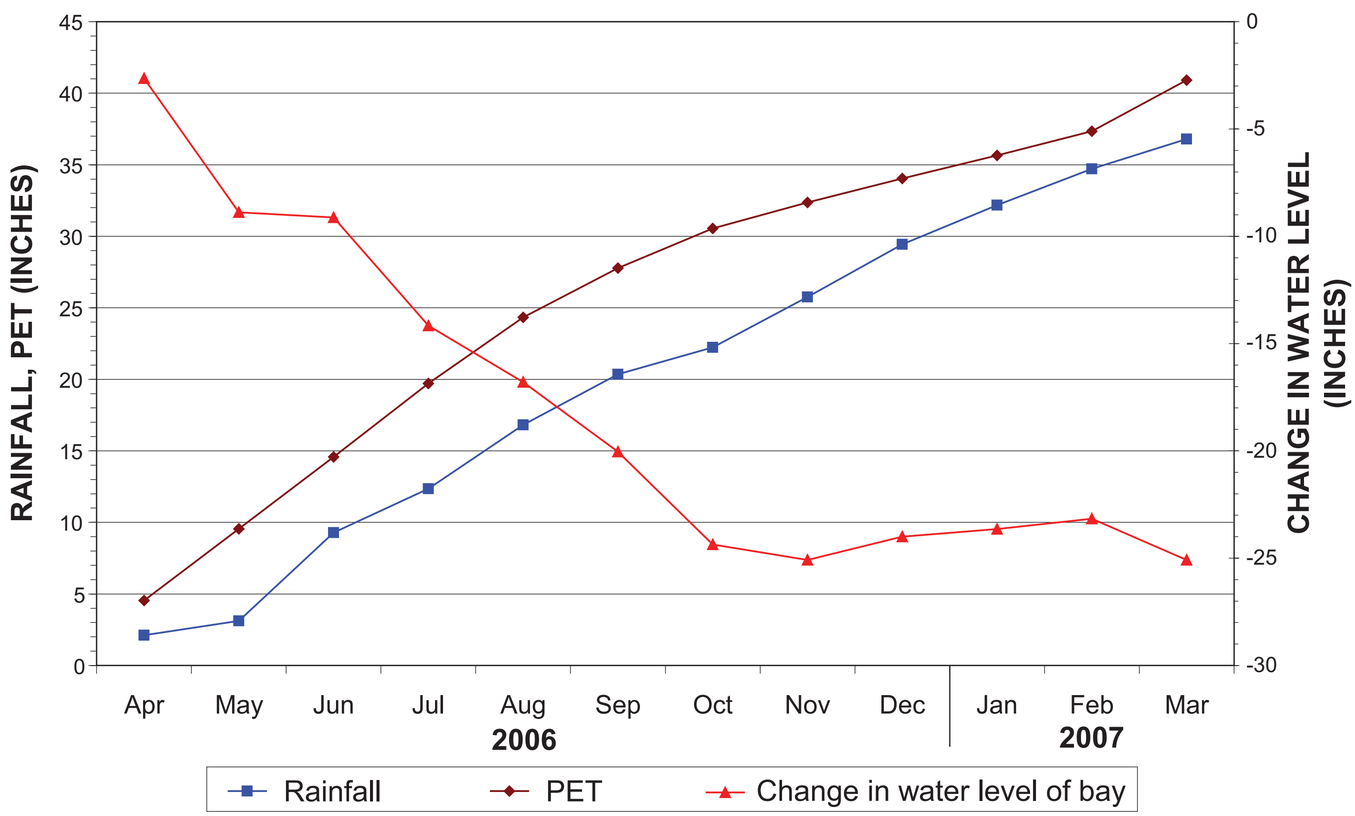


Figure 46. Cumulative rainfall, PET and change in water level at DPB for the period April 2006 through March 2007.

so water levels were extrapolated between measurement dates to estimate ΔWL_{Bay} values.

Although this simple water budget can be used to estimate the net monthly ground-water inflow or outflow component, relating the ground-water component to well water levels around the bay is challenging for several reasons. Most of the wells on site are monitoring water tables from which only lateral hydraulic gradients can be measured; however, seepage also has a vertical component that cannot readily be distinguished from the lateral component. Second, water-level measurements collected over the 12-month period show evidence for both ground-water recharge and discharge at different quadrants of the bay during the same time period.

Residuals calculated from the water-budget equation (Equation 3) suggest that ground water is a significant component of the water budget. For each month, the water-budget calculations resulted in a net ground-water outflow component. The ground-water component also exhibited two distinct behaviors. Water losses from the bay to ground water ranged from 1.4 to 3.4 inches for the period from May through November 2006, whereas ground-water losses were less than 1.0 inch for the period from December 2006 through March 2007. The large ground-water losses from May through November 2006 occurred during a period of general water-table decline around the bay caused by below-normal rainfall and increased ET rates. Many of the perimeter wells (DP2, DP4, DP5, DP11, and DP13) had water levels consistently below the bay level during this period, providing evidence for water outflow from the bay. The small losses observed from December 2006 through February 2007 were concurrent with a rewetting phase, in which the water table surrounding the bay rose. Total ground-water losses, as estimated from the water budget, were approximately 21 inches for the 12-month period.

The largest declines in bay level occurred in May (-6.2 inches), July (-5.0 inches), and October (-4.3 inches). Two of these months, May and July, experienced two of the largest monthly differences between rainfall and PET with values of -4.0 inches and -2.1 inches, respectively. The large decline observed in October, in which the difference between rainfall and PET was less than 1 inch, was probably due to ground-water outflow, which is consistent with the relatively large lateral hydraulic gradients measured between the bay and the perimeter wells (except for DP16) during this month. April had the second largest difference between rainfall and PET (-2.4 inches) and had a small calculated ground-water component (-0.2 inches). High water tables during April, which were among the highest of the study period, may have contributed to the small ground-water component by limiting lateral hydraulic gradients away from the bay.

Ditch Characterization

The top of the large plug in the DPB ditch (Fig. 2) has a surface elevation of 354.0 ft. The highest recorded water elevations in DPB during the study period occurred after a 2.6-inch rainfall event on March 21, 2006, when levels reached 352.8 ft; and therefore, recorded water levels have remained at least 1.2 ft below the plug elevation during the study period. Since the automatic water-level recorder was not installed in the bay until July, hourly data were not available for the spring and early summer. Bay elevations may have temporarily exceeded the highest measured elevation in March (352.8 ft), but the maximum elevation the bay reached is unknown. It is likely, however, that no direct surface drainage from DPB occurred through this ditch during the period from March 17, 2006, to March 31, 2007.

Visual observations of ponded water in the section of the ditch between the bay and the plug show that this ponded water is simply an extension of the bay. Directly north of the plug, on the downstream side, little to no standing water has been observed even when ponded water was observed on the upstream side. In contrast to the WPB ditch (see below), there appeared to be no surface flow through any section of the DPB ditch after the large rain events on March 21, 2006, June 13–14, 2006, and March 1–2, 2007. The study site has also experienced below-normal rainfall since data collection began in March 2006, and water levels are probably below normal. Additional water-level data obtained during more normal and wet conditions are needed to assess the impact of this ditch on any surface-water drainage from the bay or the impact of the ditch on the water-table regime between the bay and the outlet culvert. Specifically, the question of how often water elevations in the bay exceed the elevation of this plug needs to be addressed.

A surface elevation was measured in the WPB ditch along the profile, P2-P2′, which is approximately its closest distance (450 ft) to the edge of DPB. The ground elevation of the bottom of this ditch was 352.6 ft, which is only a few tenths of a foot lower than the maximum observed water level in DPB since mid-March 2006. The bed elevation of this ditch is also more than 4 ft higher than the lowest bed elevation of the bay, which suggests that the WPB ditch does not cause direct seepage from DPB. During the fall and early winter of 2006, no water was observed in the WPB ditch, and the water table was below the bottom of the ditch. This ditch, however, may drain the local water table along the northwest side of the bay during wetter periods. This drainage may limit the magnitude of hydraulic gradients toward DPB, and thus reduce ground-water discharge to the bay that otherwise may occur. There is little evidence that the WPB ditch has affected the water levels in DPB during the relatively dry 12-month study period from April 2006 through March 2007. More data are needed in this area during higher water-table conditions to assess the ditch's impact on the local water table.

Though DP15 and DP16 (along profile P2-P2′) have had higher water-level elevations compared to other areas of the bay, the WPB ditch along this profile remained dry from late September through mid-February. This suggests that the ditch has had little effect on the local water table during this period as water tables have remained below the bed of the ditch. By middle to late February, depressions in the ditch channel began to fill with water and water elevations were approximately the same as those in DP15. Small outflows were observed from the WPB ditch at the outlet culvert after the March 21, 2006, June 13–14, 2006, and March 1–2, 2007 rain events. For the March 2007 event, however, there was little to no flow observed at the WPB ditch along profile P2-P2′ (1,200 ft upstream of the culvert) even though the ditch held nearly 6 inches of standing water. Surface flow through the WPB ditch is impeded due to fallen debris, vegetation, and localized depressions along much of the WPB ditch channel. There may be a threshold water level that must be reached before ditch outflow is unimpeded.

SUMMARY

Data on bay water levels, ground-water levels, and rainfall have been presented for just over a 12-month study period from mid-March 2006 through March 2007 at DPB. A preliminary monthly water budget has also been computed to assess the influence of ground water on water levels in the bay. Additional data have also been provided on the soil sediments in the bay-upland system, and a characterization of the ditches potentially influencing the hydrology of the bay has been presented. The water-level elevations in the bay-upland system measured through the 12-month study period have highlighted the complexity of understanding the interaction of ground water with the surface water of Carolina bays.

Measured rainfall at DPB from April 2006 through March 2007 was approximately 9.0 inches below the long-term average at the Blackville 3W weather station. The rainfall and water-elevation data can be divided into four general periods: 1) a wet period extending from mid-March through mid-April 2006; 2) a drying period from April through September 2006; 3) a dry period in October and November 2006; and 4) a rewetting period from December 2006 through March 2007. Though long-term data should be acquired to further refine the nature of these “hydrologic” phases, these distinctions are useful in describing the hydrology of the bay for this 12-month study period.

Highest bay water levels (352.8 ft) were observed in the wet period on March 23, 2006, and water elevations in installed wells (DP1–DP5, except DP3, which was approximately 1 ft below the bay) were above or near the bay. Water elevations in the installed wells remained near the bay through April, but began to markedly decrease in May due to increased ET rates and below-average rainfall. Water levels continued to generally decline through the summer and early fall (drying phase) despite temporary increases associated with large rain events on June 13–14, August 11–12, and September 14, 2006. Through much of the summer and early fall period, water levels in installed wells (except for DP1, DP6, DP15, and DP16) were below levels in the bay. During the dry phase in October and November 2006, well-water elevations were markedly below that of the bay (except for DP15 and DP16). The bay, during this period, appears perched above the surrounding water table, and this perching effect may be due, in part, to the low permeability of the loamy sediments lining the bed of the bay. The rewetting phase began in early December and continued through March 2007. This phase was characterized by substantial increases in nearly all well-water elevations despite the below-normal rainfall experienced at DPB from January through March 2007. The bay elevation during January and February 2007 increased only slightly (approximately 0.2 ft), however, and by the end of March had receded back to the dry conditions observed during November 2006.

Lateral hydraulic gradients have been calculated along four profiles across the bay-upland system (Figs. 31–34) and were somewhat variable in magnitude and direction over the study period. Negative gradients signify that conditions exist for the movement of ponded water in the bay to the surrounding ground water, while positive gradients suggest the movement of ground water into the bay. Data collected during the study period illustrate the complex temporal and spatial variability of surface water-ground water interactions at DPB.

Negative gradients were generally observed on the southern half of the bay during the drying and dry phases of the study period, with the largest gradients (2–3 percent) measured along the southwest quadrant. Small positive gradients were observed in the southeast (DP2) and southwest (DP4) quadrants during the wet period in March 2006. Small positive gradients (less than 1 percent) were also observed at DP17 (directly south of the bay) during much of the rewetting phase in the winter of 2007, while negative gradients, though smaller than measured in their dry and drying phases, remained between the bay and wells DP2 and DP4.

Consistent negative gradients have also been observed directly north of the bay even during the wet phase in March 2006 and suggest that this margin may consistently be a bay discharge area. Positive gradients have been measured in the northwest quadrant of the bay since measurements began in this area in mid-September 2006. These positive gradients, though small (less than 1 percent), show that this quadrant may be a source of ground-water inflow to the bay even during a dry period. Negative gradients were measured for most of the study period in the northeast quadrant (DP5) of the bay; however, these gradients never exceeded 0.5 percent. A very small positive gradient (much less than 1 percent) was observed temporarily during the wet period in late March 2006.

Vertical hydraulic gradients in a downward direction were observed in the southwest margin of the bay at piezometers DP11 and DP12. These gradients, which ranged from 2 to 5 percent during the study period, suggest water seepage from the surficial sandy layer to the deeper sandy clay loam layer; however, along the western margin, a similar piezometer cluster (wells DP13 and DP14) had negligible gradients for much of the study period.

Water levels in wells DP1 and DP6 were highly variable through the 12-month study period and had strong responses to large rainfall events. Water levels typically rose 3–4 ft after large rainfall events of 1.0 inch or more. Data from two piezometers installed adjacent to DP1 (DP19 and DP20) show that a sandy clay layer approximately 10 ft below ground surface may be semi-impermeable, which creates a temporary and localized perched water-table condition. This perched condition is also believed to be occurring at DP6, which has a similar soil profile as DP1. Water elevations at DP1 and DP6, which are located in open areas with little vegetation, also contrasted with those of other upland wells (DP7, DP8, and DP10) located in forested areas. Wells DP7, DP8, and DP10 had much smaller responses to rainfall events during the summer and early fall, which is likely to be due to the increased ET rates at these wells.

The preliminary water budget provides further evidence of bay discharge to the surrounding ground water. For each month from April 2006 through March 2007, water-budget computations indicated a net ground-water loss from the bay. Despite the potential errors associated with estimating PET, the large magnitude of the ground-water component for many of these months suggests that ground water seepage is an important component of DPB's water budget. The ground-water loss is somewhat consistent with the negative lateral and vertical hydraulic gradients measured along much of the bay's margins during most of the study period. Water-budget results also show no evidence for a net monthly ground-water inflow to the bay from April 2006 through March 2007, despite the existence of positive hydraulic gradients measured between the bay and wells DP15–17 during the dry and rewetting periods of the study. Owing to the below-normal rainfall at the site over the 12-month study period, however, the lack of ground-water inflow may be expected, and additional data collected over wetter conditions is needed to better understand the ground-water component.

The ground-surface elevation of a large plug in the DPB ditch, approximately 150 ft from the edge of the bay, is 1.2 ft higher than the maximum bay level recorded during the 12-month study period. Ponded water was observed in the ditch upstream of the plug during the wet period in March and April, and this section of the ditch appears to be an extension of the bay. Very little ponded water has been observed in the DPB ditch downstream of this plug for the entire study period, including the wet period in March and April, and it is likely that very little to no surface outflow through this ditch has occurred.

Bed elevations in the WPB ditch measured along profile P2-P2′ are only about 0.2 ft below the maximum bay water-level elevation measured over the entire study period (352.8 ft) and are more than four feet higher than the lowest observed bed elevation in the bay. The section of the ditch along this profile is approximately the closest distance of DPB to the WPB ditch (450 ft), and the bed elevations suggest that the WPB ditch has little to no effect on the water levels in DPB. In addition, water table measurements at DP15 and DP16, both located along profile P2-P2′ between DPB and the WPB ditch, have remained above the level of the bay from September 2006 through March 2007. The WPB ditch had no standing water from September 2006 through January 2007 along this section, and though ponded water began to appear in early February 2007, there was little evidence of any surface flow through this section.

For much of the study period, however, Aiken and Barnwell Counties experienced below-normal rainfall conditions in 2006 and early 2007. The rainfall measured at DPB for the 12-month study period is 9.0 inches below the long-term average measured at the Blackville 3W station located approximately 10 miles from DPB. This has more than likely resulted in below-normal bay levels and surrounding water-table levels. As a result, water-table levels for much of the study period have been below the bottom of both the DPB ditch and WPB ditches, and bay levels have remained well below the top of the DPB plug. Therefore, the potential influence of both of these ditches, if any, on the water level in DPB and in the surrounding water table has been difficult to fully assess.

RECOMMENDED FURTHER STUDY

Although the DPB and WPB ditches appear to have had little impact on the water levels in DPB during this 12-month period, a more complete description of the hydrology of DPB must include the collection of long-term data that includes wetter periods with normal to above-normal rainfall. These data must be collected before any final conclusions can be made on the hydrologic disturbance of DPB and before any potential restoration strategies could be recommended and implemented. Several specific questions need to be addressed:

1) How frequently, if ever, do bay elevations exceed the surface elevation of the DPB plug?

2) During wetter-than-normal conditions north-northwest of the bay, what effects do the WPB and DPB ditches have on the local water table, and do these effects have an influence on the water levels in the bay?

3) During wetter conditions, is there a significant ground-water inflow component to the bay's water budget?

The main objectives of further study will include the long-term monitoring of the site (at least 1 or 2 years), which should include wetter hydrologic conditions, and a final assessment of the degree of hydrologic disturbance. Rainfall, temperature, and automatic water-level data in the bay and the three selected wells (DP1, DP3, and DP15) should be collected at the site over the next 1 to 2 years. Measurements in the remaining 17 wells should be made on a biweekly basis, and the need for additional wells should be evaluated to fill in any significant gaps in the ground-water data. These long-term data can be used to answer the questions posed above, and to compute a long-term water budget. Lastly, any recommendation of potential restoration needs and strategies, based on the analysis of long-term data, should be developed during the final phase of the study.

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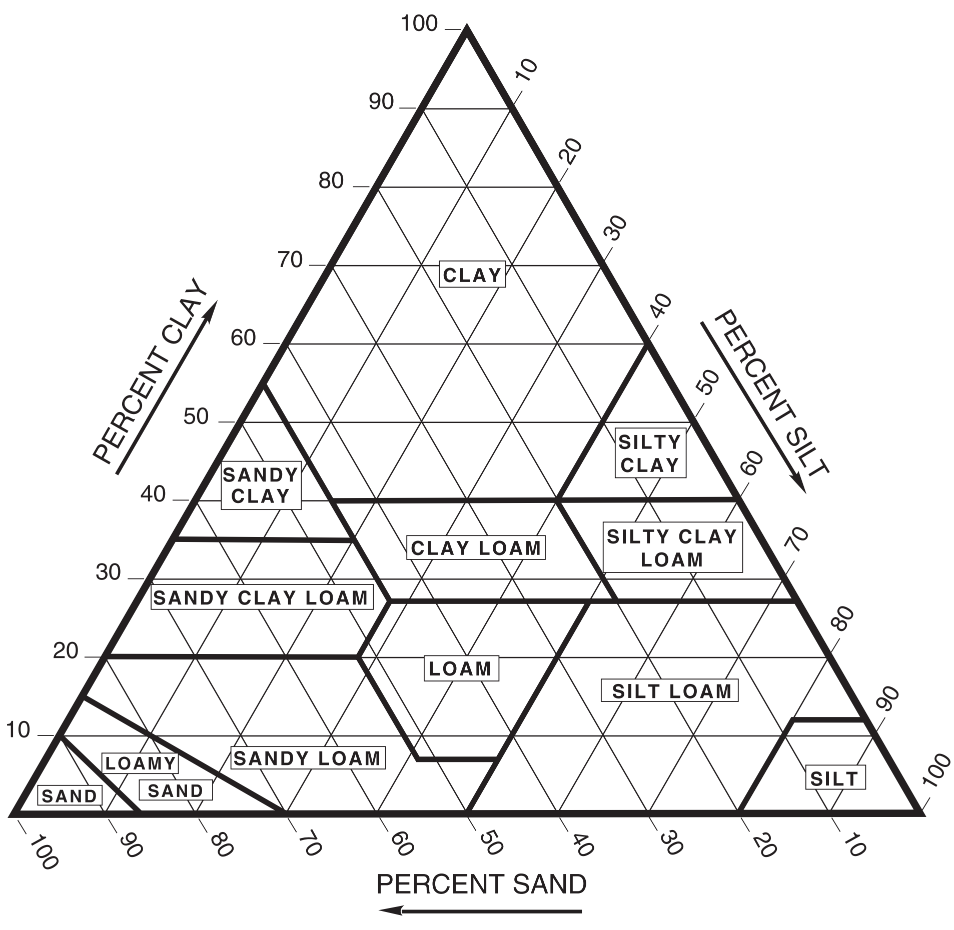
Appendix I

Analysis of soil samples collected from wells DP10-DP20 and at two sites in DPB

Soil descriptions from boreholes at wells DP1-DP9 can be found in Open-File Report 11 (Harder and others, 2006)

Soil texture for each sample was analyzed by feel based on a method by Thien (1979) from which percentages of sand, silt, and clay were estimated. From these percentages each sample was classified as one of the soil groups shown in the figure below. Soil colors were reported by using the Rock-Color Chart, and any mottling or redox concentrations (areas of highly oxidized material) were described. The Rock-Color Chart uses the Munsell color system and is available from the Geological Society of America, P.O. Box 9140, Boulder, CO 80301. Grain sizes were also reported for any sand, granules, and pebbles found in a sample, as well as their degree of sorting.

Wells DP19 and DP20 were assumed to have a similar profile as described at DP1, which is located within 8 ft of these two wells. Similarly, DP11 was assumed to have the same profile as DP12 (installed within 6 ft of DP11), and DP14 was assumed to have the same profile as DP13 (installed within 6 ft of DP14).



Well: DP10		Described by: S. Harder			Date: 9/26/06	
Depth (ft)	**Lithology**	**Grain size**	**Sorting**	**Minerology**	**Color**	**Remarks**
surface	sandy loam 15% clay	f-vc, few small granules	vp - p		dark yellowish brown (10YR 4/2)	roots common
1.3	loamy sand 10-15% clay	f-vc, few granules, subrounded to subangular	vp	rare	moderate yellowish brown (10YR 5/4)	
2.1	loamy sand 10-15% clay	f-vc, few granules, subrounded to subangular, medium sand dominant	vp	trace	dark yellowish orange (10YR 6/6)	sand grains are iron coated; few roots
3.6	loamy sand 10-15% clay	f-vc, subrounded to subangular	vp	trace	dark yellowish orange (10YR 6/6)	sand grains are iron coated
5.3	loamy sand to sand 5-10% clay	f-vc, few to no granules, subrounded to subangular, medium sand dominant		trace	white to very light gray (N9–N8)	very “clean”
6.5	loamy sand 10-15% clay	f-vc, few granules, subrounded to subangular	p	trace	dark yellowish brown (10YR 4/2)	
7.6	sandy loam 15% clay	f-vc, few granules, subrounded to subangular	vp		dusky yellowish brown (10YR 2/2)	

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: DP10		Described by: S. Harder			Date: 9/26/06	
Depth (ft)	**Lithology**	**Grain size**	**Sorting**	**Minerology**	**Color**	**Remarks**
8.5	sandy loam 15% clay	f-vc, few granules, medium sand dominant				
9.1	sandy loam to loamy sand 10-15% clay	f-vc, few granules, medium sand dominant	p	rare	dark yellowish brown (10YR 4/2)	
9.8	loamy sand 10-15% clay	f-vc, few granules, medium sand dominant	p	rare	pale yellowish brown (10YR 6/2)	
10.3	sandy loam 15% clay	f-vc, few granules, medium sand dominant	p	rare	dark yellowish brown (10YR 4/2)	
10.9	sandy clay loam 20-30% clay	fine to medium sand dominant, few granules			light gray (N7)	dark yellowish orange mottles (common)
11.7	sandy clay loam 25-35% clay	fine to medium sand dominant, few granules			light gray (N7)	light brown mottles (common)
12.2	sandy clay loam 25-35% clay	medium sand dominant, few pebbles (0.5 cm)			light gray (N7)	dark yellowish orange mottles (common), light brown mottles (few)

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: DP10			Described by: S. Harder		Date: 9/26/06	
Depth (ft)	**Lithology**	**Grain size**	**Sorting**	**Minerology**	**Color**	**Remarks**
12.7	sandy clay loam 25-30% clay	medium sand dominant, few granules			very light gray to light gray (N8–N7) mixed with heavy dark yellowish orange mottles	dark yellowish orange mottles (very common)
13.9	sandy clay loam 30-35% clay	granules common, few pebbles (up to 1.5 cm)			very light gray (N8) mixed with heavy dark yellowish orange mottles	dark yellowish orange mottles (common), dark and moderate reddish brown mottles (few)
14.9	sandy clay loam 30-35% clay	medium to coarse sand dominant, few granules			very light gray (N8) mixed with heavy dark yellowish orange and moderate reddish brown mottles	dark yellowish orange mottles (common), moderate reddish brown mottles (common)
15.9	sandy clay loam 30-35% clay	sand is less coarse, no granules			very light gray (N8)	less mottling, moderate red mottles (few), dark yellowish orange mottles (few), dark reddish brown mottles (few)
16.8	sandy clay loam 30-35% clay	sand is less coarse, no granules			very light gray (N8)	less mottling, moderate red mottles (few), dark yellowish orange mottles (few), dark reddish brown mottles (few)
17.7	sandy clay loam 30-35% clay	medium to coarse sand dominant, no granules or pebbles			very light gray (N8)	brown mottles (few), yellowish orange mottles (few)
18.7	sandy clay loam 30-35% clay	sand is more coarse, few granules			very light gray (N8)	mottles increase, grayish orange mottles (few), dark yellowish orange mottles (few), red and reddish brown mottles (few)

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: DP12 Described by: S. Harder Date: 9/27/06

Depth (ft)	Lithology	Grain size	Sorting	Minerology	Color	Remarks
surface	loam, organic	very little sand, silty			brownish black (5YR 2/1)	roots common, organic
0.7	loam to sandy loam 15-20% clay	fine sand dominant			grayish black (N2)	few roots
1.2	sandy loam 15% clay	fine sand dominant, few more coarser grains			grayish black (N2)	
1.8	sandy loam 15-20% clay	fine sand dominant, few coarse to very coarse grains			dusky yellowish brown (10YR 2/2)	
2.3	loamy sand 10-15% clay	f-c, fine to medium sand dominant	vp		dusky yellowish brown (10YR 2/2)	
3.1	loamy sand 10-15% clay	f-vc, fine to medium sand dominant	vp		light browish gray (5YR 6/1)	
3.8	loamy sand 10% clay	f-vc, fine to medium sand dominant	p	trace	pale yellowish brown (10YR 6/2)	

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: DP12 Described by: S. Harder Date: 9/27/06

Depth (ft)	Lithology	Grain size	Sorting	Minerology	Color	Remarks
4.4	loamy sand 10% clay	f-vc, fine to medium sand dominant, few granules, pebble (0.7 cm)	p	trace	yellowish gray (5YR 7/2)	
5.1	sandy loam to sandy clay loam 20-25% clay	f-vc, medium sand dominant, granules more common, few pebbles (0.5–0.7 cm)	vp	trace	yellowish gray (5YR 7/2)	
5.7	sandy clay loam 20-25% clay	f-vc, coarser than above, pebbles more common (up to 1.0 cm)			yellowish gray (5YR 7/2)	
6.3	sandy clay loam 20-25% clay	f-vc, coarser than above, pebbles more common			yellowish gray (5YR 7/2) to light gray (N7)	
7.2	sandy clay loam 25-30% clay	increase in clay, coarse sand common, few pebbles (less than 1.0 cm)			white to light gray (N9–N7)	light brown mottles (few)
8.4	sandy clay loam 25-30% clay	less coarse than above, fewer granules and pebbles			white to light gray (N9–N7)	light brown mottles (few)
9.0	sandy clay loam 25-30% clay	less coarse than above, fewer granules, no pebbles			white to light gray (N9–N7)	light brown mottles (few and faint)

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: DP12		Described by: S. Harder			Date: 9/27/06	
Depth (ft)	**Lithology**	**Grain size**	**Sorting**	**Minerology**	**Color**	**Remarks**
9.8	sandy clay loam to clay loam 25-30% clay	medium sand dominant, few coarse grains, no granules or pebbles		mica common	white to light gray (N9–N7)	brown mottles (few)
10.2	sandy clay loam to clay loam 25-30% clay	medium sand dominant, few coarse grains, no granules or pebbles			white to light gray (N9–N7)	brown mottles (few)

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: DP13			Described by: S. Harder		Date: 10/3/06	
Depth (ft)	**Lithology**	**Grain size**	**Sorting**	**Minerology**	**Color**	**Remarks**
surface	loam, organic	fine to medium sand dominant			brownish black (5YR 2/1)	roots common, organic
0.6	sandy loam 15-20% clay	fine to medium sand dominant, few coarse to very coarse grains			grayish black to black (N2–N1)	few roots
1.2	sandy loam 15-20% clay	fine to medium sand dominant, few coarse to very coarse grains			brownish black (5YR 2/1)	
1.7	loamy sand 10-15% clay	f-vc, sand is coarser than above			grayish black (N2)	
2.2	loamy sand 10-15% clay	f-vc, sand is coarser than above			grayish black (N2)	
2.7	loamy sand 10-15% clay	f-vc, medium sand dominant			browish gray (5YR 4/1)	
3.4	sandy loam 15-20% clay	increase in clay, medium sand dominant, few coarse grains			browish gray (5YR 4/1)	

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: DP13 Described by: S. Harder Date: 10/3/06

Depth (ft)	Lithology	Grain size	Sorting	Minerology	Color	Remarks
4.4	sandy loam to sandy clay loam 20% clay	increase in clay, medium sand dominant few coarse grains			light brownish gray (5YR 6/1)	
5.1	sandy loam 15-20% clay	medium sand dominant, few very coarse grains, pebble (1.0 cm)			light gray (N7)	
5.7	sandy loam 15-20% clay	medium sand dominant, few very coarse grains			pale yellowish brown (10YR 6/2)	
6.3	sandy loam 15-20% clay	medium sand dominant, few very coarse grains, pebble (1.0 cm)			pale yellowish brown (10YR 6/2)	
6.8	sandy clay loam 25-30% clay	medium sand dominant, few granules, few very coarse grains			light gray (N7)	
7.6	sandy clay loam 30-35% clay	increase in clay, few granules, few very coarse grains, pebble (0.6 cm)			light gray (N7)	
7.9	sandy clay loam 30-35% clay	few granules, few very coarse grains			light gray (N7)	

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: DP13 Described by: S. Harder Date: 10/3/06

Depth (ft)	Lithology	Grain size	Sorting	Minerology	Color	Remarks
8.3	sandy clay 35-40% clay	increase in clay, few granules, few very coarse grains			light gray (N7)	some portions of sample are very firm, brown mottles (few and faint)
8.7	sandy clay 35-45% clay	increase in clay, few granules, few very coarse grains			light gray (N7)	
9.1	sandy clay 40-45% clay	medium to coarse sand dominant, few very coarse grains			grayish orange (10YR 7/6)	dark yellowish orange mottles (few)
9.4	sandy clay 40-50% clay	medium to coarse sand dominant, few very coarse grains			yellowish gray (5YR 7/2)	dark yellowish orange mottles (few)
9.9	sandy clay 40-50% clay	granules increase, medium to coarse sand dominant, pebble (0.5 cm)			yellowish gray (5YR 7/2)	brown mottles (few and faint)
10.3	sandy clay 40-50% clay	sand less coarse			yellowish gray (5YR 7/2)	brown mottles (few and faint)

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: DP15 Described by: S. Harder Date: 10/10/06

Depth (ft)	Lithology	Grain size	Sorting	Minerology	Color	Remarks
surface	sandy loam 15% clay	vf-c, fine to medium sand dominant	p		dusky yellowish brown (10YR 2/2)	fine and coarse roots common
0.5	sandy loam 15% clay	vf-c, fine to medium sand dominant	p		dusky yellowish brown (10YR 2/2)	few roots
0.9	loamy sand 10-15% clay	vf-c, fine to medium sand dominant	p - mod		dark yellowish brown (10YR 4/2)	
1.3	sandy loam to loamy sand 15% clay	vf-c, fine to medium sand dominant, few more coarse grains than above	p		dark yellowish brown (10YR 4/2)	
1.8	sandy loam to loamy sand 15% clay	f-c, fine to medium sand dominant	p		dark yellowish brown (10YR 4/2)	
2.3	sandy loam to loamy sand 15% clay	f-c, fine to medium sand dominant	p		pale yellowish brown (10YR 6/2)	
2.8	sandy loam 15% clay	f-c, fine to medium sand dominant, coarse grains more common			pale yellowish brown (10YR 6/2)	

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: DP15 Described by: S. Harder Date: 10/10/06

Depth (ft)	Lithology	Grain size	Sorting	Minerology	Color	Remarks
3.3	sandy loam to loamy sand 15% clay	f-vc, fine to medium sand dominant	p - mod		pale yellowish brown (10YR 6/2)	
3.9	loamy sand 10-15% clay	f-c, fine to medium sand dominant	p		dark yellowish brown (10YR 4/2)	
4.5	loamy sand 10-15% clay	f-c, fine to medium sand dominant	p		dark yellowish brown (10YR 4/2)	
4.9	loamy sand to sandy loam 15% clay	f-c, fine to medium sand dominant	p		dark yellowish brown (10YR 4/2)	
5.4	sandy loam 15% clay	f-c, fine to medium sand dominant	p		dusky yellowish brown (10YR 2/2)	
5.9	sandy loam 15-20% clay	small increase in clay, fine to medium sand dominant			dusky yellowish brown (10YR 2/2)	
6.9	sandy loam 15% clay	small decrease in clay, fine to medium sand dominant			grayish black (N2)	

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: DP15 Described by: S. Harder Date: 10/10/06

Depth (ft)	Lithology	Grain size	Sorting	Minerology	Color	Remarks
7.8	sandy loam to loamy sand 15% clay	fine to medium sand dominant, few more coarse grains			grayish black (N2)	
8.2	sandy loam to loamy sand 15% clay	fine to medium sand dominant, few more coarse grains			grayish black (N2)	
8.7	sandy loam 15% clay	f-vc, fine to medium sand dominant, few more coarse grains	p - vp		dusky yellowish brown (10YR 2/2)	
9.5	sandy loam 15% clay	f-vc, fine to medium sand dominant, few more coarse grains	p - vp		dusky yellowish brown (10YR 2/2)	
10.1	sandy loam 15% clay	f-vc, fine to medium sand dominant, few more coarse grains	p - vp		dusky yellowish brown (10YR 2/2)	
10.7	sandy loam 15% clay	f-vc, fine to medium sand dominant, few more coarse grains	p - vp		dusky yellowish brown (10YR 2/2)	
11.5	sandy loam 15% clay	f-vc, fine to medium sand dominant, few more coarse grains	p - vp		dusky yellowish brown (10YR 2/2)	

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: DP15		Described by: S. Harder			Date: 10/10/06	
Depth (ft)	**Lithology**	**Grain size**	**Sorting**	**Minerology**	**Color**	**Remarks**
11.8	loamy sand to sandy loam 15% clay	f-c, fine to medium sand dominant	p - vp		brownish gray (5YR 4/1)	
12.1	loamy sand to loamy sand 15% clay	f-c, fine to medium sand dominant			brownish gray (5YR 4/1)	
12.6	loamy sand 10-15% clay	f-vc, decrease in clay, few granules	vp		white to medium light gray (N9–N6)	
13.2	sandy loam to loamy sand 15% clay				pale yellowish brown (10YR 6/2)	
13.9	sandy clay loam 25-30% clay	f-vc, increase in clay, fine to medium sand dominant, few granules, pebble (0.5 cm)			very light gray (N8) mixed with brownish gray (5YR 4/1)	
14.5	sandy clay loam 25-30% clay	fine to medium sand dominant, fewer coarser grains			light gray (N7)	medium gray mottles (few), brown mottles (few and faint)
14.9	sandy clay loam to sandy clay 30-40% clay	f-c, increase in clay, medium sand dominant			light to very light gray (N8–N7)	

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: DP16 Described by: S. Harder Date: 10/11/06

Depth (ft)	Lithology	Grain size	Sorting	Minerology	Color	Remarks
surface	loam 15-25% clay	vf-c, fine to medium sand dominant			dusky brown (5YR 2/2)	roots common
0.5	loam to clay loam 20-30% clay	vf-m			black to brownish black (N1–5YR 2/1)	fine to large roots common
1.4	loamy sand to sandy loam 15% clay	f-c, decrease in clay, fine to medium sand dominant			brownish black (5YR 2/1)	
2.0	loamy sand 10-15% clay	f-c, decrease in clay, fine to medium sand dominant			dark to dusky yellowish brown (10YR 4/2–2/2)	
2.5	sandy loam to loamy sand 15% clay	f-c, fine to medium sand dominant, coarse grains increase			dark yellowish brown (10YR 4/2)	
3.2	sandy loam to loamy sand 15% clay	f-vc, fine to medium sand dominant, few granules, increase in coarser grains	p		dark yellowish brown (10YR 4/2)	
3.9	sandy loam to loamy sand 15% clay	f-vc, medium sand dominant, few granules, increase in coarser grains			dark yellowish brown (10YR 4/2)	

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: DP16 Described by: S. Harder Date: 10/11/06

Depth (ft)	Lithology	Grain size	Sorting	Minerology	Color	Remarks
4.3	sandy loam to loamy sand 15% clay	f-vc, fine to medium sand dominant, few granules, increase in coarser grains			dark yellowish brown (10YR 4/2)	
5.3	sandy loam to loamy sand 15% clay	f-c, medium sand dominant			dark yellowish brown (10YR 4/2)	
6.8	loamy sand 10-15% clay	f-vc, medium sand dominant, more coarse to very coarse grains	p - vp	trace, feldspar	light brownish gray (5YR 6/1)	
7.9	sandy loam 15-20% clay	f-vc, increase in clay, medium sand dominant, few granules			pale yellowish brown (10YR 6/2)	
8.4	sandy loam 15-20% clay	f-vc, medium sand dominant, few granules			pale yellowish brown (10YR 6/2)	
9.0	sandy clay loam 25-30% clay	f-vc, medium sand dominant, increase in clay			pale yellowish brown (10YR 6/2)	
9.3	sandy clay loam 25-30% clay	f-vc, medium sand dominant			pale yellowish brown (10YR 6/2)	

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: DP16 Described by: S. Harder Date: 10/11/06

Depth (ft)	Lithology	Grain size	Sorting	Minerology	Color	Remarks
9.6	sandy clay loam 30-35% clay	f-c, medium sand dominant, small increase in clay			pale yellowish brown (10YR 6/2)	
10.0	sandy clay loam 30-35% clay	f-vc, medium sand dominant, coarse grains more common			pale yellowish brown (10YR 6/2)	dark yellowish orange mottles (few)
10.5	sandy clay loam 25-30% clay	increase in sand, medium sand dominant, coarse sand more common			pale yellowish brown (10YR 6/2)	
10.9	sandy clay loam 25-30% clay	medium sand dominant			light gray (N7)	dark yellowish orange mottles (common)
11.2	sandy clay loam 25-30% clay	medium sand dominant			light gray (N7)	

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: DP17 Described by: S. Harder Date: 10/11/06

Depth (ft)	Lithology	Grain size	Sorting	Minerology	Color	Remarks
surface	loam 10-25% clay	f-m			dusky brown (5YR 2/2)	many fine roots
0.5	sandy loam 15-20% clay	f-c, fine to medium sand dominant	mod		dusky yellowish brown (10YR 2/2)	few fine roots
1.1	sandy loam 15-20% clay	f-vc, fine to medium sand dominant			grayish black (N2)	
1.6	loamy sand to sandy loam 15% clay	f-vc, decrease in clay, fine to medium sand dominant, coarse and very coarse sand more common, few granules	p		brownish black (5YR 2/1)	
2.2	loamy sand to sandy loam 15% clay	f-c, fine to medium sand dominant			dark yellowish brown (10YR 4/2)	
2.8	loamy sand to sandy loam 15% clay	f-vc, fine to medium sand dominant, few granules, pebble (1.0 cm)	p		pale yellowish brown (10YR 6/2)	
3.4	sandy loam 15-20% clay	f-vc, granules/pebbles more common	vp		pale yellowish brown (10YR 6/2)	

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: DP17 Described by: S. Harder Date: 10/11/06

Depth (ft)	Lithology	Grain size	Sorting	Minerology	Color	Remarks
3.8	sandy clay loam 25-35% clay	increase in clay, coarse sand more common, few granules, few pebbles			pale yellowish brown (10YR 6/2)	
4.2	sandy clay 35-40% clay	coarse and very coarse sand common, few granules			pale yellowish brown (10YR 6/2)	
5.0	sandy clay to sandy clay loam 30-40% clay	very coarse sand common to abundant, granules common, few pebbles (less than 1.0 cm)			mix of light gray (N7) and pale yellowish brown (10YR 6/2)	
5.9	sandy clay 35-45% clay	very coarse sand common to abundant, granules common, few pebbles (less than 1.0 cm)			mix of very light gray (N8) and dark yellowish orange (10YR 6/6)	dark yellowish orange mottles (abundant)
6.7	sandy clay 35-45% clay	very coarse sand common to abundant, granules common, few pebbles (up to 2.5 cm)			mix of very light gray (N8) and dark yellowish orange (10YR 6/6)	dark yellowish orange mottles (abundant), friable
7.5	sandy clay 35-45% clay	very coarse sand common to abundant, granules common, few pebbles			mix of very light gray (N8) and dark yellowish orange (10YR 6/6)	dark yellowish orange mottles (abundant), light brown mottles (common)
8.5	sandy clay 35-45% clay	very coarse sand common to abundant, granules common, pebbles more common (up to 2.5 cm)			mix of very light gray (N8) and dark yellowish orange (10YR 6/6)	dark yellowish orange mottles (abundant), light brown mottles (common)

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: DP17 Described by: S. Harder Date: 10/11/06

Depth (ft)	Lithology	Grain size	Sorting	Minerology	Color	Remarks
9.1	clay > 50% clay	increase in clay, less sand, some pockets of coarse sandy clay			mix of very light gray (N8) and dark yellowish orange (10YR 6/6)	
10.0	sandy clay 35-40% clay	very coarse sand common to abundant, granules common, few pebbles (up to 3.8 cm)			dark yellowish orange (10YR 6/6)	
10.8	sandy clay 35-45% clay	coarse and very coarse sand common, fewer granules and pebbles			mix of light gray (N7) and dark yellowish orange (10YR 6/6)	
11.5	sandy clay to sandy clay loam 30-40% clay	coarse and very coarse sand common, fewer granules and pebbles			dark yellowish orange (10YR 6/6)	
12.2	sandy clay to sandy clay loam 30-40% clay	less coarse and very coarse sand, few granules		mica	dark yellowish orange (10YR 6/6) and light gray (N7)	
12.8	sandy clay to sandy clay loam 30-40% clay	less coarse and very coarse sand, few granules, few small pebbles		mica	dark yellowish orange (10YR 6/6) and light gray (N7)	
13.3	sandy clay to sandy clay loam 30-40% clay	less coarse and very coarse sand, few granules, few small pebbles			dark yellowish orange (10YR 6/6) and light gray (N7)	

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: DP18 Described by: S. Harder Date: 4/10/07

Depth (ft)	Lithology	Grain size	Sorting	Minerology	Color	Remarks
surface	loam	vf-c, fine to medium sand dominant	p		brownish black (5YR 2/1)	fine roots common, organic
0.5	loamy sand 10-15% clay	vf-c, increase in sand, subangular, medium sand dominant	p		dusky yellowish brown (10YR 2/2)	few roots
1.3	loamy sand 10-15% clay	vf-vc, subrounded to subangular, fine to medium sand dominant	p		dark yellowish brown (10YR 4/2)	grains coated
2.2	loamy sand 10% clay	vf-c, slightly less clay, subrounded to subangular, fine to medium sand dominant	p		dark yellowish brown (10YR 4/2)	grains coated
3.0	loamy sand 10% clay	vf-c, subrounded to subangular, fine to medium sand dominant	p		pale yellowish brown (10YR 6/2)	clean
3.5	loamy sand 10% clay	vf-c, subrounded to subangular, fine sand dominant	p - mod		pale yellowish brown (10YR 6/2)	clean
4.5	loamy sand 10% clay	vf-c, subrounded to subangular, fine sand dominant	p - mod		pale yellowish brown (10YR 6/2)	clean

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: DP19 (15.0–18.2 ft) Described by: S. Harder Date: 6/5/07

Depth (ft)	Lithology	Grain size	Sorting	Minerology	Color	Remarks
15.0	sandy clay loam 25-30% clay	very coarse sand abundant, granules abundant, small pebbles common			reddish brown (10YR 5/4)	
16.2	sandy clay loam 25-30% clay	very coarse sand abundant, granules abundant, small pebbles common			mix of light brown (5YR 6/4), pale reddish brown (10YR 5/4), and very light gray (N8)	
16.9	sandy clay loam 30-35% clay				mix of light brown (5YR 6/4) and very light gray (N8)	
17.6	sandy clay loam 25-30% clay	small decrease in clay, very coarse sand abundant, granules abundant, small pebbles common			mix of light brown (5YR 6/4) and very light gray (N8), some pale reddish brown (10YR 5/4)	
18.2	sandy clay loam 25-30% clay	very coarse sand abundant, granules abundant, small pebbles common			pale to reddish brown (10YR 5/4 – 10YR 4/6) with some light brown (5YR 5/6)	

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: Bay 2 Described by: S. Harder Date: 12/12/06

Depth (ft)	Lithology	Grain size	Sorting	Minerology	Color	Remarks
surface	loam/organic	minor sand			brownish black (5YR 2/1)	many fine to medium roots, organic, maybe a silt loam
0.2	loam to loamy sand 15-20% clay	large increase in sand, fine to medium sand dominant, few coarse grains			brownish black (5YR 2/1)	fine roots common
0.2–0.4	sandy loam 15-20% clay	vf-c, subrounded to subangular	p		grayish black (N2)	some fine roots
0.4–0.6	sandy loam to loamy sand 15% clay	vf-m, decrease in clay	p		dusky yellowish brown (10YR 2/2)	few roots
0.6–0.8	sandy loam to loamy sand 15% clay	vf-c, subrounded to subangular, fine to medium sand dominant	p - mod		dark yellowish brown (10YR 4/2)	
2.0	loamy sand to sand 10% clay	vf-c, subrounded to subangular, fine to medium sand dominant	p - mod	trace	pale yellowish brown (10YR 6/2)	clean
3.0	loamy sand to sand 10% clay	vf-c, subrounded to subangular, fine to medium sand dominant	p - mod		white to very light gray (N9–N8)	clean

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: Bay 2 Described by: S. Harder Date: 12/12/06

Depth (ft)	Lithology	Grain size	Sorting	Minerology	Color	Remarks
4.4	loamy sand to sand 10% clay	vf-c, subrounded to subangular, fine to medium sand dominant	p - mod		pale yellowish brown (10YR 6/2)	clean
5.4	sandy loam 15% clay	vf-c, fine to medium sand dominant	p - vp		dark yellowish brown (10YR 4/2)	
5.6	sandy loam 15-20% clay	vf-c, fine to medium sand dominant, very few granules	p - vp		dark yellowish brown (10YR 4/2)	
6.3	sandy loam 15-20% clay	vf-vc, subrounded to subangular, fine to medium sand dominant	p		pale yellowish brown (10YR 6/2)	
6.8	sandy loam 15-20% clay	vf-vc, subrounded to subangular, fine to medium sand dominant	p		pale yellowish brown (10YR 6/2)	
7.5	sandy clay to clay 40-50% clay	large increase in clay, medium sand dominant, few coarse grains, small pebble (0.8 cm)		trace	dark yellowish brown (10YR 4/2)	brown mottles (few and faint)
8.1	sandy clay 40-45% clay				dark yellowish brown (10YR 4/2)	brown mottles (few and faint)

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: Bay 2			Described by: S. Harder		Date: 12/12/06	
Depth (ft)	**Lithology**	**Grain size**	**Sorting**	**Minerology**	**Color**	**Remarks**
9.3	sandy clay loam 30-35% clay	f-vc, decrease in clay, fine to medium sand dominant			dark yellowish brown (10YR 4/2)	
10.1	sandy clay loam 35% clay	f-vc, fine to medium sand dominant, fewer coarse grains				light brown mottles (few and faint), dark gray mottles (few)

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Well: Bay 3 Described by: S. Harder Date: 6/6/07

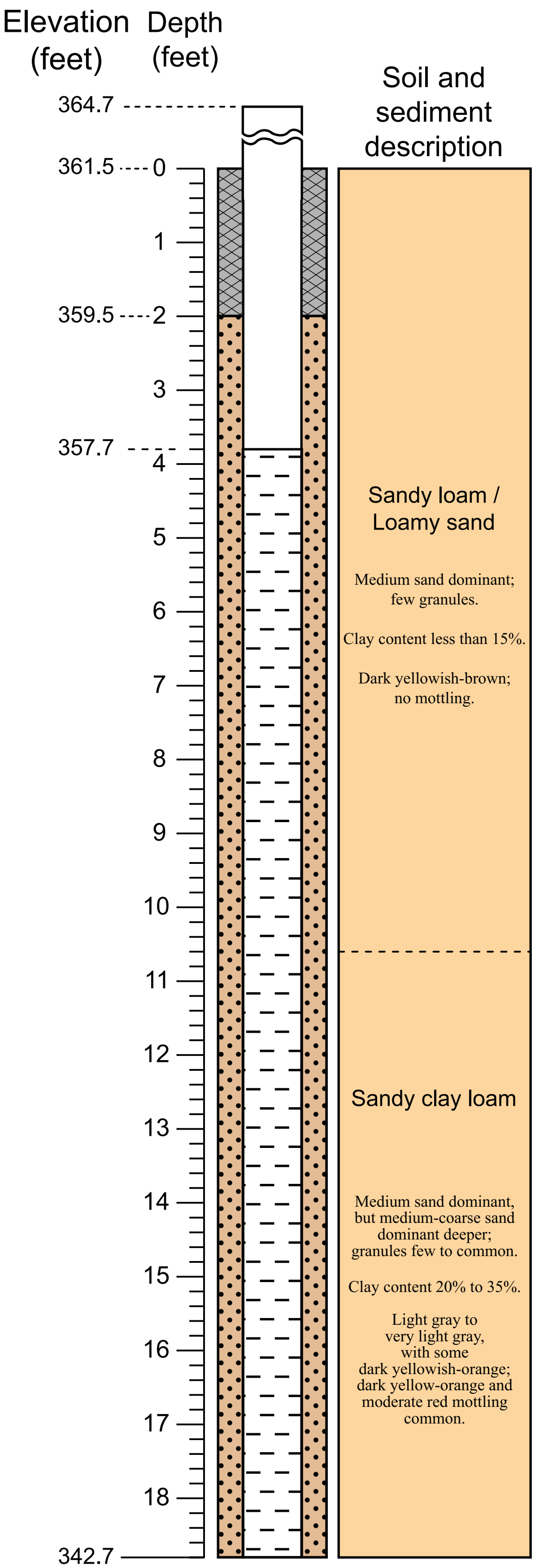
Depth (ft)	Lithology	Grain size	Sorting	Minerology	Color	Remarks
surface	loam/organic	vf-c, very fine to medium sand dominant			brownish black (5YR 2/1)	some roots and stems, fine to medium
0.4	silt loam to silty clay loam 20-30% clay	minor sand, very fine to medium sand dominant			brownish black (5YR 2/1)	smooth, few fine roots and stems, clay content hard to determine
0.8	silt loam to silty clay loam 15-30% clay	slight increase in clay and sand, very fine to medium sand dominant			dusky yellowish brown (10YR 2/2)	clay content hard to determine
1.3	silty clay loam 30-40% clay	minor sand, very fine to medium sand dominant			dusky yellowish brown (10YR 2/2)	clay content hard to determine
2.1	sandy loam 15-20% clay	vf-vc, large increase in sand, very fine to medium sand dominant	vp		brownish gray (5YR 4/1)	

Grain size: vf - very fine; f - fine; m - medium; c - coarse; vc - very coarse. Sorting: vp - very poor; p - poor; mod - moderate.

Appendix II

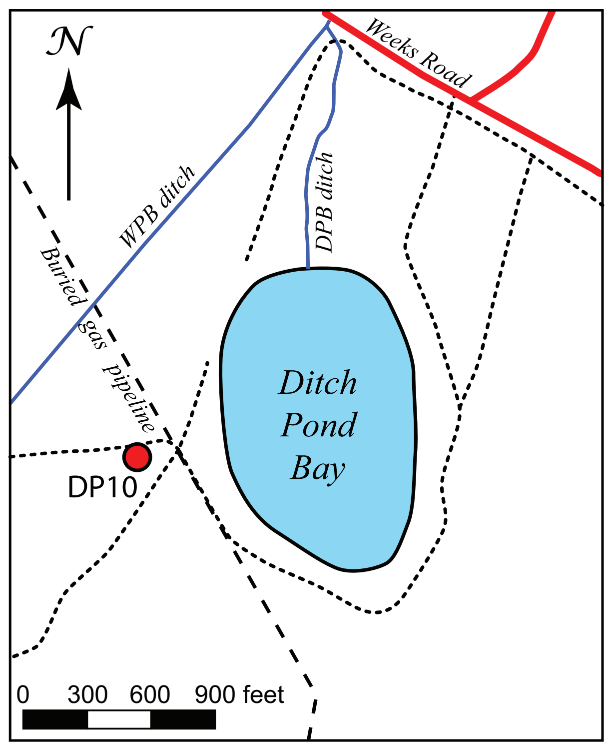
Schematic well diagrams for DP10–DP20

Well diagrams for DP1-DP9 can be found in SCDNR Open-File Report 11 (Harder and others, 2006)

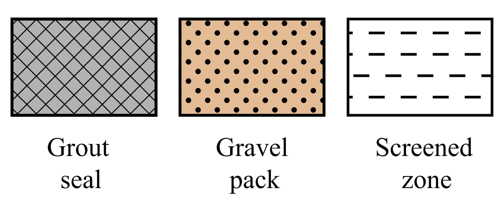


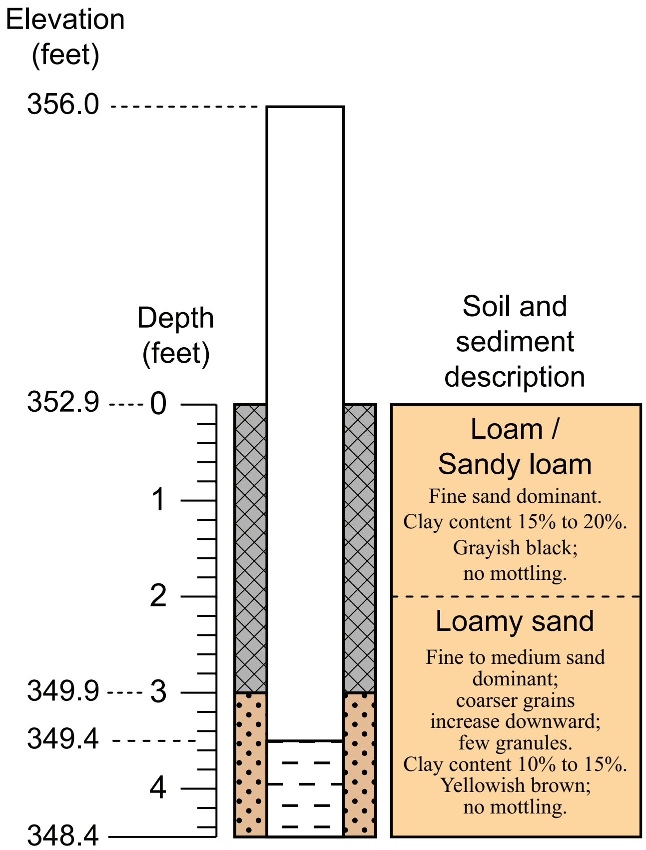
Well: DP10

DNR well number: AIK-2616
Latitude: 33º 25′ 5″
Longitude: 81º 28′ 10″
Land surface elevation: 361.5 feet
Well depth: 18.8 feet
Stand pipe height: 3.1 feet
WL measuring point: Top of casing
MP Elevation: 364.7 feet
Well diameter: 2 inches
Material: PVC
Screen interval: 3.8 to 18.8 feet
Screen size: #10 slot
Gravel pack material: #2 sand
Gravel pack depth: 2.0 to 18.8 feet
Grout: Cement, to 2.0 feet below ground
Date of installation: 6/20/06
Installed by: Gellici, Harder



Well-Construction Diagram Legend





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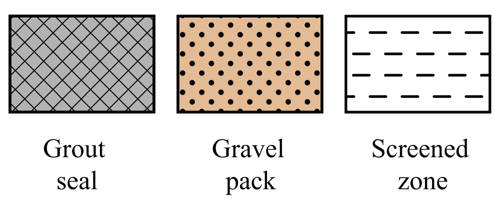
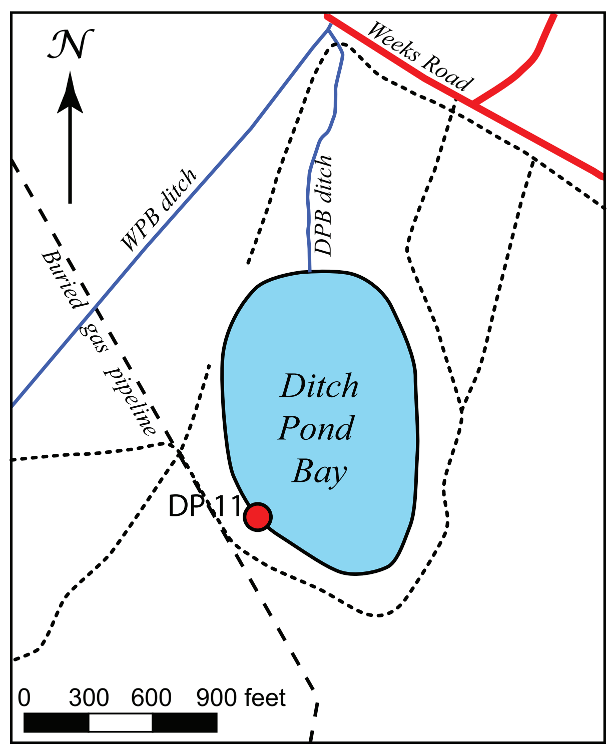
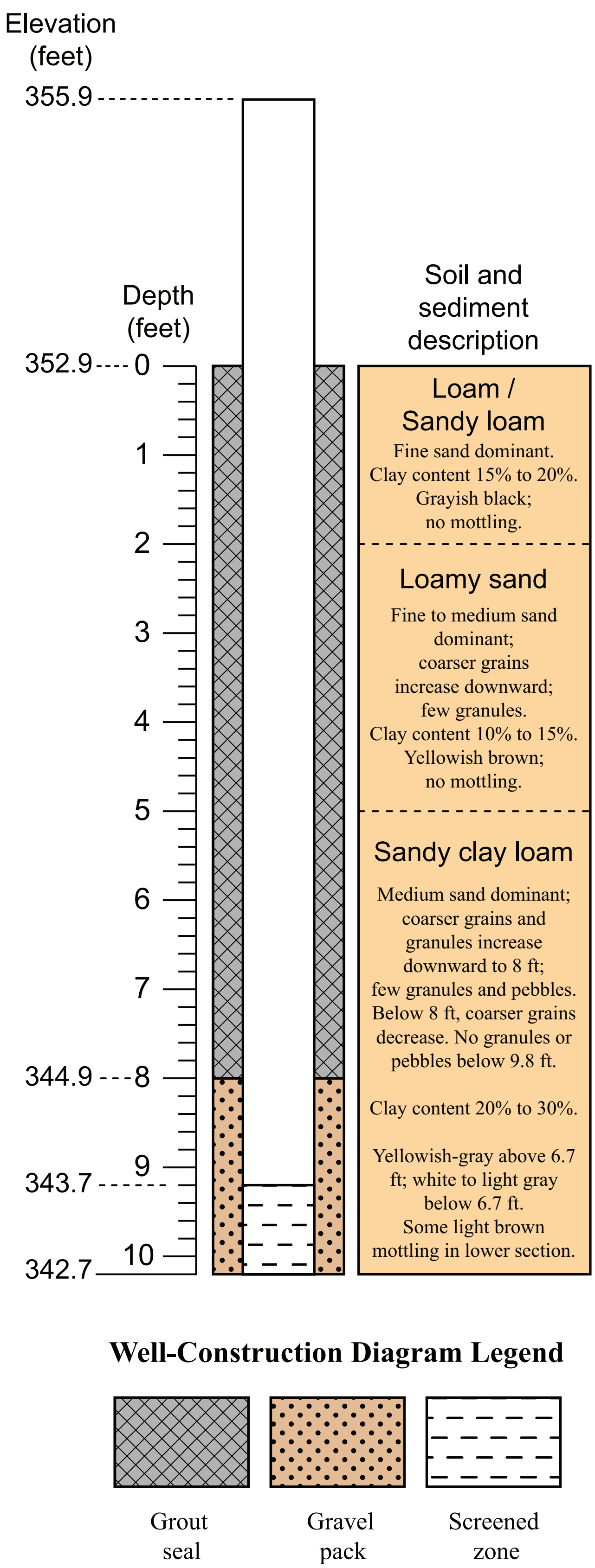


Well: DP11

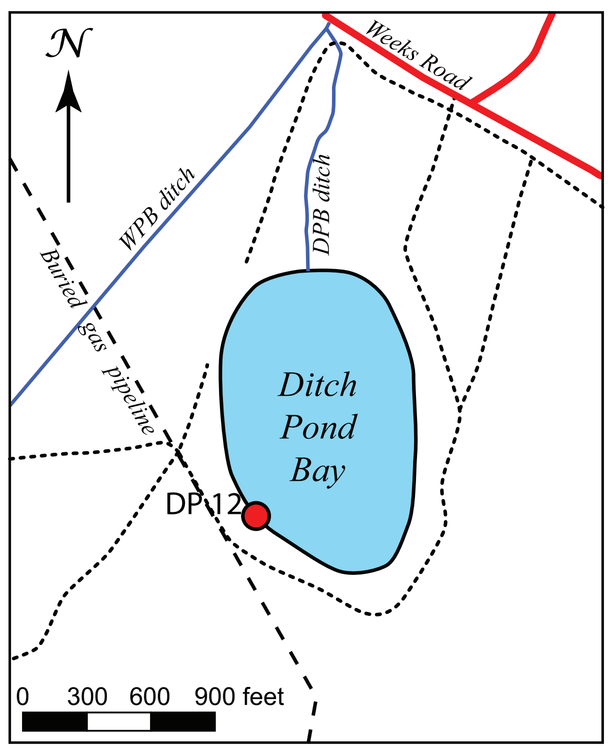
DNR well number: BRN-997
Latitude: 33º 25′ 2″
Longitude: 81º 28′ 4″
Land surface elevation: 352.9 feet
Well depth: 4.5 feet
Stand pipe height: 3.1 feet
WL measuring point: Top of casing
MP Elevation: 356.0 feet
Well diameter: 2 inches
Material: PVC
Screen interval: 3.5 to 4.5 feet
Screen size: #10 slot
Gravel pack material: #2 sand
Gravel pack depth: 3.0 to 4.5 feet
Grout: Bentonite, to 3.0 feet below ground
Date of installation: 8/29/06
Installed by: Gellici, Harder

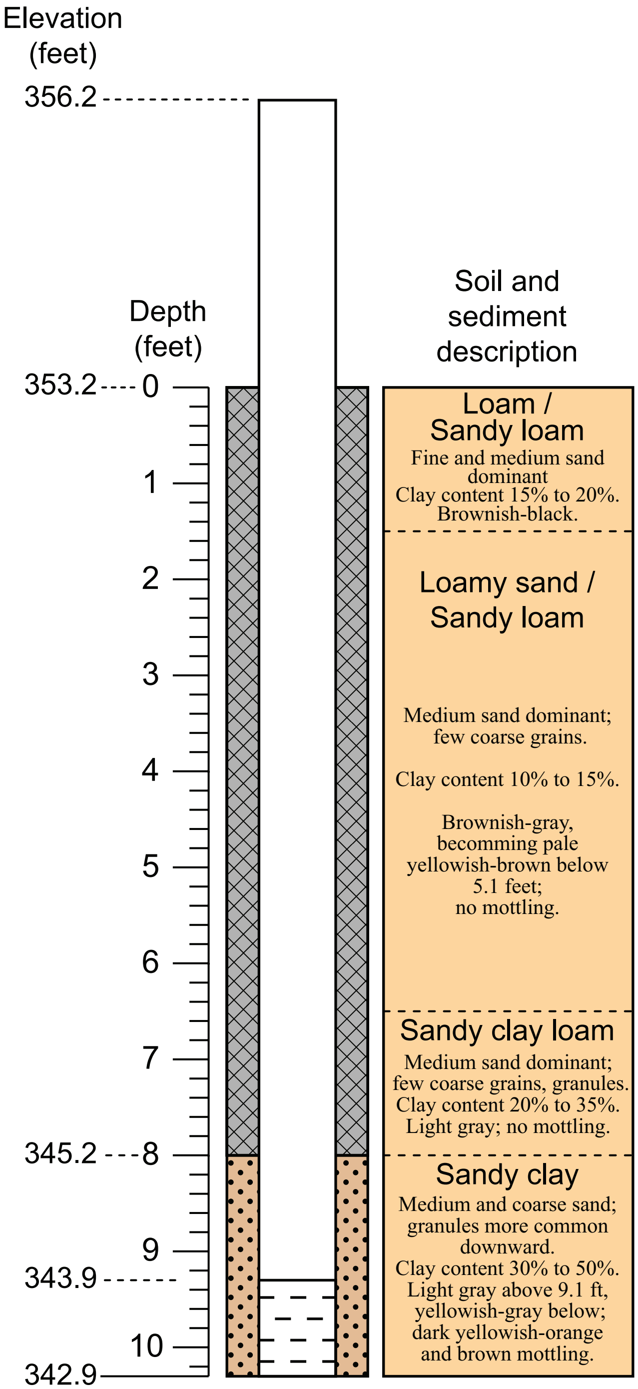




Well: DP12

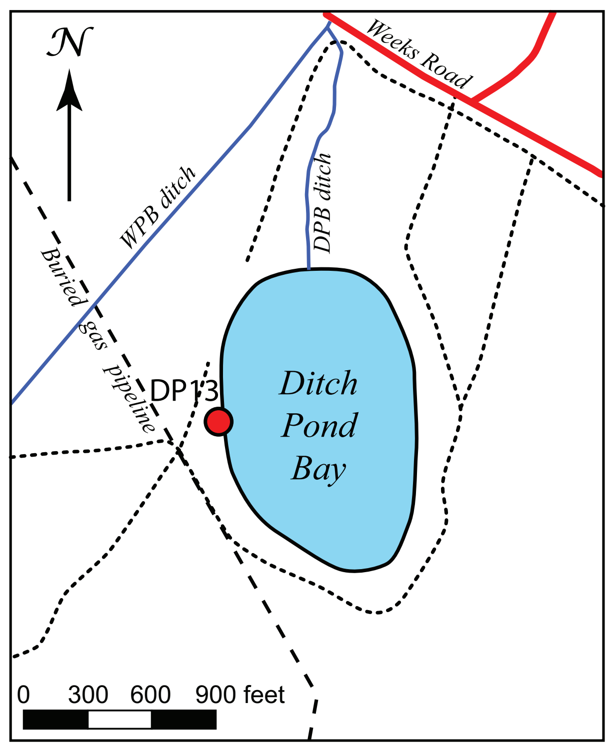
DNR well number: BRN-998
Latitude: 33º 25′ 2″
Longitude: 81º 28′ 4″
Land surface elevation: 352.9 feet
Well depth: 10.2 feet
Stand pipe height: 3.0 feet
WL measuring point: Top of casing
MP Elevation: 355.9 feet
Well diameter: 2 inches
Material: PVC
Screen interval: 9.2 to 10.2 feet
Screen size: #10 slot
Gravel pack material: #2 sand
Gravel pack depth: 8.0 to 10.2 feet
Grout: Bentonite, to 8.0 feet below ground
Date of installation: 8/29/06
Installed by: Gellici, Harder



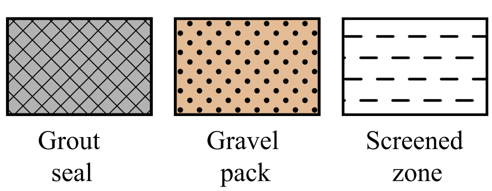


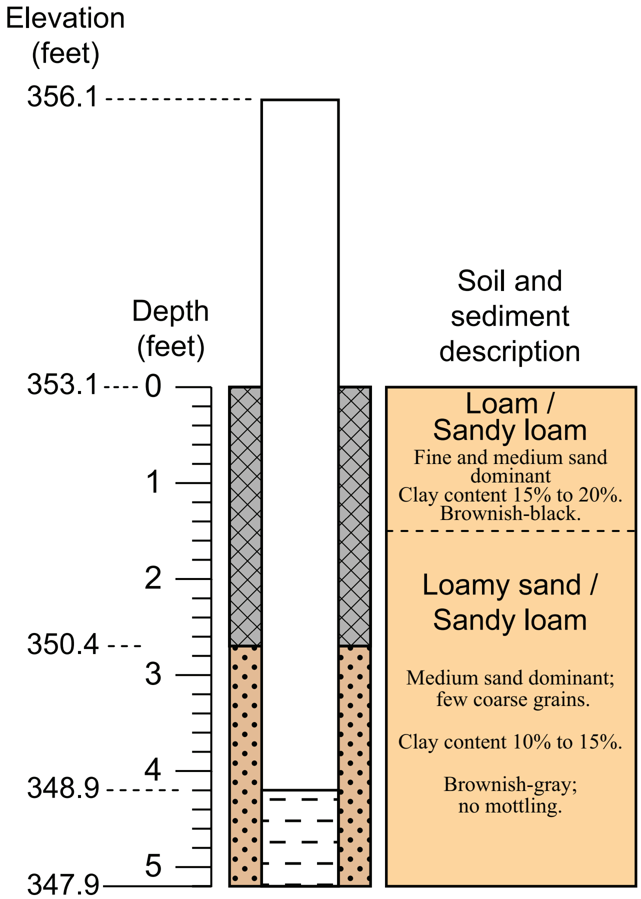
Well: DP13

DNR well number: AIK-2619
Latitude: 33º 25′ 6″
Longitude: 81º 28′ 7″
Land surface elevation: 353.2 feet
Well depth: 10.3 feet
Stand pipe height: 3.0 feet
WL measuring point: Top of casing
MP Elevation: 356.2 feet
Well diameter: 2 inches
Material: PVC
Screen interval: 9.3 to 10.3 feet
Screen size: #10 slot
Gravel pack material: #2 sand
Gravel pack depth: 8.0 to 10.3 feet
Grout: Bentonite, to 8.0 feet below ground
Date of installation: 9/8/06
Installed by: Gellici, Harder



Well-Construction Diagram Legend

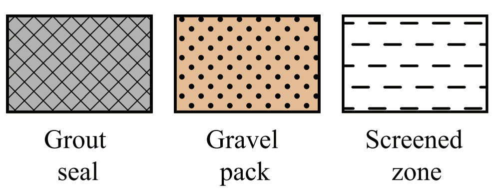


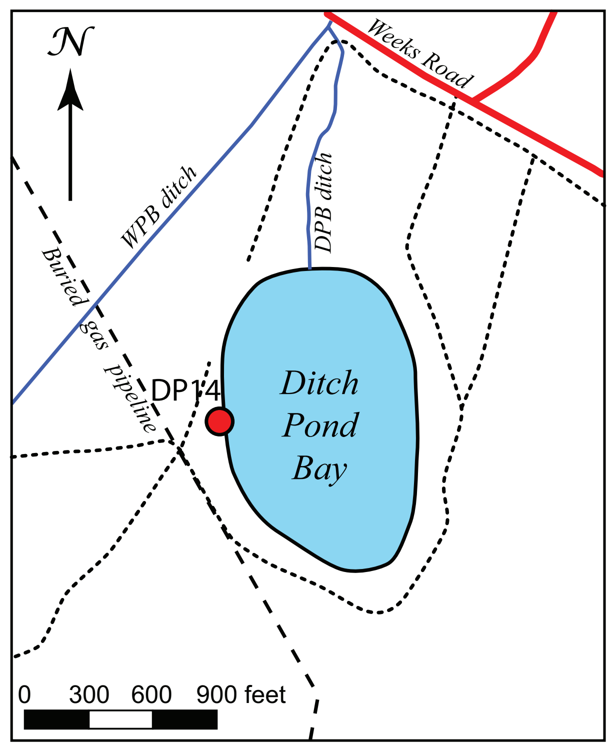


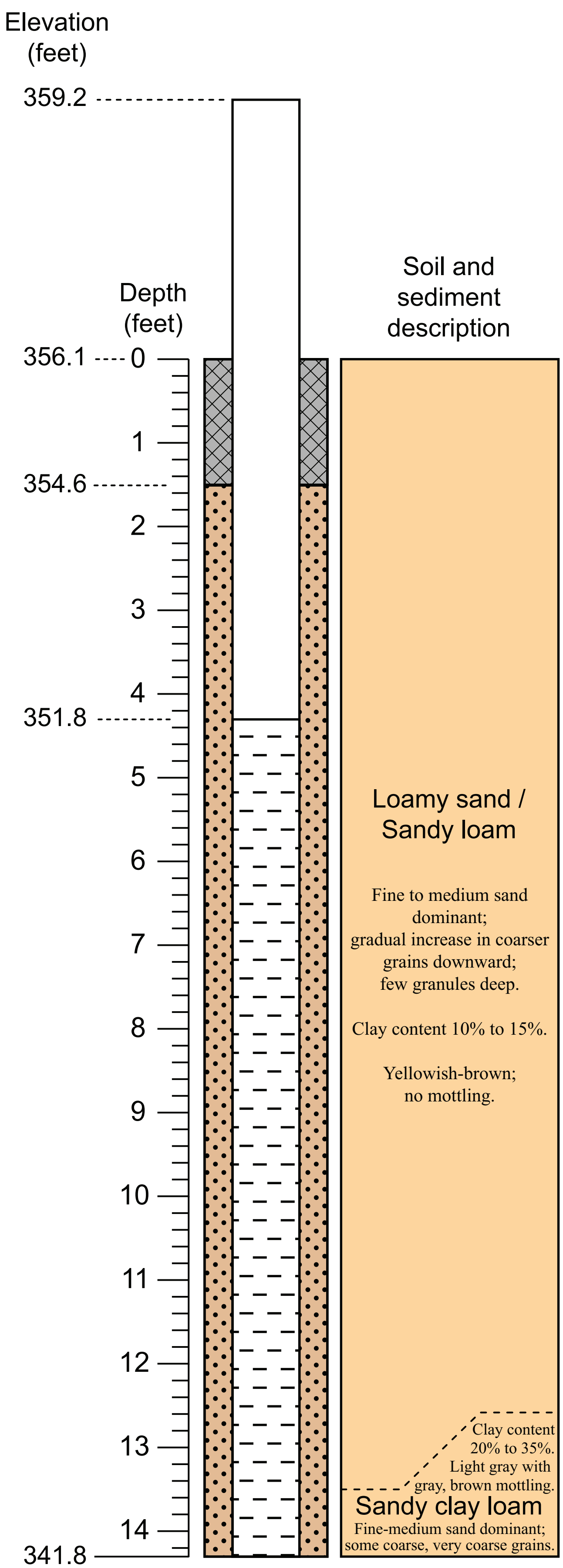
Well: DP14

DNR well number: AIK-2620
Latitude: 33º 25′ 6″
Longitude: 81º 28′ 7″
Land surface elevation: 353.1 feet
Well depth: 5.2 feet
Stand pipe height: 3.0 feet
WL measuring point: Top of casing
MP Elevation: 356.1 feet
Well diameter: 2 inches
Material: PVC
Screen interval: 4.2 to 5.2 feet
Screen size: #10 slot
Gravel pack material: #2 sand
Gravel pack depth: 2.7 to 5.2 feet
Grout: Bentonite, to 2.7 feet below ground
Date of installation: 9/8/06
Installed by: Gellici, Harder

Well-Construction Diagram Legend

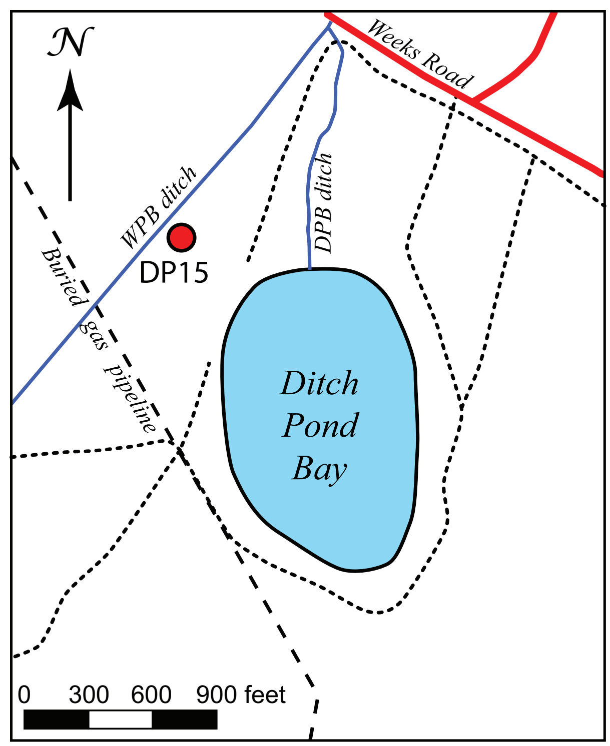






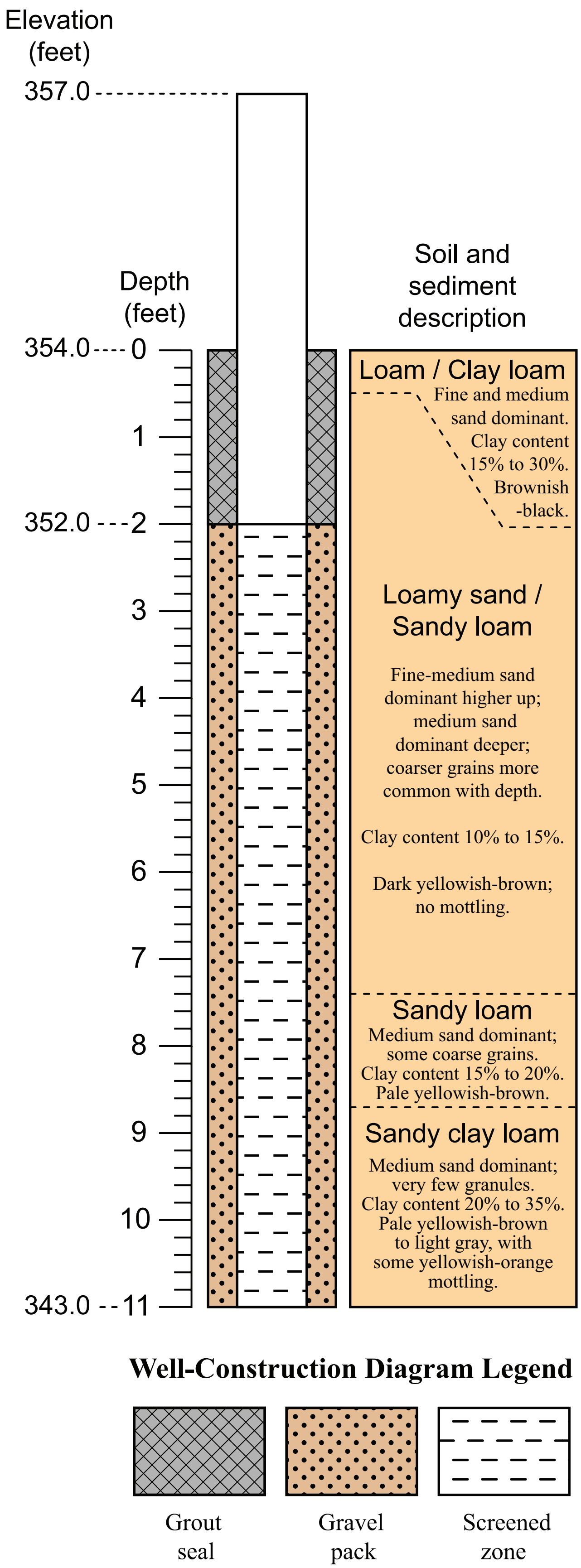
Well: DP15

DNR well number: AIK-2621
Latitude: 33º 25′ 15″
Longitude: 81º 28′ 9″
Land surface elevation: 356.1 feet
Well depth: 14.3 feet
Stand pipe height: 3.1 feet
WL measuring point: Top of casing
MP Elevation: 359.2 feet
Well diameter: 2 inches
Material: PVC
Screen interval: 4.3 to 14.3 feet
Screen size: #10 slot
Gravel pack material: #2 sand
Gravel pack depth: 1.5 to 14.3 feet
Grout: Bentonite, to 1.5 feet below ground
Date of installation: 9/21/06
Installed by: Gellici, Harder



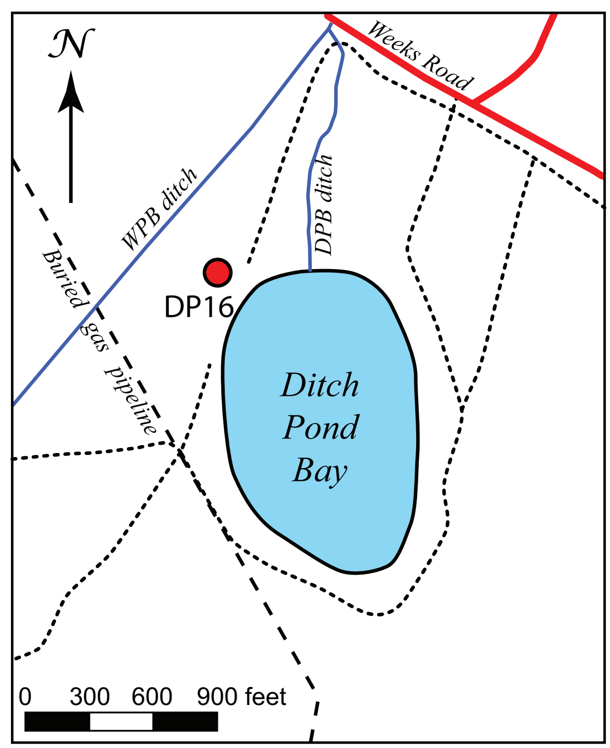
Well-Construction Diagram Legend

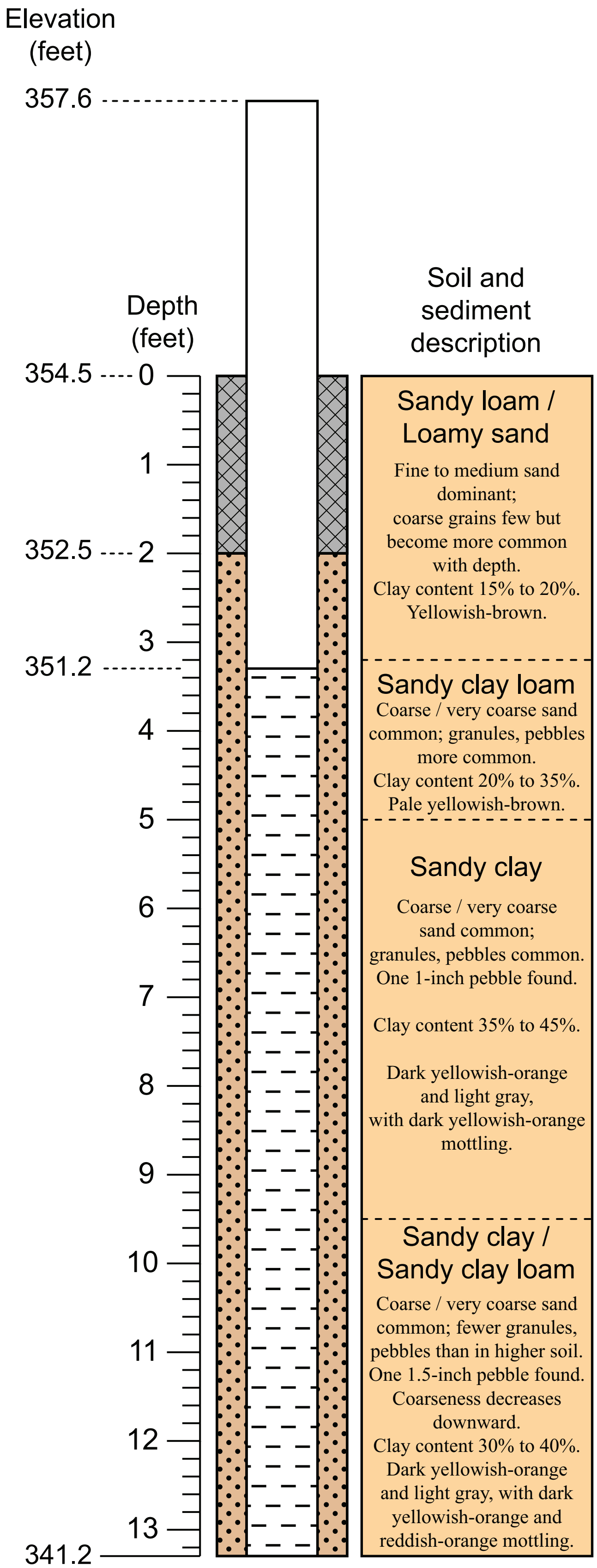
Grout seal | Gravel pack | Screened zone



Well: DP16

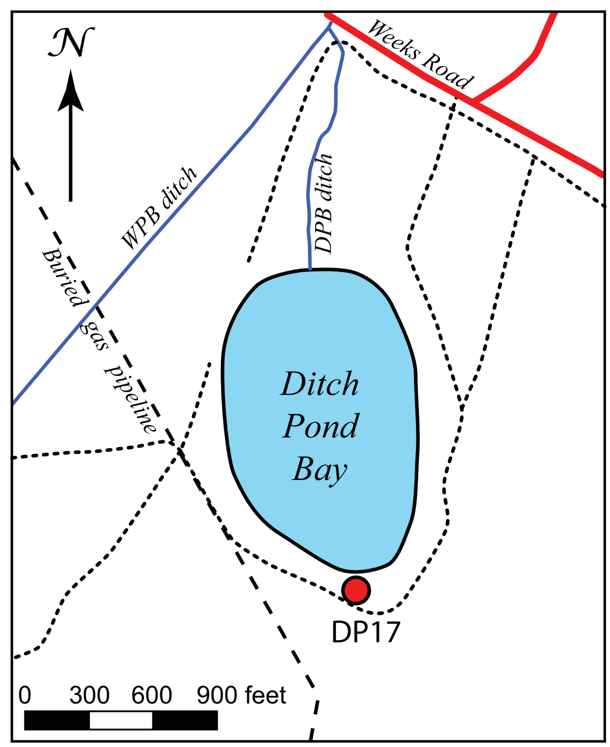
DNR well number: AIK-2622
Latitude: 33º 25′ 14″
Longitude: 81º 28′ 7″
Land surface elevation: 354.0 feet
Well depth: 11.0 feet
Stand pipe height: 3.0 feet
WL measuring point: Top of casing
MP Elevation: 357.0 feet
Well diameter: 2 inches
Material: PVC
Screen interval: 2.0 to 11.0 feet
Screen size: #10 slot
Gravel pack material: #2 sand
Gravel pack depth: 2.0 to 11.0 feet
Grout: Bentonite, to 2.0 feet below ground
Date of installation: 9/21/06
Installed by: Gellici, Harder



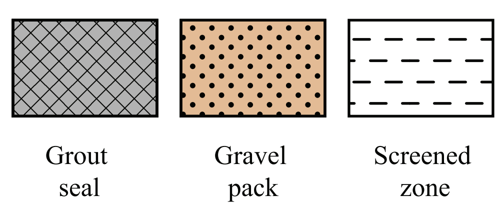


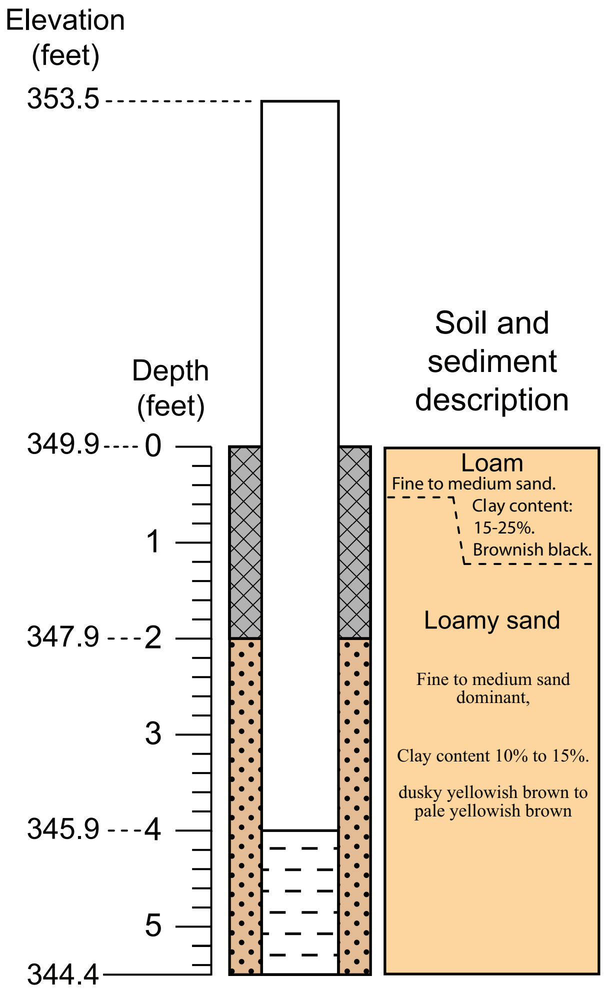
Well: DP17

DNR well number: BRN-999
Latitude: 33º 24′ 55″
Longitude: 81º 27′ 59″
Land surface elevation: 354.5 feet
Well depth: 13.3 feet
Stand pipe height: 3.0 feet
WL measuring point: Top of casing
MP Elevation: 357.6 feet
Well diameter: 2 inches
Material: PVC
Screen interval: 3.3 to 13.3 feet
Screen size: #10 slot
Gravel pack material: #2 sand
Gravel pack depth: 2.0 to 13.3 feet
Grout: Cement, to 2.0 feet below ground
Date of installation: 9/29/06
Installed by: Gellici, Harder



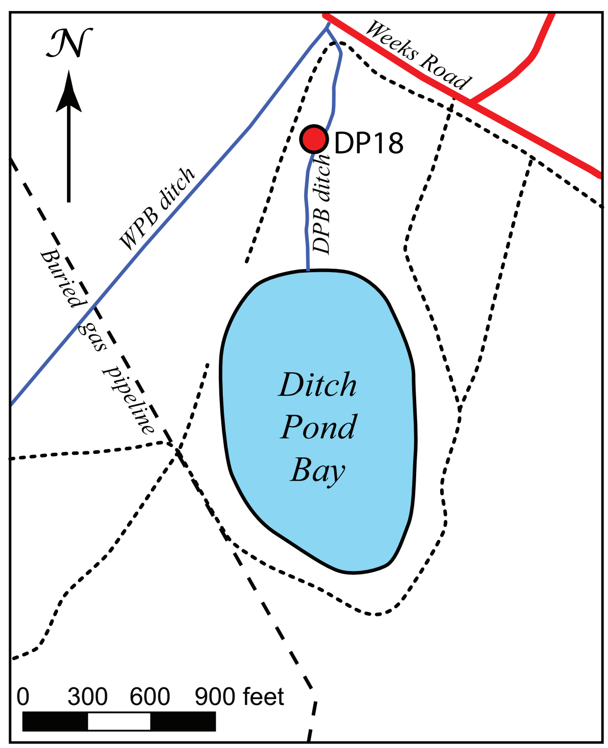
Well-Construction Diagram Legend





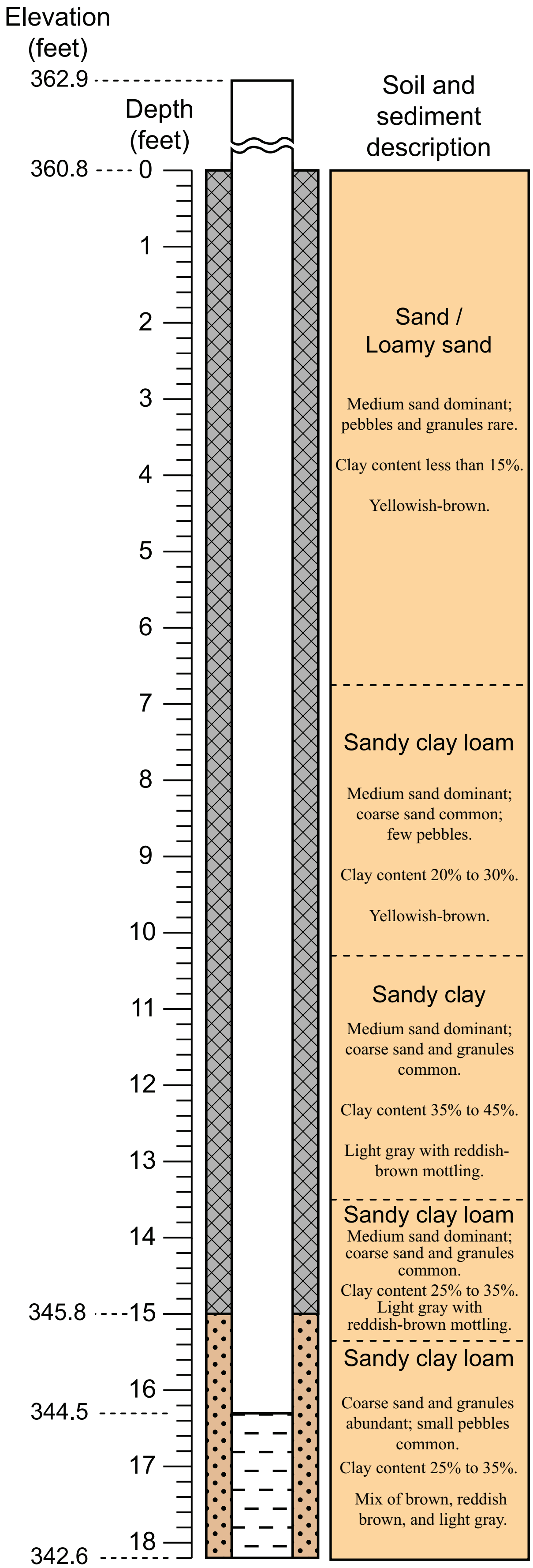
Well: DP18

DNR well number: AIK-2623
Latitude: 33º 25′ 19″
Longitude: 81º 28′ 1″
Land surface elevation: 349.9 feet
Well depth: 5.5 feet
Stand pipe height: 3.6 feet
WL measuring point: Top of casing
MP Elevation: 353.5 feet
Well diameter: 2 inches
Material: PVC
Screen interval: 4.0 to 5.5 feet
Screen size: #10 slot
Gravel pack material: #2 sand
Gravel pack depth: 2.0 to 5.5 feet
Grout: Cement, to 2.0 feet below ground
Date of installation: 10/5/06
Installed by: Gellici, Harder



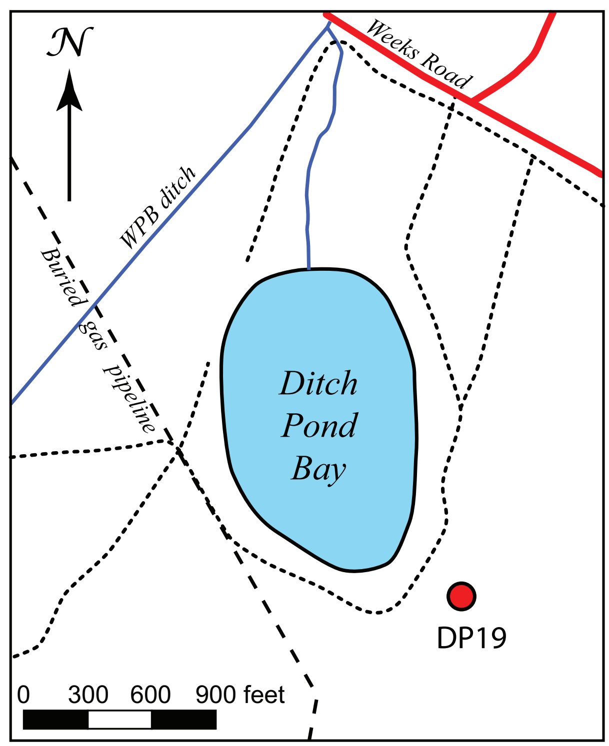
Well-Construction Diagram Legend

Grout seal | Gravel pack | Screened zone

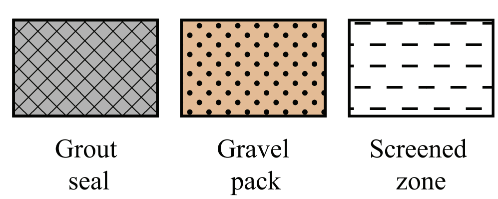


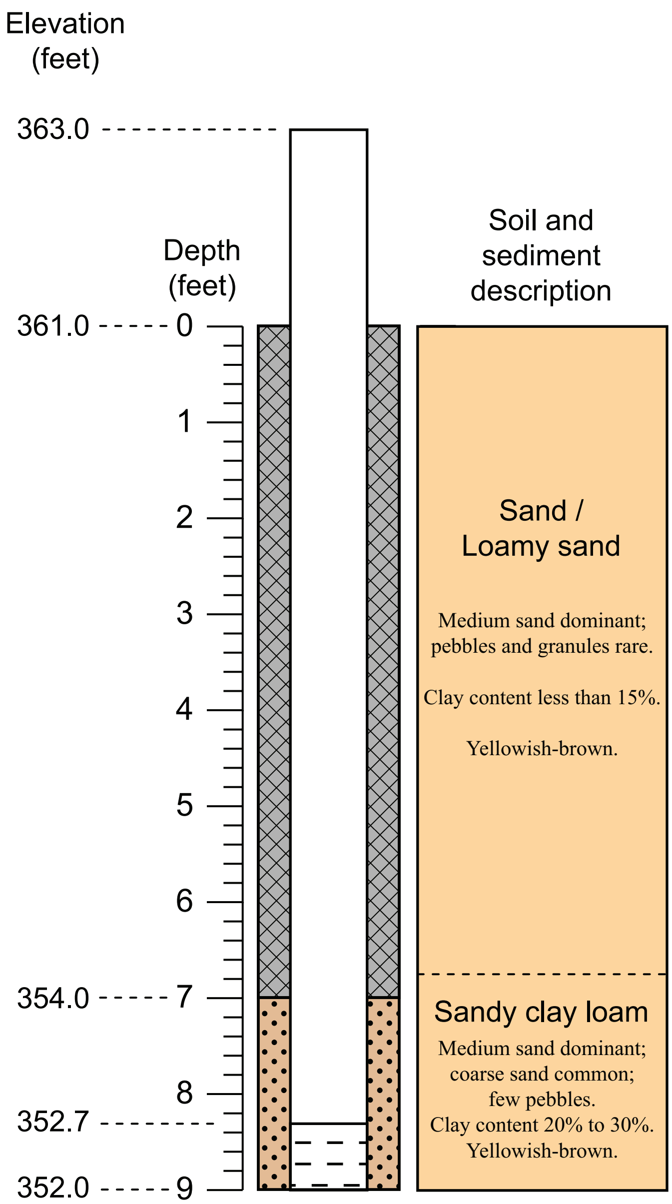
Well: DP19

DNR well number: BRN-1000
Latitude: 33º 25′ 1″
Longitude: 81º 27′ 51″
Land surface elevation: 360.8 feet
Well depth: 18.2 feet
Stand pipe height: 2.2 feet
WL measuring point: Top of casing
MP Elevation: 362.9 feet
Well diameter: 2 inches
Material: PVC
Screen interval: 16.3 to 18.2 feet
Screen size: #10 slot
Gravel pack material: #2 sand
Gravel pack depth: 15.0 to 18.2 feet
Grout: Bentonite, to 15.0 feet below ground
Date of installation: 11/14/06
Installed by: Harder, Wachob



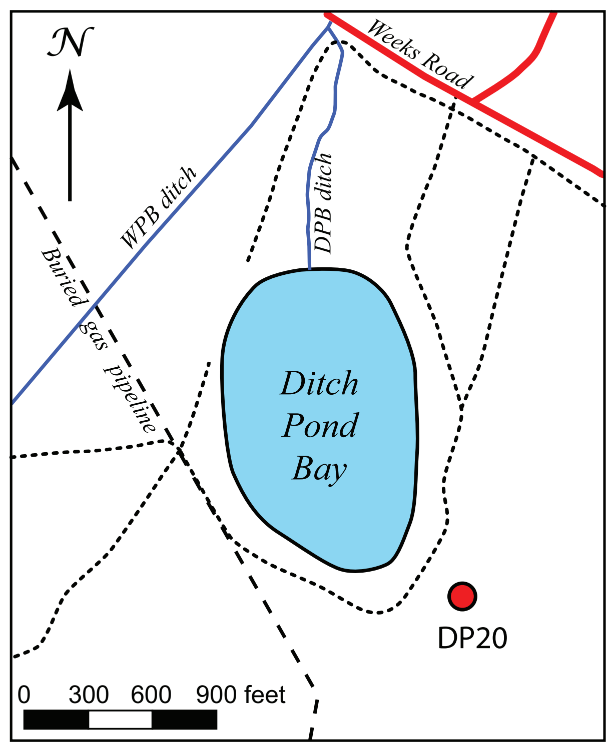
Well-Construction Diagram Legend





Well: DP20

DNR well number: BRN-1001
Latitude: 33º 25′ 1″
Longitude: 81º 27′ 51″
Land surface elevation: 361.0 feet
Well depth: 9.0 feet
Stand pipe height: 2.1 feet
WL measuring point: Top of casing
MP Elevation: 363.0 feet
Well diameter: 2 inches
Material: PVC
Screen interval: 8.3 to 9.0 feet
Screen size: #10 slot
Gravel pack material: #2 sand
Gravel pack depth: 7.0 to 9.0 feet
Grout: Bentonite, to 7.0 feet below ground
Date of installation: 12/13/06
Installed by: Badr, Harder, Wachob



Well-Construction Diagram Legend