A GEOHYDROLOGICAL INVESTIGATION OF GOLD HEAD BRANCH STATE PARK, CLAY COUNTY, FLORIDA

By

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Abstract of Thesis Presented to the Graduate School
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A GEOHYDROLOGICAL INVESTIGATION OF THE GOLD HEAD BRANCH STATE PARK, CLAY COUNTY, FLORIDA

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Chair: Joann Mossa
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The Gold Head Branch State Park in Clay County, Florida contains an unusual geomorphological feature termed a steephead ravine that has been formed and advanced through undercutting of the headwall, eroding the sandy soil as water is discharged from the shallow subsurface. The Gold Head Branch stream is formed from this clear water and other springs and seeps along the ravine sidewalls. The local region is a recharge zone for the Floridan aquifer and most precipitation infiltrates into the soil and is subsequently transported within the subsurface.

Theories regarding the origin of steephead ravines often contend that a relatively impermeable or semi-permeable stratigraphic layer restricts downward percolation of infiltrating precipitation, thereby causing discharge of subsurface water at the headwall and sidewalls of the ravine. Test borings drilled at two other steephead headwalls in the Florida panhandle (Schumm, 1995) found no stratigraphic control of groundwater discharge and this study also found that groundwater was discharging at the headwall without downward restriction. Additionally, the longitudinal profile of Gold Head Branch stream does not have significant slope breaks that would indicate stratigraphic control. The geohydrology of the ravine was investigated by drilling at the steephead headwall, hand augering within the ravine, testing soil infiltration, surveying, and by synthesizing and interpreting lake levels, well levels, and climatic data in the region.

Findings of this study may have implications for the Floridan aquifer and its connection to surface water in the area. Based on the surveyed elevation difference between the top of the headwall and base of the headwall, and depth of the surficial aquifer encountered during drilling of the test boring at the top of the headwall, there is approximately a three foot mounding effect as groundwater is focused and subsequently discharged at the base of the steephead headwall.

The largest mature trees in the headwall area of the Gold Head ravine are predominately sweetgum, southern magnolia, and pignut hickory and several were cored during this study utilizing an increment borer. Tree-ring width residuals from pignut hickory (carya glabra) tree cores obtained near the headwall were related to independent variables including lake levels, precipitation, temperature, and seasonal combinations using ordinary least squares regression. This study found that temperature during three key months, (June, July, August), had a more significant relationship than most precipitation variables and a combination of weighted (June, July, August) rain and temperature with August temperature and August precipitation produced the best model to interpret the climatic signal stored within the hickory trees. Southeastern pignut hickory is shade tolerant and develops a deep tap root so growing within the ravine where shallow groundwater is abundant, rain and sunshine availability in the competitive ravine environment is less important than temperature.

CHAPTER 1
INTRODUCTION AND OBJECTIVES

1.1 Background

The Gold Head Branch state park in north-central Florida (Figure 1-1) contains an unusual geomorphological feature termed a steephead ravine. This ravine is approximately 45 feet deep and contains a 1.5 mile long clear stream - Gold Head Branch (Figure 1-2), that is formed from water seeping from the steep valley walls and that eventually discharges into Lake Johnson (Figure 1-3). There are three principal springs in the upper portion of the ravine and several others seeping water from the ravine walls. The ravine lengthens and enlarges naturally through headwall erosion as groundwater seeps from the slopes, carrying away sediment. The cool moist ravine is covered by a dense canopy of trees including loblolly pines, longleaf pines, hickory trees, and southern magnolias. The plant community within the ravine is extremely diverse including some rare and endangered species (White, 1983). A primary objective of this research was to determine if there was stratigraphic control involved during the origin and development of the seepage springs. If a relatively impermeable layer is present near the base of the steephead wall and unconsolidated homogeneous sediments exist above with a high infiltration capacity, then the water seepage within the ravine is a direct result of the restriction of downward percolation of groundwater.

The first account of steephead ravines and their characterization is by Sellards and Gunter in 1918, through observation of surficial sediments alone, describing the sapping features in west Florida between the Apalachicola and Ocklocknee Rivers - “A characteristic feature of this topography is the development of what is known locally as “steepheads”. These steepheads are due to the fact that indurated sands and sandy clays overlie slightly indurated sands and clays and shell marls. The surface waters pass into the earth and, upon reaching the underlying clay or marl beds, emerge as springs. The indurated sandy clays near the surface stand up vertically, while the softer sands, at a greater depth where the springs emerge, wash easily. The result is the formation of a nearly vertical bluff, at the base of which springs emerge supplying small streams. This bluff or streamhead assumes in time a semi-circular form, which is the "steephead". The steephead thus formed is retained by the stream as it gradually extends its way back into the plateau. The depth of the steephead from the plateau is usually from 50 to 60 or more feet, depending upon the depth at which the ground waters emerge as springs." The description provided by Sellards and Gunter is well founded and generally accepted as accurate even today although Schumm, 1995 investigated two steephead ravines in west Florida including exploratory boreholes at the steephead plateaus and didn't find any stratigraphic control near where the springs emerge. This study investigated if the Gold Head Branch springs at the head of the ravine are controlled by a horizon such as clay, marl, or cemented sand (hardpan) that prevents downward percolation of groundwater and creates seepage discharge within the ravine.

The work of Robert E. Horton (1945), with its emphasis upon the role of surface infiltration, has had considerable influence on hydrology and geomorphology in the past sixty years. The Horton model delineates between rainfall which infiltrates the surface (which contributes to long-term baseflow and is not responsible for surface erosion) and the rainfall in excess of infiltration capacity which, as overland flow, is responsible for storm runoff and erosion of surface sediments. During a storm, a constant decrease of surface infiltration occurs until a constant low value is reached where the infiltration capacity falls below that of the rainfall intensity and subsequently, overland flow occurs.

The central Florida area is characterized by discontinuous highlands separated by broad valleys that resulted from numerous sea transgressions which created relict shoreline features such as beach ridges that parallel the Atlantic coastline. Within the Central Highlands of the Florida peninsula is the most extensive area of closely spaced lakes in North America (USGS, 1998). The location of the seepage springs of Gold Head Branch State Park is regionally near the extreme southern end of the north-south trending Trail Ridge feature (Figure 1-4) which extends northward into southern Georgia and is thought to represent a barrier island and/or beach ridge during a period of sea transgression (White, 1970). The Gold Head ravine is within the Interlachen Karstic Highland--a major recharge zone for the Floridan aquifer. The existence of the Gold Head Branch seepage springs may be related to depositional controls that existed during the formation of the Trail Ridge. The development of drainage patterns relative to these steephead features doesn't usually conform to Horton's classic pattern of development. The lack of conformance to Horton's relations is theorized to be the result of incompletely developed drainage patterns (Schumm, et al., 1995). Advance of the steephead wall may be episodic and possibly related to fire (which destroys considerable vegetation leading to increased erosion and mass movement), human activities and groundwater capture by other streams that might redirect groundwater flow away from the springs, and extensive and prolonged rain events.

Four lakes occur within Gold Head Branch State Park [now divided into Little Lake Johnson (Figure 1-5) and Big Lake Johnson (Figure 1-6) due to low lake levels], Pebble Lake, Deer Lake and Sheeler Lake. Deer Lake was previously called the Devils Wash Basin (see Figure 1-2) and is NE of the steephead ravine headwall. Sheeler Lake is immediately west of the ravine and has been pollen-dated to an age of at least 24,000 years B.P (Watts, 1980). Pebble Lake (Figure 1-7) is immediately west of Little Lake Johnson and previously was supplied with water by a small steephead spring north of the lake. The seep north of Pebble Lake has recently flowed water after a hurricane and severe rain events (personal comm., Florida State Parks) although currently the groundwater seep above Pebble Lake is dry due to historically low water levels. So currently, Pebble Lake is principally supplied through groundwater seepage. Seepage lakes are generally more susceptible to drought and groundwater level fluctuations.

1.2 History and Land Use

The original inhabitants of north central Florida were the Timucua Indians (Swanton, 1928) who farmed corn and fished along the shores of the St. Johns River during the summer and then hunted game inland and collected berries, nuts, and herbs during the winter months (Blakey, 1976). The Spanish and French explored the region beginning in the early 1500's and within a century European diseases had severely impacted the Timucua people. The British, Spanish, and French fought over the region until the late 1700's when Britain and eventually the Americans gained control. The Timucua people were eventually wiped out by the Seminole Indians and the British army (Swanton, 1946). The area became a United States territory in 1821 and later in 1845 became a state. The land near the Gold Head Branch State Park was initially settled before the civil war after the U.S. Army subdued the aggressive Seminole Indians and construction of a sawmill in 1870 (Figure 1-8) led to development in the area. Turpentine production and logging were the initial uses and "cat faces" (cuts to extract pine resin) on some of the longleaf pine trees can still be seen. Later, a grist mill and cotton gin of unique design were operated within the ravine. A railway connecting Green Cove Springs and Melrose, Florida was constructed in 1858 leading to increased settlement and distribution of timber, turpentine, cotton, citrus, and corn. The Palatka and Starke road from the 1800's ran through the park east of the ravine and portions of the old road can still be seen today. There were some early homesteaders in the Gold Head area during the nineteenth century and farming occurred near Deer Lake East of the ravine. The Civilian Conservation Corps (CCC) built roads, cabins, and trails creating the park in the 1930's. The cotton industry in the region was wiped out by the boll weevil in 1946 (Blakey, 1976).

Historical records indicate the area was completely clear-cut by approximately 1920 although some areas of the ravine were partially spared from the logging operations. Secondary growth and reintroduction of several species including longleaf pine (pinus palustris) has created a lush and unique environment within the ravine (Figure 1-9). A longleaf pine tree was cored on the west side of the Gold Head stream in 1982 and was dated to 185 years old (White, 1983).

There have been three hundred and forty-seven plant species identified (White, 1983) within the ravine which is part of a unique ecosystem encompassing many different animals, birds, and salamander species. The Florida state champion sweet gum was formerly located in the ravine until the top of the tree fractured. Since 1971 the Department of Natural Resources has been burning the sand hills in the park every two or three years (Figure 1-10) and reintroduced additional longleaf pines. Controlled burning in the sandhill areas is an important contribution to the health of the forest since natural fires were drastically reduced many years ago. Pinus palustrus (longleaf pine) relies on frequent fires to clear encroaching species since it is fire tolerant and would be crowded out otherwise.

The Gold Head Branch stream has been altered near its discharge point at Lake Johnson several times since the initial mill and associated dammed pond were constructed in 1870. Water diversion projects for the mills and later recreation at Lake Johnson altered the natural drainage of the stream and attempts have been made by the park system and St. Johns River Water Management District to restore the natural course of the Gold Head Branch. The Park Service has placed supports and geotextiles in some steep areas of the ravine to aid in stabilization of the soils. The two most powerful hurricanes to impact the Gold Head area within the last one hundred years occurred in 1960 - Donna and 1964 – Dora.

A large sand mining operation owned by Florida Rock Industries is currently active immediately west of the Gold Head Branch State Park (Figures 1-11 and 1-12) and has been extracting ancient beach sand for over 40 years, based upon aerial photos of the region. The area that has been mined was formerly the site of a steephead ravine, stream, and small lake similar in configuration to Gold Head, although smaller in scale. The surface mine is hydrologically upgradient of the southern portion of Gold Head Branch State Park and may be influencing groundwater levels in the region. Reduced rainfall in the recent past has dropped water levels considerably with drought conditions in 2000-2002 causing local officials to divert significant amounts of water from Lake Magnolia southward towards the Keystone Heights region.

A few supports have been emplaced where the steep ravine sidewalls are collapsing and geotextiles have been installed at the steephead headwall to help prevent further back-cutting of the headwall. Aerial photos taken in 1970 (Figure 1-13), 1984 (Figure 1-14), and 2006 (Figure 1-15) show the growing sand mining pit WSW of the park, changing lake levels, and clear cutting of nearby second growth trees.

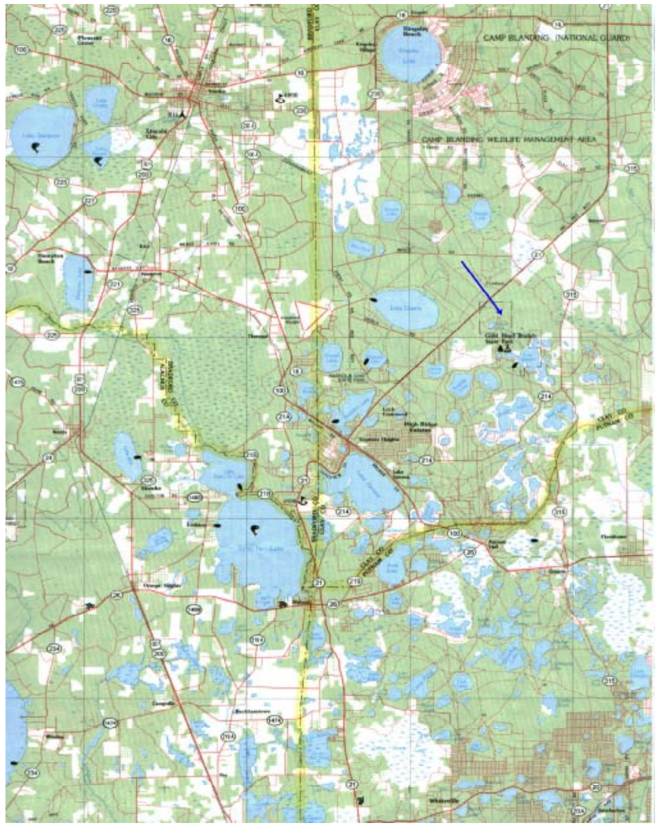

Figure 1-1. Gold Head Branch State Park Regional location map, note arrow.

Figure 1-2. Gold Head Branch stream, typical reach (2008).

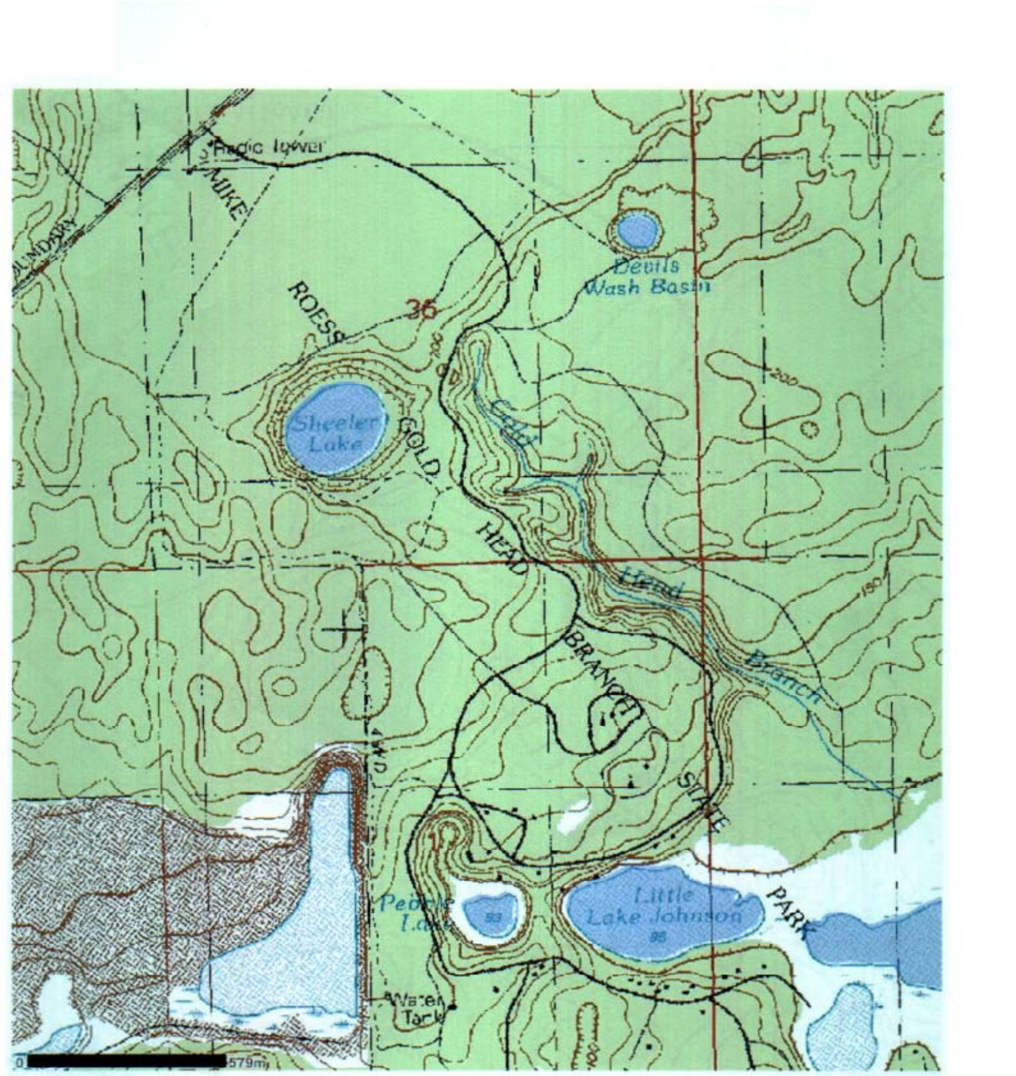

Figure 1-3. Topographic map of Gold Head Branch State Park area, U.S.G.S.

2 BUREAU OF GEOLOGY

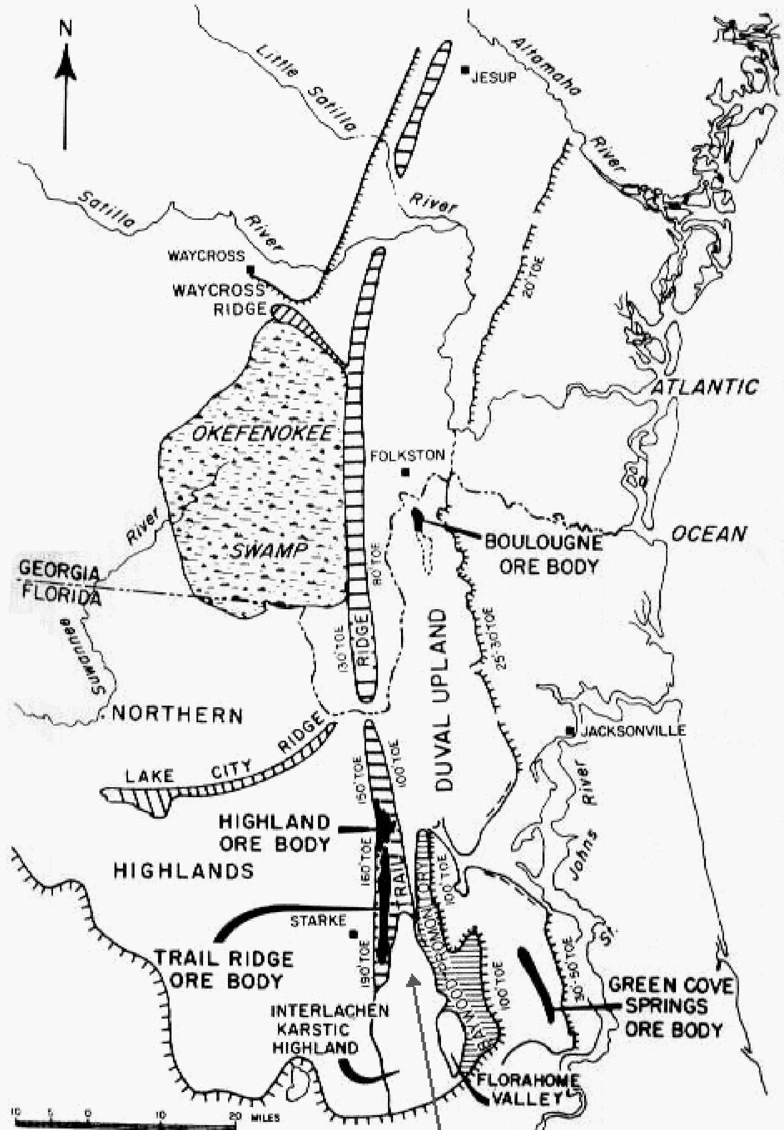

Figure 1. Location map.

Figure 1-4. Geomorphological map of NE Florida/SE Georgia. Arrow near bottom indicates Gold Head location (White, 1970)

Figure 1-5. Photograph of Little Lake Johnson- Looking East, (2007).

Figure 1-6. Photograph of Big Lake Johnson basin – note slope in foreground (2007).

Figure 1-7. Pebble Lake, looking southeast (2008).

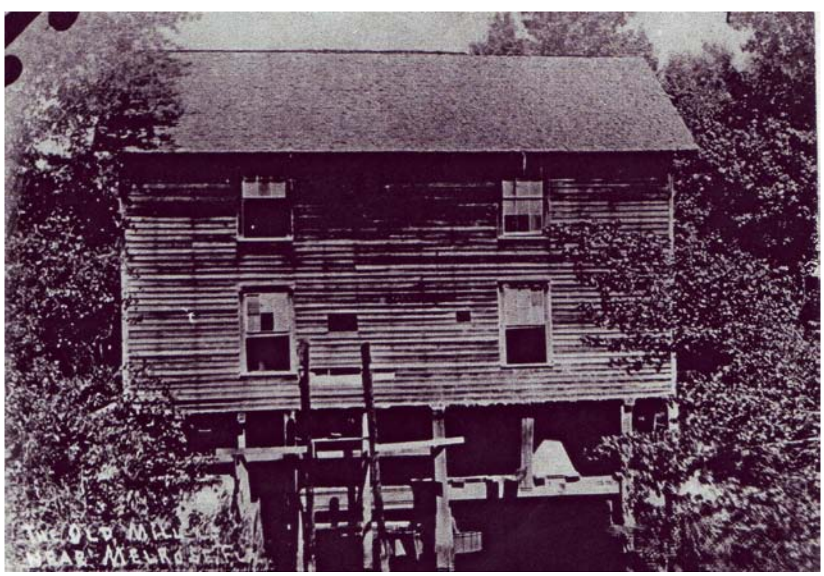

Figure 1-8. Old sawmill in Gold Head ravine–only known picture before demolition, date unknown.

Figure 1-9. A competitive environment for plants exists within the ravine which contains approximately 1,000 species (2007).

Figure 1-10. Recent Controlled Burn of Upland Sandhill Pine (2007).

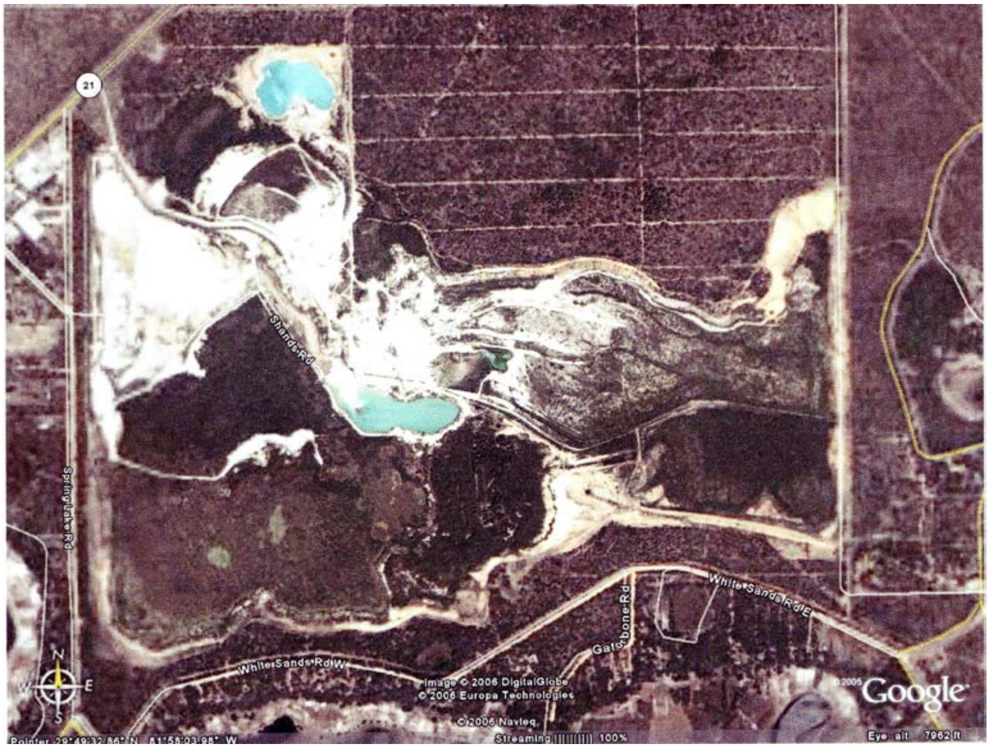

Figure 1-11. Sand mining pit adjacent to Gold Head Park – note, Pebble Lake immediately east of pit (GoogleEarth, 2006).

Figure 1-12. Inactive NE Corner of Sand Mining Pit, NW of Pebble Lake (2007).

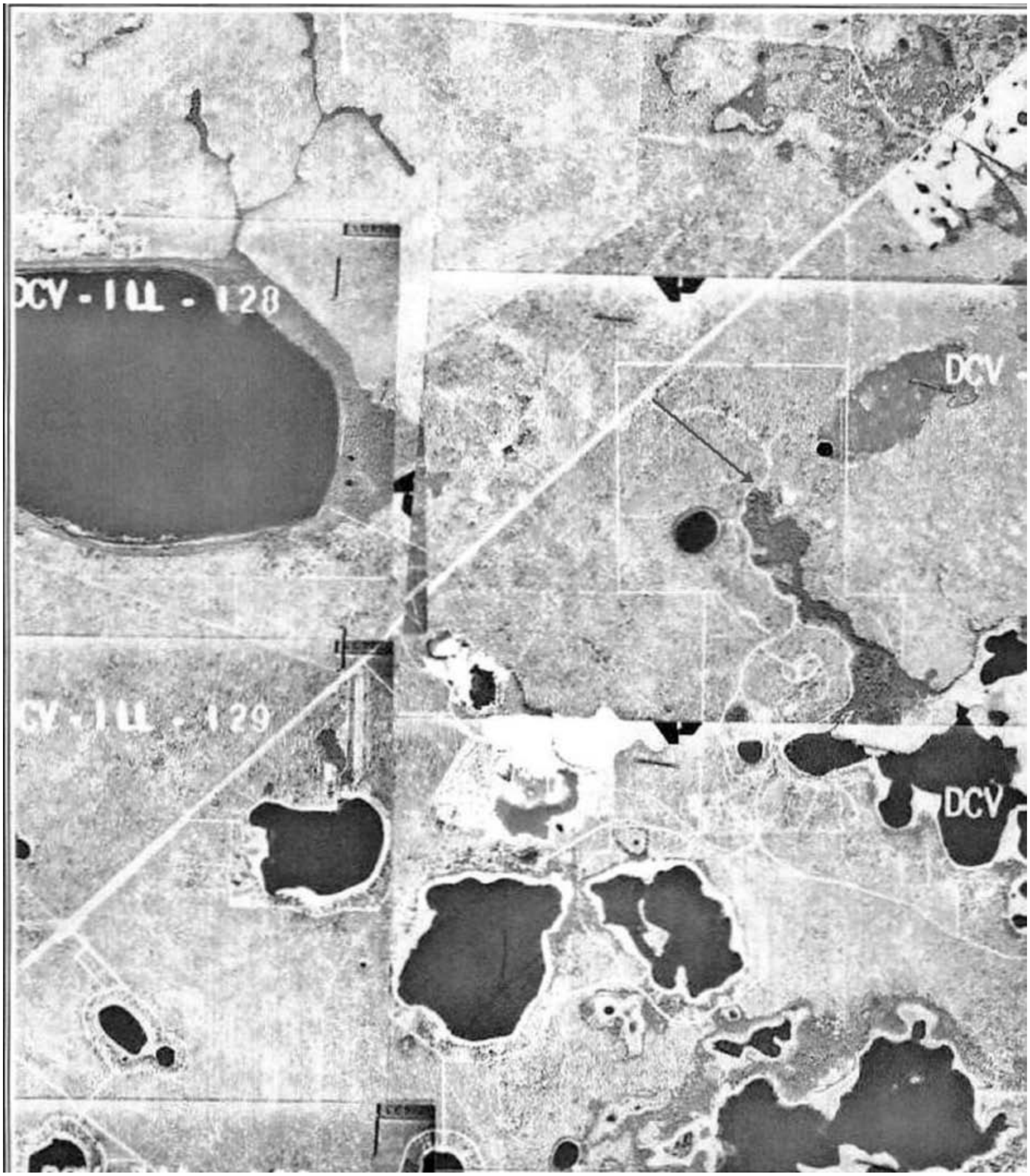

Figure 1-13. Aerial photograph of Gold Head area – 1970.

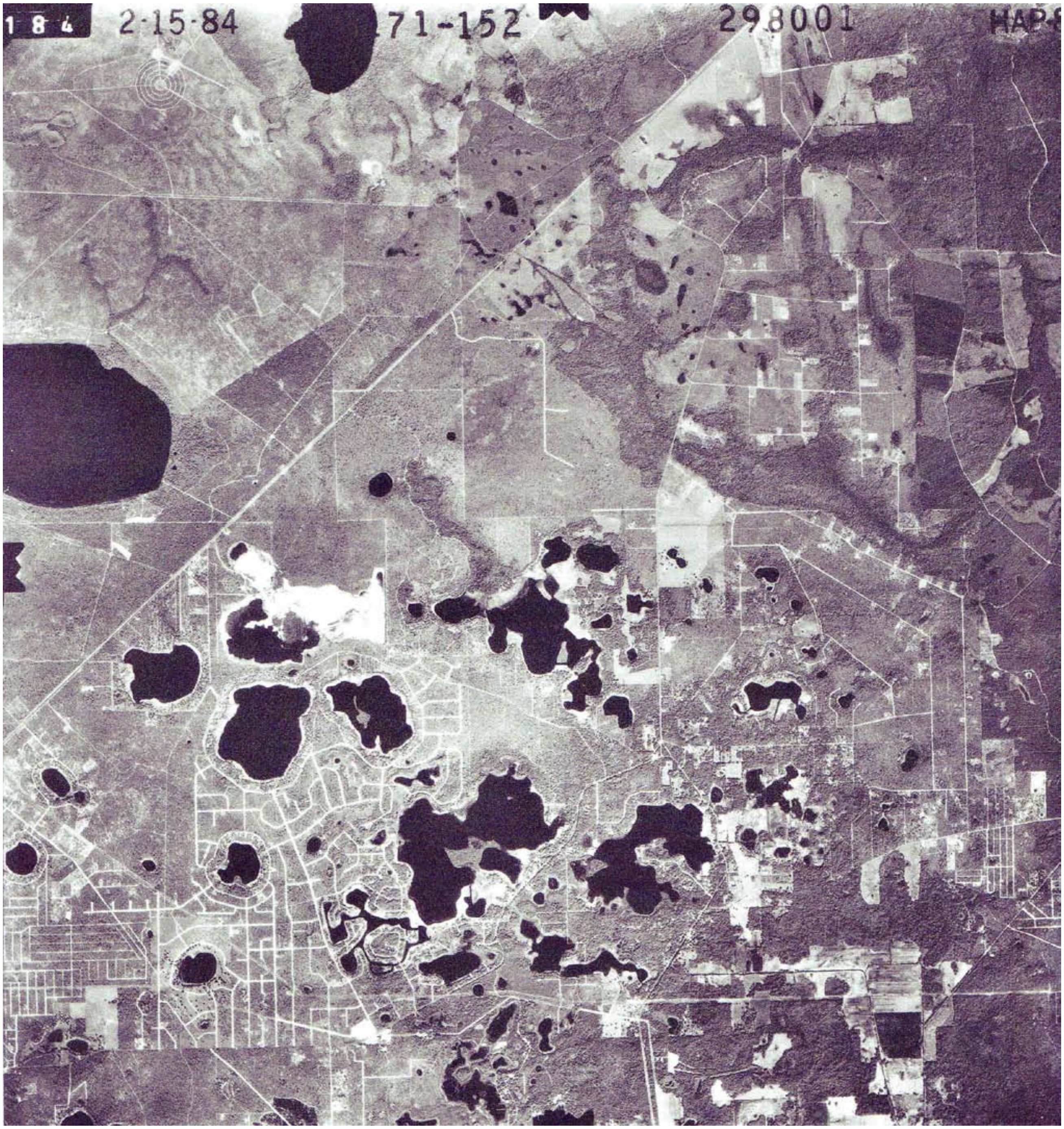

Figure 1-14. Aerial photograph – February, 1984. Gold Head in central portion of photo.

Figure 1-15. Regional aerial photo, 2006 (note – Lake Lowry is large lake WNW of Gold Head Park.

CHAPTER 2
STUDY AREA AND LITERATURE REVIEW

2.1 Geologic Setting and Geohydrology

The ravine at Gold Head Branch State Park and the physical environment of the nearby area have been created and shaped by several geological processes. The ravine lies on the extreme southern end of the Trail Ridge geomorphological feature which is thought to have a relict littoral origin representing a barrier or spit which had a lagoon or sound to landward during a period of sea transgression (White, 1970). The Trail Ridge is a relict marine feature probably associated with the Okefenokee Shoreline (McNeil, 1950). The existence of the Gold Head ravine and seepage springs may be related to depositional controls that existed during the formation of the Trail Ridge. Its exact relation to sea level is not clear but the southward littoral drift on the eastern Atlantic seaboard is thought to have existed for a long time based on not only current capes and spits which have distal ends extending southward but also from similar tendencies of relict spits and capes such as the Lake Wales Ridge. The northernmost expression of the Citronelle formation sediments of the Lake Wales Ridge is thought to occur near the Gold Head ravine (Ketner and Mcgreevy, 1959). The Citronelle was deposited during the late Pliocene and early Quaternary as a fluvial feature with sediments originating from the north (White,1970 and Pirkle,1960). These sediments were reworked by coastal processes such as washing and resorting (Doering, 1960).

Sea level changes during the Pleistocene occurred several times along the Florida coast and associated sediment deposition was influenced by the Central Highlands or Peninsular Arch – a land ridge trending north-south through the center of the Florida peninsula. Based on the preservation of the lower sections of relict beach ridges, marine transgressions did not cover the Central Highlands subsequent to their formation (White, 1970). The basins occupied by lakes which parallel the relict beach ridges are arranged in lines along the length of the ridges. These lakes would seem to be first generation sinks rather than second or multiple generation karst reactivated after marine submergence and reemergence, since second generation sinks would not plausibly be related in pattern to beach ridges which postdate their original development (White, 1970).

Beneath the surficial sediments lies limestone that has been subject to differential dissolution creating sinkhole lakes. Changing sea levels,water tables, surface erosion, arterial flow, and barrier island configurations led to increased erosion in isolated swales between beach ridges. These processes contributed to dissolution of the underlying limestone. Sinkholes in Florida nearly always form in areas of recharge to the Floridan aquifer. Three types of sinkholes are present in central Florida – subsidence, solution, and collapse, and are related to the thickness of sediments overlying the limestone of the Floridan aquifer. Subsidence sinkholes occur when there is a thin layer of sediments overlying the limestone and solution sinkholes are formed when the limestone is exposed at the surface. Collapse sinkholes are usually created during drought periods although extended heavy rainfall can also precipitate collapse as the weight of the overburden exceeds the structural integrity of the roof. In areas where the overburden is relatively thick but the intermediate confining unit is breached or absent, the formation of collapse sinkholes occurs. Collapse happens due to weakening of the Floridan carbonates by erosional and solution processes and is often triggered during periods when the aquifer water levels are low.

The oldest carbonates in the area are of Eocene age – the Oldsmar and Lake City limestones characterized by fragmental, dolomitic limestone . The Avon Park Limestone exists above these formations and although similar to the Oldsmar and Lake City Limestones, contains interbedded peat lenses (Clark, et al., 1964) which are thought to represent a former lagoonal environment enclosed by a broad carbonate bank (Chen, 1965). The Avon Park is approximately 300 feet below sea level in the Gold Head area and is overlain by the Ocala Group limestone (which is the principal aquifer for Florida) and consists of gradational layers of weathered limestone and alternating layers of hard to soft, tan to brown crystalline limestone and dolomitic limestone (Clark et al., 1964). The surface of the Ocala is often highly weathered and in the Starke, Florida area (approximately 20 miles west of Gold Head) is known to be approximately 230 feet thick (Puri and Vernon, 1964). The Hawthorne Formation of Miocene age overlies the Ocala Group in Northern Florida and consists of a heterogenous mix of sand, silt, clay, marl, shell, and carbonates. The Gold Head ravine is within the Interlachen Karstic Highland which represents a significant recharge zone regionally for the Floridan aquifer (Figure 2-1). The ravine is slightly east of the center of the recharge area and the potentiometric contours near the Gold Head Branch State Park indicate an east-southeasterly subsurface flow within the Floridan aquifer towards Etonia Creek and the St. Johns River (Figure 2-2). The steepness of the ravine slopes (Figure 2-3) suggest that the surficial water table has been intercepted and the piezometric surface of the Floridan aquifer at Gold Head probably fluctuates and coincides with that of the surficial water table (Figure 2-4).

The lakes and Gold Head Branch stream formed by the seepage within the ravine are part of the Etonia Creek Basin which comprises approximately one hundred lakes in a two hundred and thirty square mile drainage area. The water quality within the Etonia Creek Basin is very good and a study of Lake Johnson (the discharge point for the Gold Head Branch stream approximately one and a half miles from the steephead headwall) reported the water is low in organic matter, iron, nitrates, and phosphates. The average pH for Lake Johnson (now called

Little Lake Johnson and Big Lake Johnson due to historically low water levels) was on average 5.5, a comparatively low value in the region (Clark et al., 1964; Snell and Anderson, 1970). The sandhills around the ravine have high infiltration rates and allow very little runoff, so the lakes within the Gold Head Park rely on rainfall directly upon their surface and seepage from the subsurface for their recharge. Sheeler Lake (immediately west of the ravine – Figure 2-5) and Deer Lake (northeast of the ravine – Figure 2-6) are approximately sixty feet deep, indicating a direct connection to the Ocala limestone (Floridan aquifer).

Lake Brooklyn in Keystone Heights and several other lakes in Clay County have been the focus of numerous reports and studies since the mid-1950's when the area experienced a severe drought. Relatively high water levels are shown in the earliest aerial photos of the Gold Head Park area taken in 1943 (Figure 2-7) and 1953 (Figure 2-8). The levels of Lake Johnson (Figure 2-9), Sheeler Lake, Deer Lake, and Pebble Lake within the Gold Head Branch state park have also been affected by drought although the nearby large sand mining pit, operated by Florida Rock Industries, might also be influencing the record low level within Pebble Lake which is immediately downgradient (west of) the sand pit. An aerial photo taken in 2006 (Figure 2-10) illustrates the lowered water level in Lake Johnson.

The USGS performed the first comprehensive investigation of the area in the 1950's and the results were reported by Clark, 1963 and others and included the local hydrogeology and hydrology of the upper Etonia Creek Basin. An infrared image of the Etonia basin (Figure 2-11) illustrates the lowered lake levels in the area. Later, in the 1990's the SJRWMD and the University of Florida researched the interaction of the surficial aquifer, intermediate aquifer, and Floridan aquifer. Motz and others (1991) developed groundwater flow models to aid in regulating lake levels and creating surficial water diversion projects to increase the water level in

Lake Brooklyn at Keystone Heights, most of which have had limited effectiveness. The Gold Head Branch state park has had lake levels monitored since 2001 at Sheeler Lake, since 1948 at Pebble Lake and Little Lake Johnson, and since 1958 at Big Lake Johnson, but research concerning groundwater flow and the geohydrologic system related to the seepage at the steephead and within the ravine has not been studied previously.

In areas that exhibit steephead ravines numerous investigations have previously concurred that “Groundwater percolates downward through the surficial sediments until it encounters a clay or marl. It then travels horizontally over the less permeable strata and emerges as a small spring or seep at a bluff face” (Rupert,1991) or “Many of the springs at the heads of the steephead appear to be localized along extensive layers of clay or hardpan” (Marsh, 1966). However, experiments by Howard, 1990 performed under laboratory conditions indicated that seepage drainage features can form in homogeneous sediments (Figure 2-12). Howard’s research showed that valley head erosion occurs by episodic headwall slumping, and the gradient of the experimental channels downstream of the sapping head is directly controlled by the slope of the water table in homogeneous sediments. An investigation by Schumm (1995) also indicated that steephead ravines can form in homogeneous sediments.

The development of drainage patterns relative to these steephead features often doesn’t conform to Horton’s classic pattern of development . The lack of conformance to Horton’s relations is theorized to be the result of incompletely developed drainage patterns (Schumm, et al., 1995). Advance of the steephead wall may be episodic and possibly related to fire (which destroys vegetation leading to increased erosion and mass movement), human activities, groundwater capture by other streams that might redirect groundwater flow away from the springs, and extensive and prolonged rain events. The land surface of sapping features is often flat or gently rolling, and the infiltration capacity of the soils usually exceeds the precipitation rates so Horton overland flow is rare or nonexistent.

2.2 Geomorphology and Fluvial Processes

Steephead ravines in Florida, including the Gold Head Branch, appear to have similar drainage configurations and share common characteristics of sapping features with sites in Colorado, Hawaii, New Zealand, Netherlands, Mars, and a few other select locations. Headward growth of valley heads and the development of drainage networks wholly or partly by the outflow of subsurface water have been among the most neglected and least understood factors of landform genesis (Higgins, 1984). Two different but related processes are involved: erosion by shallow throughflow or outflow of soil water (piping) and erosion by outflow of groundwater (sapping). Sapping refers to the undermining of the base of a cliff, with subsequent failure of the cliff base (Bates and Jackson, 1980). Undermining of the cliff can be caused by lateral erosion of a stream, wave action, artificial excavations, and boring mollusks (Vita-Finzi and Cornelius, 1973). The term sapping is sometimes used referring to glacial plucking or freeze-thaw at the base of cliffs in a periglacial environment. Although piping and sapping are sometimes used interchangeably (Dunne, 1980), piping is affected by soil-water through flow or shallow interflow through pipelike openings in silty soils and sediments (Jones, 1981). Progressive enlargement and collapse of a pipe may extend a gulley up a slope and extensive gulley systems exist in silts throughout the world (Gibbs, 1945). Sapping differs from piping and generally refers to groundwater outflow or seepage and is not restricted to silts or clay loams (Higgins,1982).

Groundwater sapping may occur rapidly by hydraulic pressure in unconsolidated sands (such as a receding tide at the beach) or slowly by concentrated weathering and gradual removal of consolidated sediments in seeps or springs at valley heads. At valley heads where sapping is active, groundwater outflow may be intermittent instead of continuous, such as the box canyons in the southwest United States, where Gregory, (1917) found that groundwater seepage or flowage may only occur an hour or more after a storm and then continue for only a few hours or days. Extensive escarpment valleys “coombes” occur in the English chalk formation but are now dry. These valleys are incised by blunt-end trenches that head at active springs in the valley floor and Small, (1964) concluded that the valleys were eroded headward by scarp-foot springs when the water table was higher. Images from Mariner 9 and the Viking Orbiters from 1969 through the 1970’s (Figure 2-13) rekindled interest in sapping features since Mars exhibits “fluvial features” that seem to have formed, at least in part, by some process of fluid outflow (Higgins, 1982).

Sapping valleys in Florida (Figure 2-14) are locally known as “steephead” ravines and have similar drainage configurations (Figure 2-15) to locations in other regions of the world. Drainage systems formed by sapping commonly are steep sided and blunt ended and the valley sides and heads meet the floors at a marked angle. The valley floors are commonly broad but width can vary irregularly along the length. The sapping valleys lack catchment swales or channels above their steepheads and usually have angular courses that represents some sort of subsurface control (Higgins, 1982). The longitudinal profile of sapping valleys usually differs from a fluvial eroded drainage network - the headwall region is considerably steeper than an incised channel (Figure 2-16). Sapping valleys with steepheads commonly have dendritic drainage patterns, relatively constant valley width, long main valleys with short tributaries, high tributary junction angles (55-65 degrees), and other characteristics (Schumm et al., 1995) that are similar to the Gold Head Branch system.

In the southwestern United States sapping frequently occurs where a massive sandstone overlies a shale, and groundwater movement is concentrated along joints, faults, and folds. The process of sapping in basalt and sandstone involves weathering and weakening of the rock (Stearns, 1936: Howard, 1990). The characteristics of sapping valleys in the Colorado Plateau and Hawaii include (Kochel and Piper, 1986; Howard, 1988; Kochel and Baker, 1990): light-bulb shape of basin, basin-area to canyon-area ratio is low, low drainage density, dendritic drainage pattern, theater or cirque-like valley heads, steep valley walls and flat valley bottoms, relatively constant valley width, structural control of valley alignment and planform, long main valleys with short stubby tributaries, high tributary junction angles (55-65 degrees), and hanging tributary valleys.

One of the largest drainage networks that has been attributed to sapping processes is in the central, eastern, and southern portions of the Netherlands (Devries, 1976). Holland is underlain by permeable Plio-Pleistocene alluvium and Pleistocene aolian sand and the infiltration capacity of the soils usually exceeds the precipitation rates on a mostly flat surface so the drainage system developed principally by groundwater outflow. Stream channels in Holland are sometimes called linear groundwater drains (Devries, 1974) acting in a groundwater outcrop erosion model (GOEM). In the GOEM concept the excess infiltration capacity of the soils is neglected and the surface drainage system is controlled by the climate, the topography, and the resistance of the subsurface to groundwater flow. This contrasts with the Horton model (1945) where surface runoff occurs when the infiltration capacity is exceeded and the potential for erosion exceeds the resistance to erosion. The drainage system developed by the Horton model is controlled by climate, topography, and the erodibility of the upper soil layers. The Horton model emphasizes throughflow and overland flow with subsequent channel initiation. The

Netherlands widely-spaced modern drainage system developed at the beginning of the Holocene upon a previous that existed during the Pleistocene. The drainage system developed by headward erosion through high precipitation rates occurring at low frequencies resulting in groundwater discharge or sapping within the drainage features. In contrast to the importance of the air-soil interface in the Hortonian model, the through flow model describes the situation where the greatest flows occur within the soil above some interface at which the permeability changes (Kirby and Chorley, 1967). The flow velocities of throughflow are considerably slower than overland flow, although much faster than many surficial aquifers could accommodate - typical overland flow velocities are about 27,000 cm/hour (Horton, 1945), whereas through flow velocities are approximately 20 cm/hour (Kirby and Chorley, 1967). In regions of groundwater sapping, the capacity of soils to accommodate relatively rapid movement of water towards the discharge features is critical towards formation of a sapping drainage network with headwall extension/retreat. Parallels between sapping box experiments and Mars "sapping" features includes basin length vs. basin width (Figure 2-17) and stream length vs. basin area (Figure 2-18).

The drainage pattern of steephead ravines usually doesn't conform to Horton's model and this is thought to be due to an incompletely developed drainage pattern (Schumm, et. al., 1995), although if steephead ravines can be tens of thousands of years old and have relatively constant width throughout their stream course, the point of maturity (or relatively steady-state condition) of a sapping ravine might occur much earlier than an incision into terrain that approaches a peneplain. Horton overland flow within and near sapping valleys is rare since the infiltration capacity of the soils usually exceeds the precipitation rates and the land surface is usually flat or gently rolling.

Groundwater sapping processes sometimes occur at an ocean beach (Figure 2-19). As waves recede from a beach face, the sheet of water flowing back into the ocean becomes thinner and breaks up into a reticulated diamond pattern that mimics the pattern of sand underneath it in a symbiotic relationship. Initially, the sand forms offset rows of alternating channels and bars or fans and the apex of each fan is fed by a narrow channel between the borders of the two fans above it. The residual water backflow is then concentrated in the established channels which it deepens and into which it deposits eroded sand. Outflow at the intersection dilates the sand and moves surface grains outward into the runoff forming gully heads which subsequently move headward up the slope in directions primarily controlled by directional permeability. Activity stops when the water table falls below the level of the gully heads (Higgins, 1982). Sometimes, outflow of water from the fans will form very small tributary rills (a few mm long) at the edges of the fans which act as water outflow or sapping mechanisms. A later stage of foreshore drainage development commonly includes a continuation of the rill network. When there is an impermeable substrate or the water table is relatively stable for prolonged periods, groundwater discharge often develops steep gully heads in the rill channels at the upper limit of saturation and continue along the intersection of the water table with the beach face. Groundwater sapping occurs due to increased pore pressure propelling the loose grains into the channel (Higgins, 1984). Subsequently, the gullies then advance headward up the slope by continued sapping and collapse of the unsaturated sand above. If the beach face is sloping more steeply than the water table (common with coarse sands), then the gullies can't advance very far but in fine sand where the beach face commonly parallels the water table, gullies can advance headward quite far without gaining depth. Directional permeability may partially control the gully development and could be the result of nonuniform sorting within earlier patterns in the beach sands. When the water table drops below the base of the gully head, sapping ends and the grain movement/gully development stops. These relict features are usually short-lived but provide a glimpse of processes that are similar to those on Mars and since there has been little or no surficial activity on the planet Mars for a very long time, sapping features on Mars are relatively well preserved.

2.3 Soils and Plant Community

The excessively drained soils of the sandy ridges in southwest Clay County were originally deposited as ancient beach dunes. This soil type, the Chandler, contains very little organic matter and has a high oxidation rate indicated by its white color. The sandhill community dominated by long-leaf pine and turkey oak is typical of a drought stressed soil. The mixed hardwood community at Gold Head is dominated by laurel oak (quercus laurifolia), live oak (quercus virginiana), and pignut hickory (carya glabra) and occurs on the steep slopes within the ravine (Soil Survey Staff, 1981). The Chipley and Ortega series soils are characteristic of the upland areas near the ravine in Gold Head and consist of mostly fine sand with little silt and clay (five to ten %) to a depth of eighty inches or more (Soil Survey Staff, 1973). They are formed in nearly level areas and have a darker A horizon (surface) than the Chandler series and the C horizon below is yellow-brown (Soil Survey Staff, 1977).

The lowland soils in the Gold Head ravine are also principally sand but not as well drained as the upland and slope soils since they are often saturated. These soils comprise the Rutledge series and the surface is often black loamy sand with roots and are strongly acidic (Soil Survey Staff, 1967). The lowland soils occur in nearly level terrains dominated by loblolly pine (pinus taeda), slash pine (pinus elliottii), water oak (quercus nigra), and wax myrtle (myrica cerifera) (Soil Survey Staff, 1982).

A series of soil cores were taken by White, 1983 in the Gold Head area and analyzed for organic matter, pH, calcium, phosphorus, iron, magnesium, and potassium. Bottomland samples were consistently higher in potassium, calcium, magnesium, and organics although pH was lower than the slope or ridge samples (Figure 2-20). Although nutrient levels appear to be high for the low wet areas, the constantly moist conditions in many of these areas restricts the availability of nutrients so the accessable amount may actually be low (White, 1983). Potassium, calcium, magnesium, and organics all decreased with distance from the Gold Head Branch stream, demonstrating the increased soil fertility the closer one is to the stream. Since all the soils are derived from ancient beach ridges and resorted fluvial deposits, soil types probably resulted from any particular location's relation to the surficial water table, slope, and accumulation of organic debris.

The plant community within and around the Gold Head Branch ravine is diverse and uniquely adapted to an unusual geomorphological feature. Five different communities have been identified in the study area – southern mixed hardwood, sandhill, xeric oak scrub, ruderal, and streambank (Figure 2-21). The southern mixed hardwood community includes sweet gum (liquidambar styraciflua), black gum (nyssa sylvatica), silver magnolia (Magnolia virginiana), swamp bay (persea palustrus), laurel oak (quercus laurifolia), and pignut hickory (carya glabra) in the upper portion of the ravine while the lower portion near Lake Johnson supports abundant slash pine (pinus elliotti), loblolly pine (pinus taeda), and long-leaf pine (pinus palustrus). The sandhill community in Gold Head is predominated by turkey oak (quercus laevis) and long-leaf pine (pinus palustris) with understory trees including red cedar (juniperu silicicola) and persimmon (diaspyros virginiana).

Prior to logging activities begun after the Civil War long-leaf predominated although reseeding efforts and controlled burns in the recent past have aided in pinus palustrus making a comeback. Wiregrass is abundant and many different shrubs and herbs are present. Monk

(1968) measured a higher species diversity (seventy two different species) in the sandhill herbaceous layer than in any other Florida community in the study. Lichens are also abundant – some among dead wood and leaf litter although many occur higher in the trees thereby being able to withstand the hot summers and nutrient poor conditions of the sandhills. The xeric oak scrub occurs as an interface between the mixed hardwood community and the sandhills where the ground is nearly level and the vegetation is usually dense and woody (White, 1983). Sand pine is mostly absent from the xeric oak scrub community and occurs as a few small islands in the sandhills. Herbs are sparse in the scrub since litter is not abundant although lichens are numerous and diverse. The ruderal community occurs in areas where significant human disturbance has caused soil campaction such as trails, roads, and parking areas. Also, the area near Deer Lake was previously farmed and some old field plants such as cotton weed occur there. The final plant community at Gold Head is the streambank where a dense canopy allows little light to reach the ground and the moist soil conditions support several different mosses – twenty-five different mosses and hepatics were collected by White, 1983. Also, ferns grow in dense groups underneath a canopy predominated by swamp bay (persea palustris), sweet bay (magnolia virginiana), pipestem (agarista populafolia), and black gum (nyssa sylvatica). Salamanders thrive within the Gold Head ravine and herpeto-faunal research has been conducted at several different steephead ravines in Florida utilizing drift-fences.

Sheeler Lake contains the oldest record of the mass occurrence of broad-leaved forest in the southeastern United States at the end of the late Wisconsin glacial period (Watts, 1980). Lake sediments contain a continuous pollen record dating back to 24,000 years ago and at the end of the Wisconsin glacial period (approximately 14,000 years ago) there was a warming trend with an increase in precipitation. The mesic forest declined in the area approximately 12,000 years ago as pine and oak began to dominate the forest. Few limestone sink lakes in Florida and southern Georgia have long, uninterrupted records of sedimentation. The relatively shallow lakes were mostly dry before 8,500 years ago because the water level in the Floridan aquifer within the Ocala limestone was significantly lower during the dry, late Wisconsin period. The location of Sheeler Lake near the center of a stable major groundwater recharge zone allowed the lake to continuously hold water and create a pollen record spanning 24,000 years.

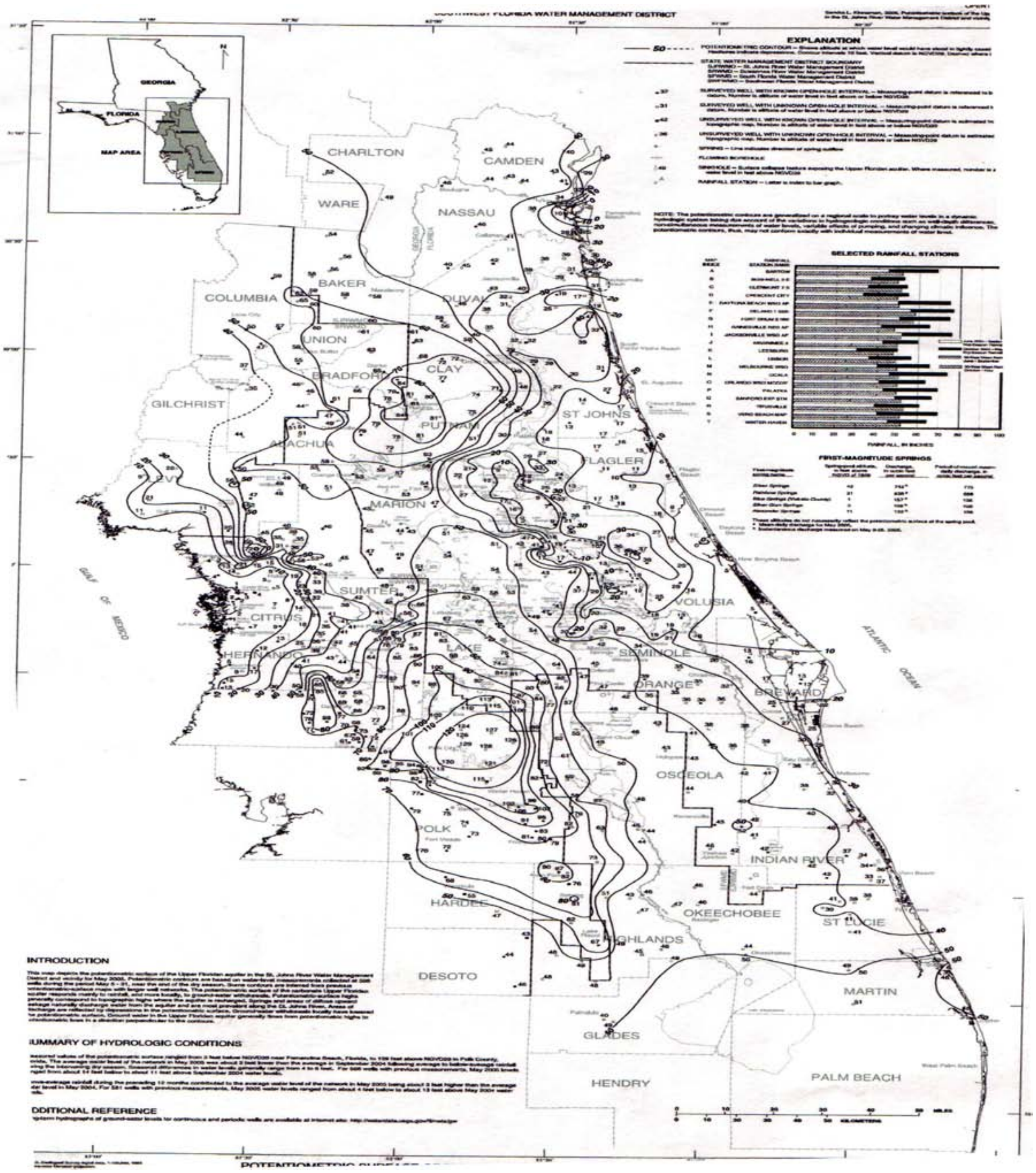

Figure 2-1. Potentiometric map of Floridan Aquifer (U.S.G.S., May, 2005), zoom to 500% for data values (feet msl).

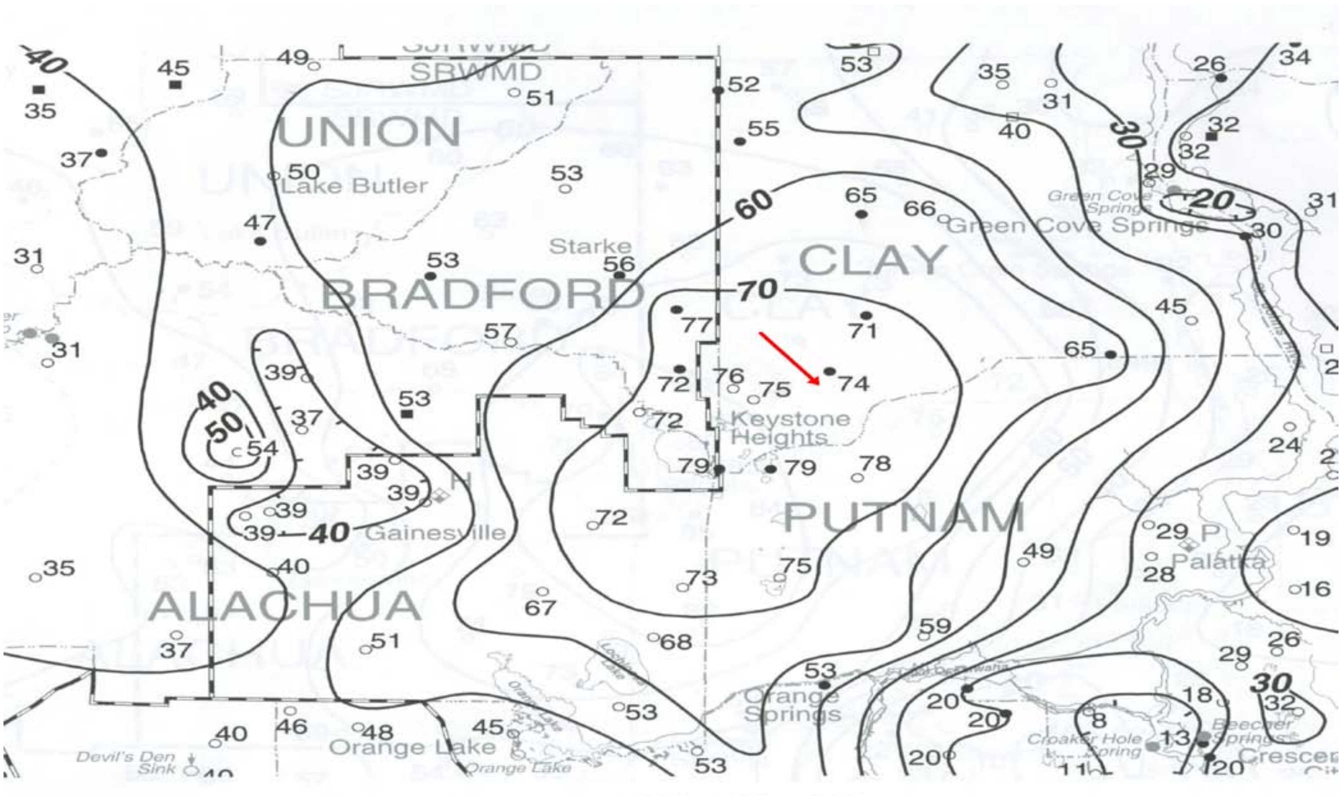

Figure 2-2. Potentiometric map of Floridan Aquifer – U.S.G.S. Septmber 2002 (arrow indicates Gold Head Park location).

Figure 2-3. Gold Head Ravine Sidewall – Note: Near vertical slope at base (2007).

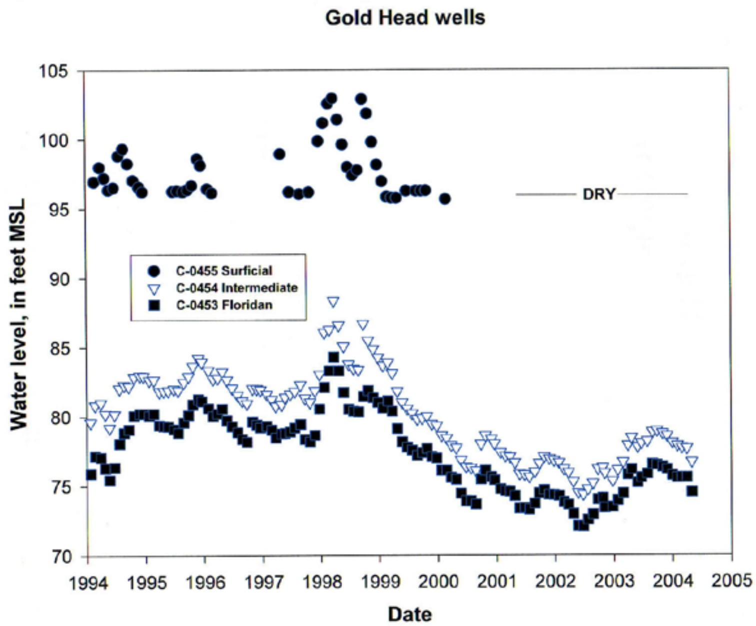

Figure 2-4. Gold Head Branch State Park supply wells water levels (USGS).

Figure 2-5. Sheeler Lake – Looking SE – Note former lake bed in foreground (2008).

Figure 2-6. Deer Lake – Looking Northwest (2008).

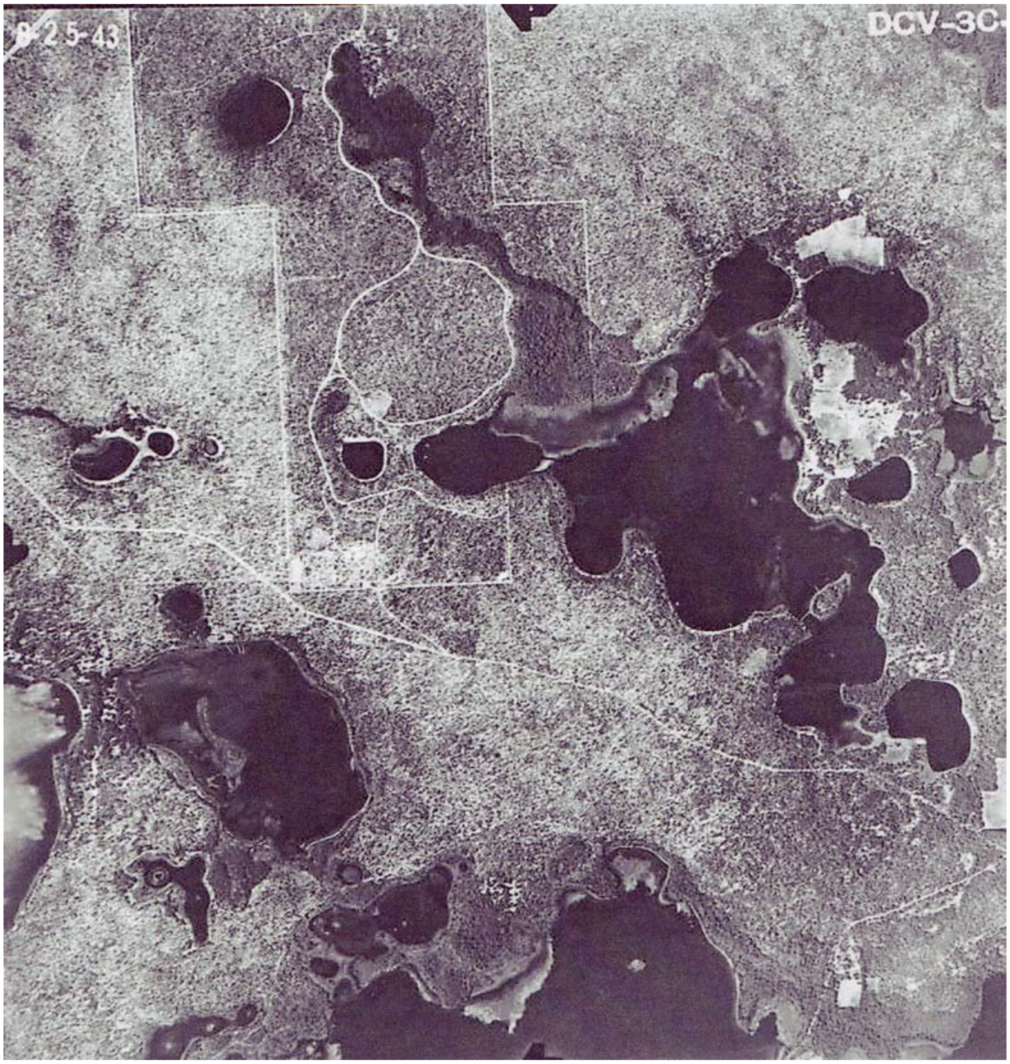

Figure 2-7. Aerial photograph of Gold Head – September, 1943.

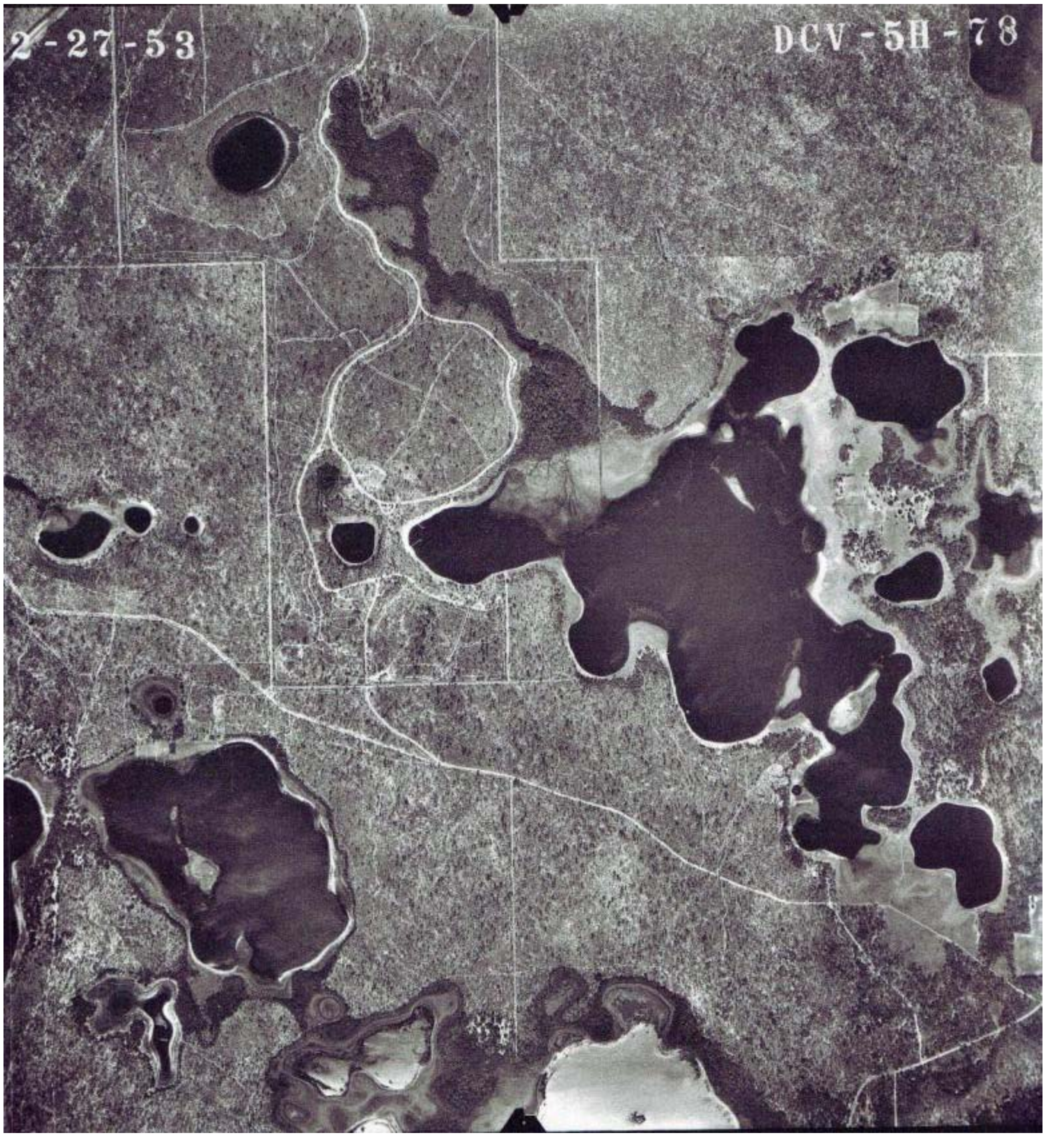

Figure 2-8. Aerial photograph of Gold Head – 1953.

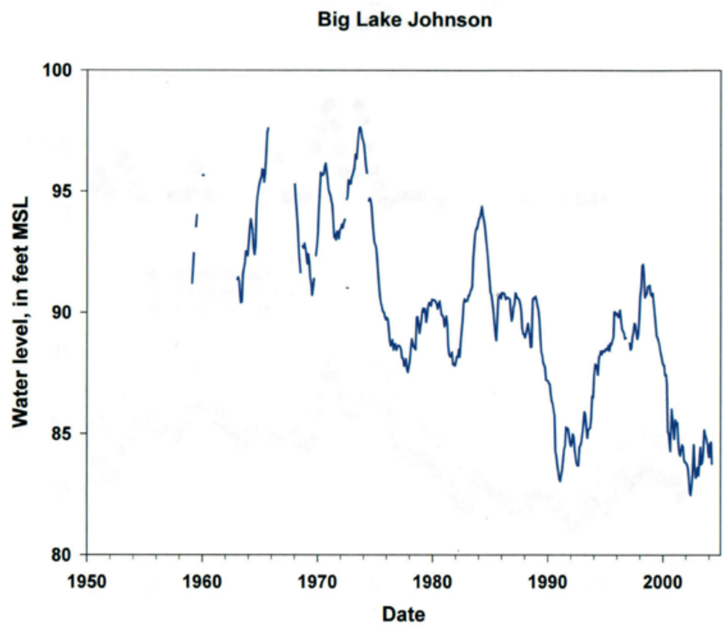

Figure 2-9. Big Lake Johnson water levels, 1960-2004.

Figure 2-10. Aerial photo of Gold Head Branch State Park – (FDOT) – 2006).

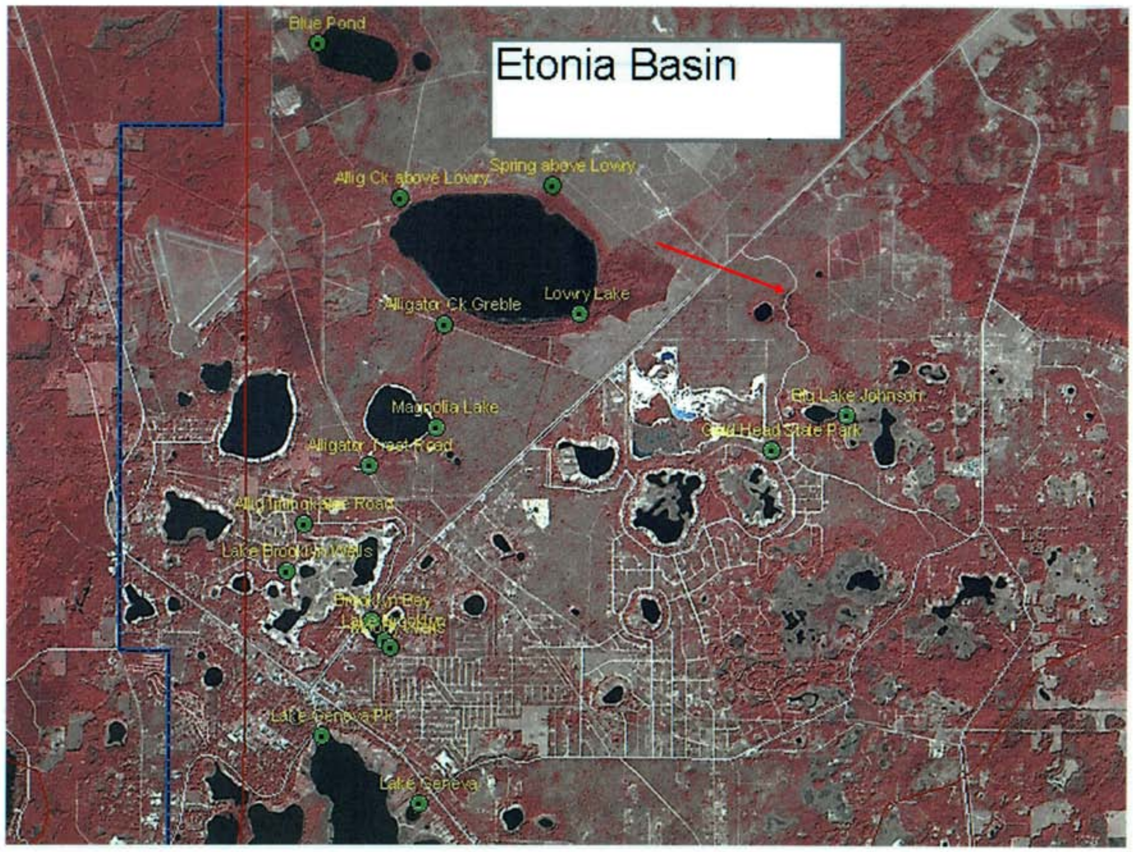

Figure 2-11. Regional infrared image of Etonia basin (arrow indicates Gold Head steephead location).

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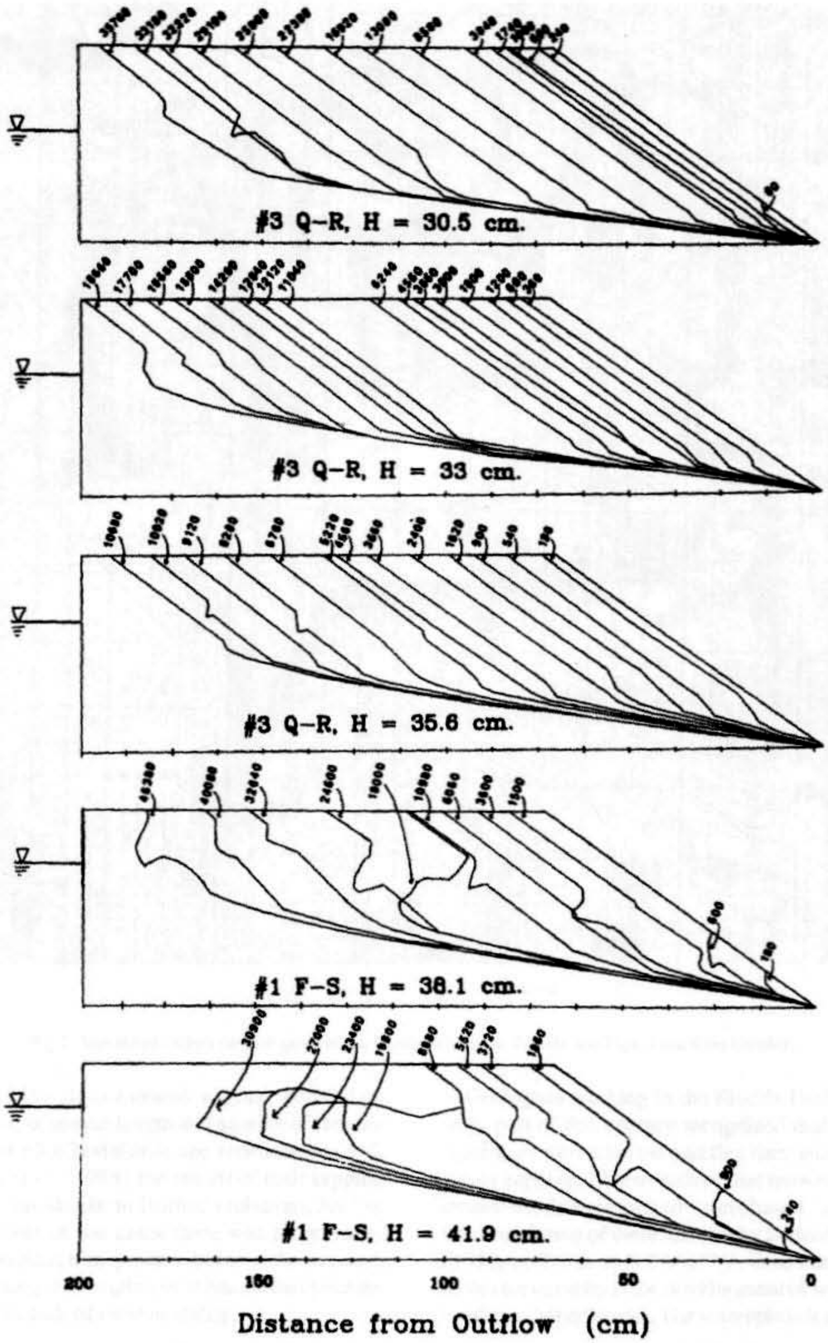


Fig. 2. Evolution of channels developed by sapping during 5 experiments. Elapsed time is given in seconds along the upper margin of each diagram. The line and triangular symbol to the left show the fixed hydraulic head relative to the outflow that was maintained during the experiment. Uniform, angular crushed quartzite was used in the experiments; #3 Q–R was a coarse sand and #1 F–S was a medium sand. H is height of water table in cm (from Howard, 1990).

Figure 2-12. Evolution of Channels Developed by Sapping during 5 Laboratory Experiments(Howard, A.D., 1990).

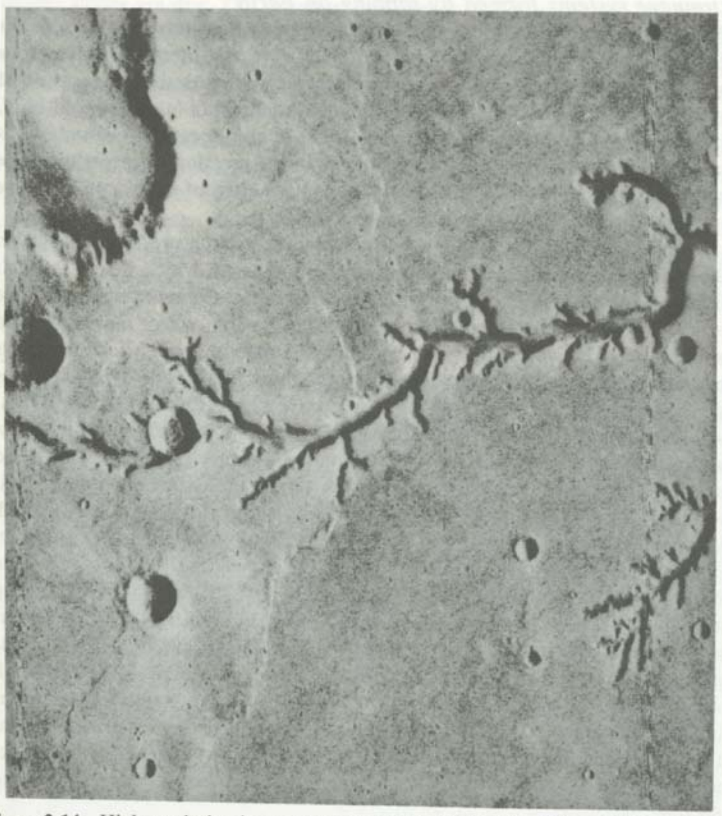


Figure 2.14 High-resolution image of part of the western end of Nirgal Vallis, about 500 km south of the eastern end of Valles Marineris. Nirgal is a valley-like form with a total length of about 700 km, which Baker (1980b) has shown must have been developed by outflow sapping. Specially processed Viking 1 Orbiter orthographic image, no. 466A54. Frame dimensions are 73 km × 80 km.

Figure 2-13. A High-Resolution Image of Part of the Western End of Nirgal Vallis, Mars (73 km x 80 km), (Higgins, C.G., 1982)

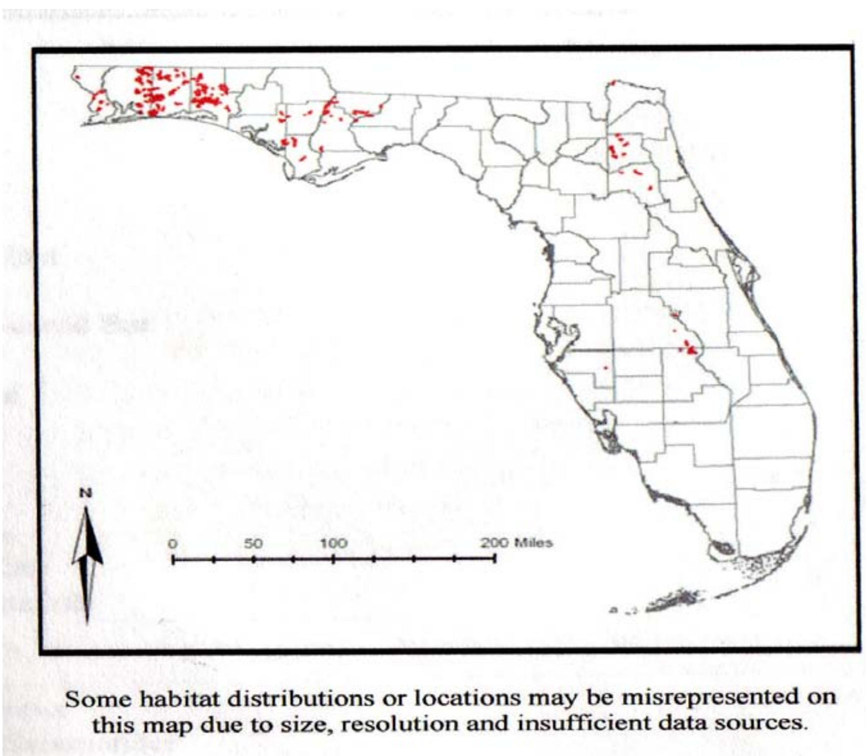


Figure 2-14. Florida Steephead Location Map (Haley, 2005).

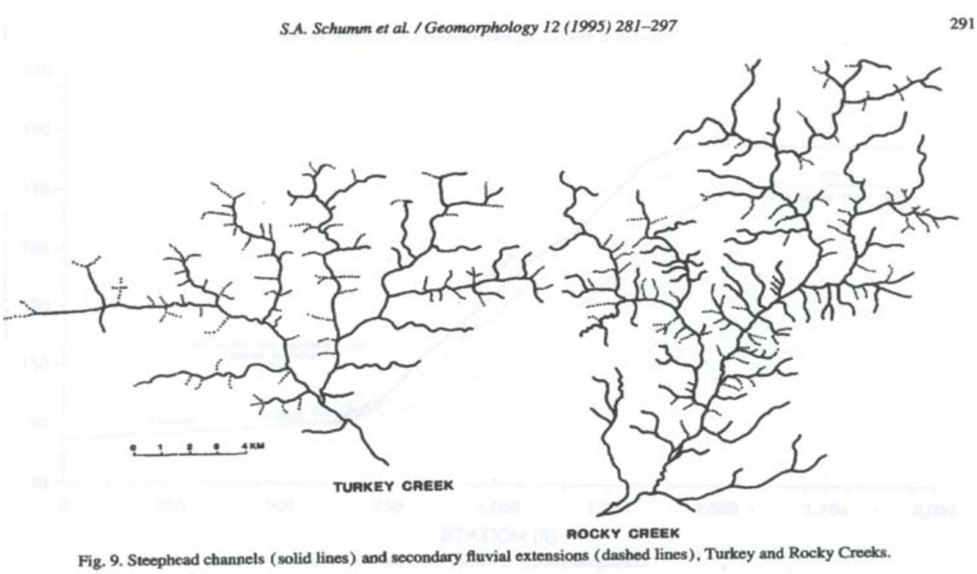


Figure 2-15. Steephead Channels and Secondary Fluvial Extensions, Turkey and Rocky Creeks, Florida Panhandle, Schumm, S.A. et al, 1995

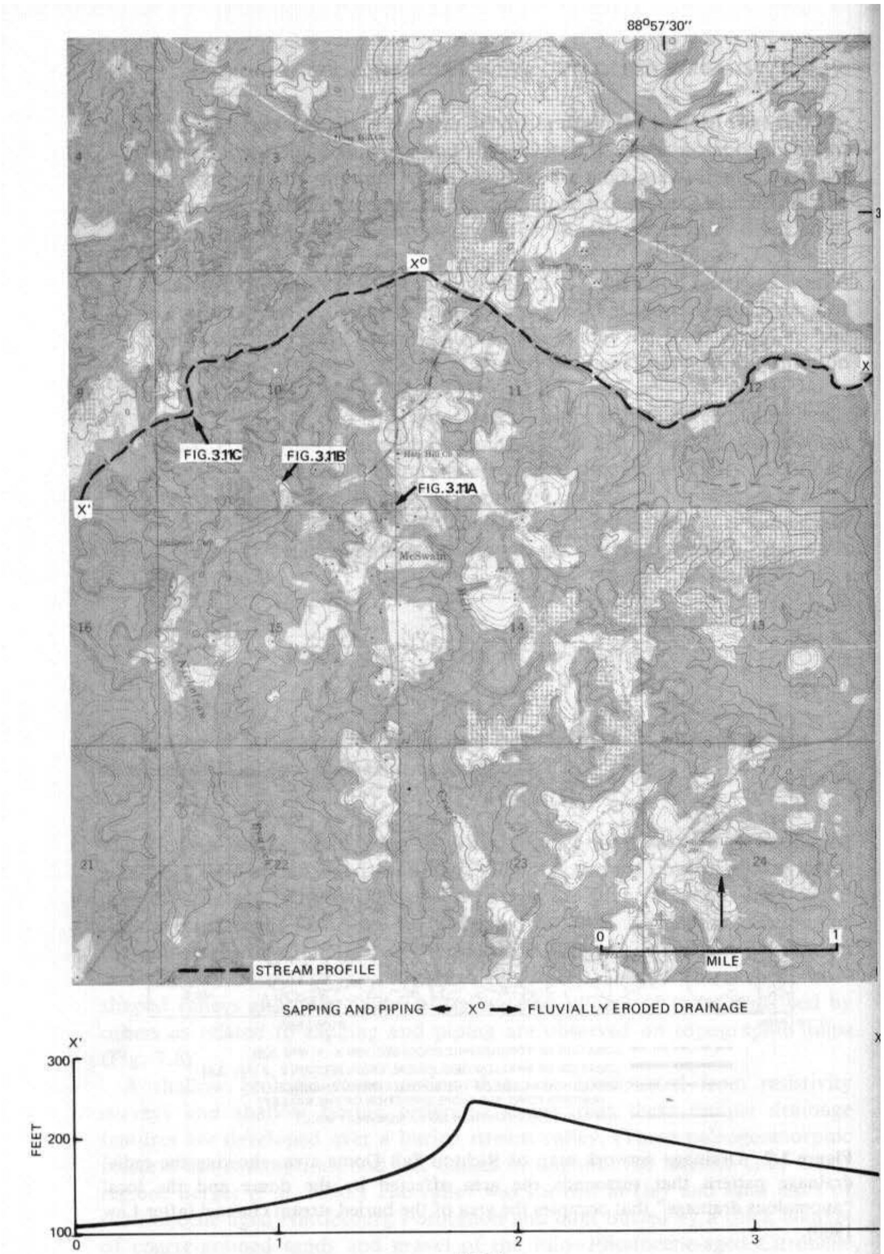


Figure 3.8 A topographic map and a stream profile of the southern part of Richton Dome area showing the distinct differences in topographic expression between fluvially eroded landforms and those that are formed under the influence of sapping and piping.

Figure 2-16. Longitudinal Profile of Sapping Valleys vs. Incised Channels Higgins, C.G. and Coates, D.R., 1990.

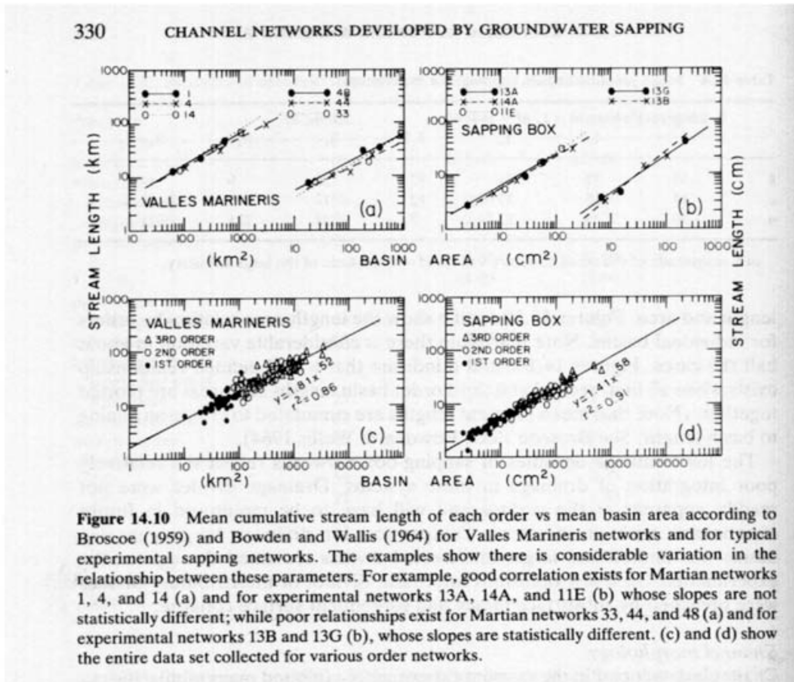


Figure 14.10 Mean cumulative stream length of each order vs mean basin area according to Broscoe (1959) and Bowden and Wallis (1964) for Valles Marineris networks and for typical experimental sapping networks. The examples show there is considerable variation in the relationship between these parameters. For example, good correlation exists for Martian networks 1, 4, and 14 (a) and for experimental networks 13A, 14A, and 11E (b) whose slopes are not statistically different; while poor relationships exist for Martian networks 33, 44, and 48 (a) and for experimental networks 13B and 13G (b), whose slopes are statistically different. (c) and (d) show the entire data set collected for various order networks.

Figure 2-17. Mean Cumulative Stream Length of each Order vs. Mean Basin Area for Valles Marineris Networks and Experimental Sapping Networks.(Higgins, C.G., 1982)

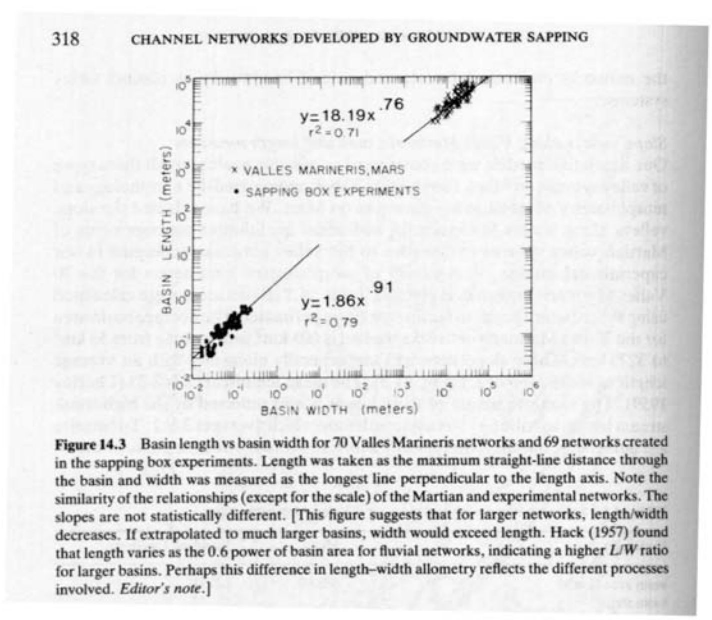


Figure 14.3 Basin length vs basin width for 70 Valles Marineris networks and 69 networks created in the sapping box experiments. Length was taken as the maximum straight-line distance through the basin and width was measured as the longest line perpendicular to the length axis. Note the similarity of the relationships (except for the scale) of the Martian and experimental networks. The slopes are not statistically different. [This figure suggests that for larger networks, length/width decreases. If extrapolated to much larger basins, width would exceed length. Hack (1957) found that length varies as the 0.6 power of basin area for fluvial networks, indicating a higher *L/W* ratio for larger basins. Perhaps this difference in length–width allometry reflects the different processes involved. *Editor's note.*]

Figure 2-18. Groundwater Sapping Basin Length vs. Basin Width – Mars vs. Sapping Experiments (Kochel, R.C. et al, 1985)

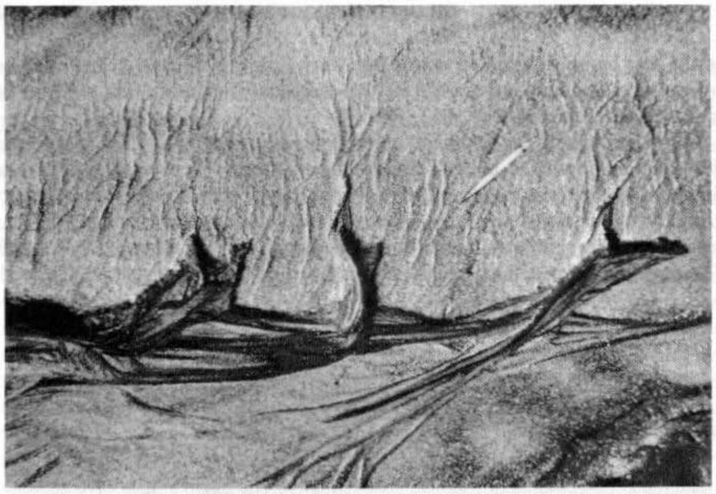


Figure 2.5 Initiation of small, steep-walled gullies by groundwater outflow sapping along earlier rill channels, Bermuda Avenue Beach, San Diego, California, February 2, 1971. Outflow and sapping were active when photograph was taken, but would not continue much longer; falling water table is indicated by successive terraces in middle gully and at right, and by abandoned highest headscarps. Width of view about 1 m.

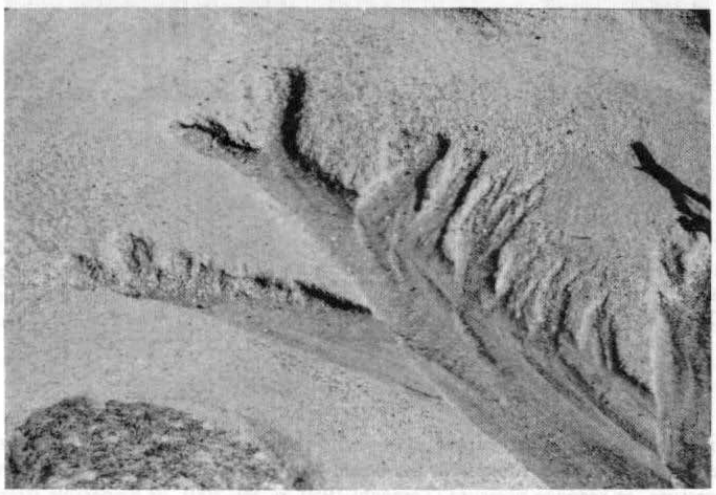


Figure 2.6 Active gullying by headward sapping entirely by groundwater outflow in coarse sand where locally steeper slope of the foreshore and constriction of groundwater flow owe to a partially buried boulder (lower left). Low tide at Carmel River Beach, February 1972. Trends of channels closely parallel those of the earlier diamond pattern. Width of view about 1.5 m.

Figure 2-19. During falling tides the foreshores of many beaches develop steep-headed incised drainage ways that are similar to larger scale drainage system features on Earth and Mars (Higgins, 1984). The beach sapping systems are formed by groundwater outflow where the water table intersects the beach face.

TABLE 1

Nutrient Content of Soil Samples Taken in Gold Head Branch Park

Samples from each of ten transects were combined for each core depth (0-10, 10-20, 20-30 cm). Each value represents an average of the three depths for a slope position. Nutrients are in ppm. The samples were analyzed by IFAS Soil Testing Lab.

	pH	%OM	P	Ca	Mg	Fe	K
Bottomland	4.5	2.70	2.3	78	36.0	3.8	17.0
Midslope	4.9	0.95	1.5	60	12.0	7.1	6.6
Topslope	5.2	0.46	3.8	25	5.0	12.0	4.0
Sandhill	5.2	0.43	4.1	16	1.0	11.4	5.3

Figure 2-20. Soil nutrient analyses from samples at Gold Head Branch Park (White, 1983).

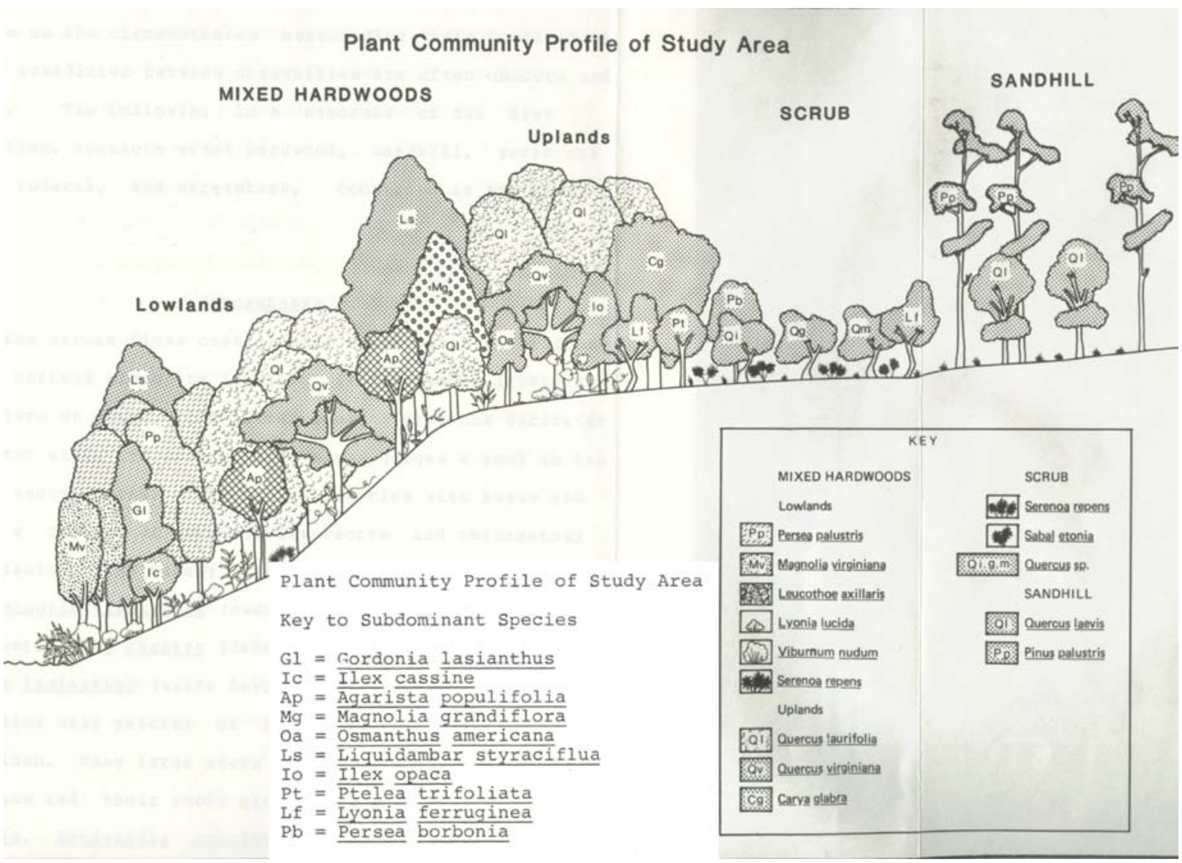


Figure 2-21. Plant Community Profile of Gold Head Branch Park (White, 1983)

CHAPTER 3
MATERIALS AND METHODS

3.1 Soil Borings

Soils immediately adjacent to the Gold Head ravine headwall and in the upper portion of the ravine were investigated to determine if there is a relatively impermeable layer present that restricts downward percolation of water. A borehole located near the Gold Head steephead wall was drilled to a depth of 68 feet below land surface (bls) utilizing a mud-rotary rig to sample the subsurface sediments with a split-barrel soil sample tube according to the American Society for Testing and Materials (ASTM) standard penetration test (SPT) guidelines (Designation: D 1586-99). The mud-rotary test borehole was drilled approximately 50 feet north of the steephead wall and two-foot split-spoon sampling was continuous from the surface to the end-of-boring (Figures 3-1 and 3-2). The surficial water table was encountered at approximately forty-one feet below land surface and the boring was continued to a total depth of sixty-eight feet below land surface. A cross-section of the steephead area illustrates the relationship of the surficial aquifer to the spring discharge and Gold Head Branch stream (Figure 3-3). There was no confining nor semi-confining layer encountered during drilling (Appendix A) and fine to medium sand predominated until fifty-five feet bls when silty to clayey sand with carbonates was encountered (with a trace of shell). This weathered zone represents reworked limestone mixed with ancient beach sand and fluvial deposits and is approximately ten feet below the level of the main springs issuing from the base of the steephead wall. Additionally, five hand augers were performed in the extreme upper portion of the ravine floor to a maximum depth of five feet and no confining nor semi-confining layer was found. Heaving sands from the hydrostatic pressure of the shallow water table prevented deeper boring even when a temporary PVC casing was installed (Figure 3-4). Clean white sand sampled from one of the hand augers represents an ancient beach ridge and is similar to sediment that is currently being surface mined nearby immediately west of the Gold Head Branch State Park. This formation underlies the entire course of the Gold Head stream and sieve analysis resulted in seventy percent medium sand and thirty percent fine sand with no silt or clay present.

3.2 Lake Levels and Hydrology

The lakes and Gold Head Branch stream (Figure 3-5) are in the upper portion of the Etonia Creek Basin which contains about 100 lakes, encompassing a 230 square mile drainage area acting as a recharge zone for the Floridan aquifer. Surface and shallow groundwater moves south-southeast to Etonia Creek which meets the St. Johns River north of Palatka. The surficial aquifer(s) are hydraulically connected to the Floridan aquifer (Ocala limestone) and published potentiometric maps of the area by the USGS indicates groundwater flow within the Floridan is east-southeast in the Gold Head park region.

The steephead ravine in Gold Head Branch State Park is an unusual geomorphological feature that has advanced headward by undercutting of the ancient reworked marine and fluvial sediments. It is possibly tens of thousands of years old and has advanced at a relatively slow rate of anywhere from a few inches per century to several feet (Howard, 1990) during and after events such as hurricanes, fires, and heavy sustained rain. The steephead has formed as a result of highly permeable soils and consistently abundant groundwater in a relatively stable geohydrological environment. Several smaller steepheads exist in the area although relict features of marine processes are present regionally because the very high infiltration rates of the soil and relatively low relief have limited surface drainage and erosion. The groundwater sapping valley at Gold Head doesn’t conform to the traditional Hortonian model of fluvial systems which is probably due to an incompletely developed drainage pattern unique to sapping valleys. Experimental studies of spring sapping valleys in homogeneous sediments seem to reproduce the conditions of steephead stream development very well, including the lack of need for an impermeable zone near the area of spring discharge. When lengthening of the ravine ceases or slows significantly, lateral seepage into the valley predominates and a long period of widening follows. The ravine at Gold Head is actively widening and this can be seen where groundwater seeps and springs are flowing from the base of the sidewalls.

3.3 Tree Rings

During this study, several tree cores were obtained from mature trees located in the upper portion of the ravine and the two best cores (hickory) were utilized to investigate the climatic signal stored within the trees. Coring the largest trees present near the steephead, three species predominated – hickory, magnolia, and sweet gum with the hickory trees occurring on the steeper slopes, often on the upper portion. The oldest tree cored was a magnolia occurring on the eastern slope of the ravine and dated to one hundred and forty-one years old, although most trees were between the age of seventy and one hundred years old. Fire scars were not observed in any of the cores – the steep upper portion of the ravine may be naturally protected from fire as well as logging operations since the slope varies from 40 degrees to near vertical in some areas. Variables analyzed for the tree core study include residuals from the tree ring widths, rain – Paynes Prairie, rain – Gold Head Park, rain – Camp Blanding, rain – Melrose, rain – (1946-2006), rain – Gainesville (University and Airport), rain – (June, July, August), rain – (June), rain – (July), rain – (August), rain – (September), rain – (Gold Head Park in August), rain – (weighted-June, July, August), temperature – (annual-average), temperature – (June, July, August – summed and averaged), and temperature – (August).

The tree core samples analyzed for this study were obtained from mature hickory trees utilizing an increment borer at breast height and advanced slightly beyond the center of the tree. The cores were stored within large straws and placed in a map case until they were mounted/glued on an oak core holder and subsequently sanded flat in steps using progressively finer sandpaper (#100, #220, #320, #400, #600, #1000, #1500) until suitable for microscopic analyses. Tree ring widths were measured and ordinary least squares regression provided residuals that were used to analyze possible relationships to climatic variables. Tree ring widths cannot be directly used to analyze the stored information – only the residuals (difference between the observed ring and the expected ring width from the equation for the line) are plotted against climatic/growth variables.

Tree ring series store information about tree history and forest dynamics. The principle factors that affect tree ring growth include precipitation, temperature, humidity, competition from nearby plants for sunlight, water, and nutrients, soil types, ageing – most species growth slows with maturity, and species type – growth rate varies considerably (Figure 3-6). Density varies within each ring from the earlywood (spring/summer) to the latewood (late summer/fall). The latewood is denser, contains resin ducts, and can be identified by its darker color and reduction of the number of vessels and vessel size as the tree prepares for dormancy during the winter.

Figure 3-1. Test borehole during continuous split-spoon soil sampling utilizing small, tracked rig near top of steephead headwall, facing south (April, 2007).

Figure 3-2. Mud-rotary drilling in progress – Ford F450 support truck for water supply (2007).

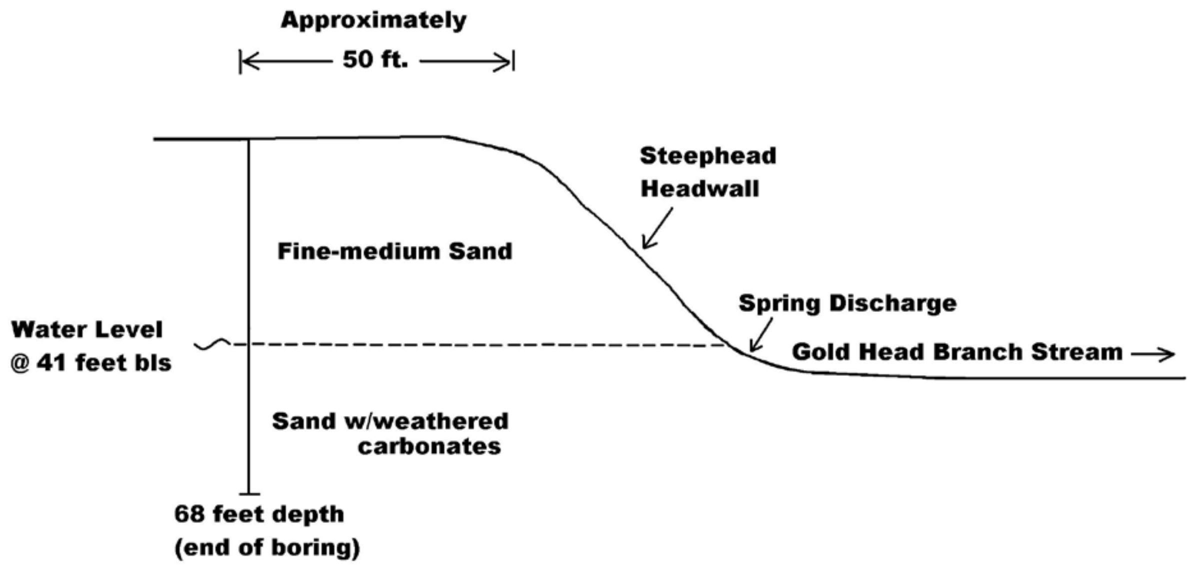


Figure 3-3. Cross-section of steephead headwall at Gold Head- (Note-not to scale).

Figure 3-4. Hand augering through temporary PVC surface casing near Gold Head ravine headwall (note sledgehammer and drive block), 2007.

Figure 3-5. Gold Head Branch stream – middle segment (2007).

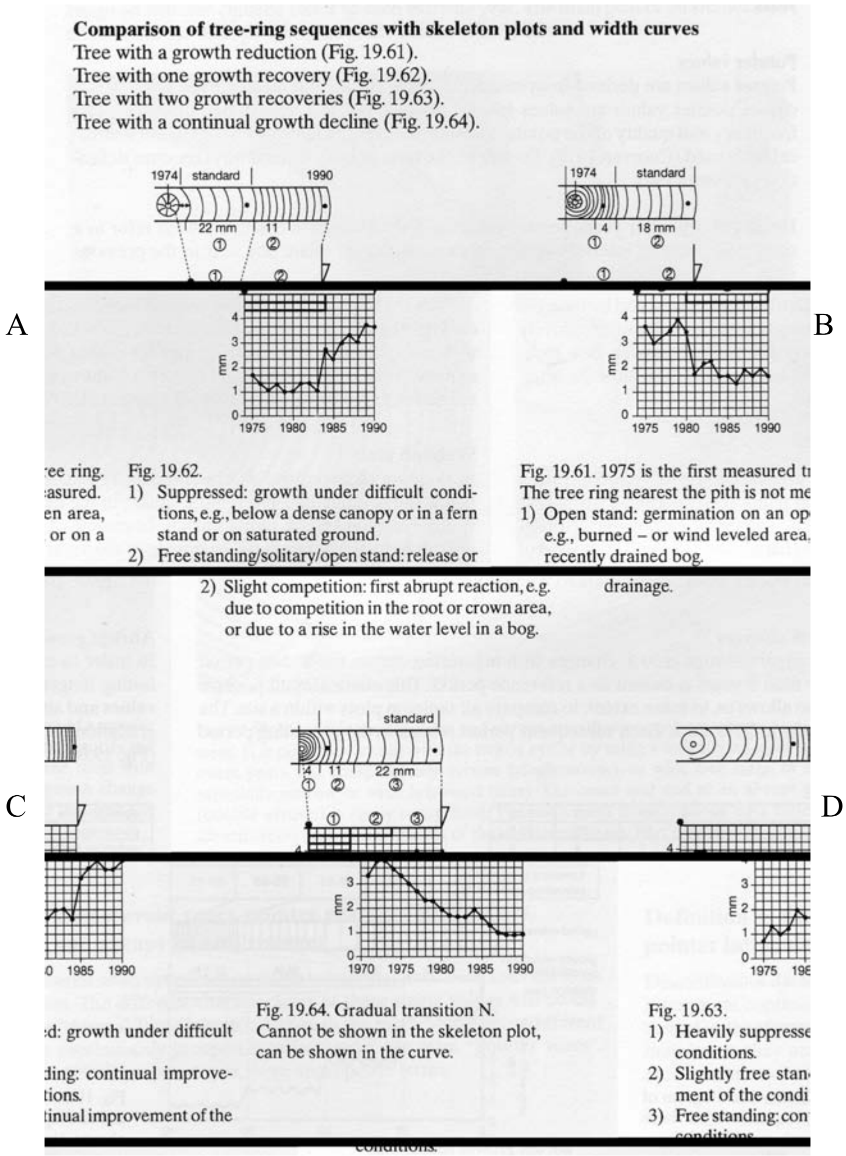


Figure 3-6. Comparison of tree-ring sequences with skeleton plots and width curves. A) growth reduction; B) one growth recovery;C) two growth recoveries; D) continual growth decline (Schweingruber, 1996).

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Geohydrology and Lakes

An elevation survey was performed during this investigation (utilizing a transit and survey staff) for water levels at Little and Big Lake Johnson, Sheeler Lake, and Deer Lake relative to the steephead headwall and the main springs issuing from the upper portion of the ravine. A land and lake survey was completed by the Department of the Interior in 1936 prior to the construction of the park (Figures 4-1 and 4-2) and lake levels were compared to the 2007 survey. Results indicated that the water level of Lake Johnson has fallen approximately eight feet from 1936 to 2007 and a corresponding drop (eleven feet) was found for Sheeler Lake. Deer Lake experienced a nine foot drop in water level over the seventy year period indicating that the geohydrological system is relatively stable except for Pebble Lake. In June, 2008, Pebble Lake was nearly dry and approximately seventy-seven feet in elevation (one foot deep) indicating that the water level has dropped nearly twenty feet in seventy-two years. Aerial photographic imagery shows much of the decline occurred within the last twenty-five years. The springs discharging from the ravine headwall region are supplying Lake Johnson continuously with surficial water thereby helping to prevent it from experiencing a water level drop such as Pebble Lake has experienced. The large open-pit sand mining operation directly west and hydraulically upgradient of Pebble Lake might be a contributing cause of Pebble Lake's low level. In 1936 the water level of Pebble Lake was two feet higher than Lake Johnson although in June 2008, the water level in Little Lake Johnson was approximately ten feet higher in elevation compared to Pebble Lake. If Lake Johnson was supplied entirely from groundwater it probably would be experiencing significantly lower water levels. The area of sand excavation encompasses a former lake derived from a smaller steephead ravine discharge system. The main springs that emerge from the base of the steephead headwall were also surveyed and found to be approximately forty-six feet from the top of the headwall. Correlated to the elevation of the borehole drilled at the top of the headwall and the depth of the water table encountered (forty-one feet below land surface) there was a groundwater mounding effect of approximately three feet form the boring location (fifty feet north of the headwall) to the main springs issuing from the base of the headwall.

The center of the regional Floridan aquifer recharge zone exists near Lake Lowry immediately west of the Gold Head Park and historically Lake Lowry has little variation in level since there is abundant water in the subsurface. As one moves eastward toward the St. Johns River water levels become increasingly susceptible to flucuations in annual precipitation and historically low levels in Lake Johnson, Pebble Lake, and other lakes in the area illustrate the effects of prolonged periods of drought. A regression of Pebble Lake levels relative to rainfall at Gold Head, rain-(June, July, August), and rain-August resulted in an adjusted R squared of 0.708 with two outliers removed (standard error of 3.61) and adding temperature as a variable degraded all the models. When running the same three independent variables of rain relative to lake levels at Little Lake Johnson and Big Lake Johnson with the same outliers removed (based on studentized residuals), the result was an adjusted R squared of 0.560 and 0.447, respectively. Lake levels from Pebble Lake and Little Lake Johnson from 1946 to 2006 were correlated with precipitation data to examine possible relationships. Continuous Big Lake Johnson level data exists from 1968 to the present and Sheeler Lake levels from only 2001-present. There is no water level data from Deer Lake. The comparison of Pebble Lake to Little Lake Johnson (immediately east of and hydrologically downgradient) using OLS regression (n=60) resulted in an adjusted R squared of 0.696 with a standard error of 4.96. The close proximity of Pebble

Lake to Little Lake Johnson would suggest that there might be a better lake level interrelationship and historically the data suggests this to be the case until Pebble Lake was impacted by the sand mining pit, immediately upgradient, which began excavation in the 1960's and has since experienced considerable expansion. Although Little Lake Johnson is supplied with groundwater similar to Pebble Lake, it also receives a significant surface supply from Gold Head Branch stream (Figure 4-3). Since 1976, Pebble Lake has experienced lake levels lower than Little Lake Johnson (with a few exceptions) and considering the hydraulic gradient direction (ESE) in this area, a possible contributing factor is the sand mining pit. During the drought period between 1999 and 2001 Pebble Lake dropped twenty feet while Little Lake Johnson only fell less than five feet and this anomalous occurrence might represent a "tipping point" being crossed. Although both lakes have since recovered from the recent drought, Pebble Lake is still lower than Little Lake Johnson. Based on the regression analysis of Pebble, Little, and Big Lake Johnson relative to rainfall, it is possible that Pebble Lake is more susceptible to periods of drought since it is considerably smaller (less storage capacity) and loses it surface supply from the small steephead spring that previously supplied it when there was sufficient rainfall. Time series plots indicate Pebble Lake has greater water level variation than Lake Johnson (Figure 4-4). Covariance plots of lake levels indicate a positive relationship between Big Lake Johnson and Pebble Lake, Big Lake Johnson and Little Lake Johnson, and a strong positive relationship between Pebble Lake and Little Lake Johnson (Figure 4-5).

The presence or absence of phreatophytes can influence lake levels when occurring near lake shorelines. The uptake of water by plants such as willow trees can have a significant affect upon lake levels and also cause fluctuations seasonally since dormancy in winter considerably reduces uptake of nutrient solutions (Fetter, 1980). Logging of trees near lake shorelines and fire events can impact annual and seasonal variations in lake levels.

The lakes in the Gold area are principally supplied by groundwater flow in a recharge zone for the Floridan aquifer. Analyses of lake levels and water well levels indicate a hydraulic connection between the surficial aquifer, the Floridan aquifer, and surface water. Water supply for the Gold Head Branch Park is provided by a Floridan well (Figure 4-6) completed to a depth of 375 feet below land surface (bls). Analysis of water levels from this well gauged during September, 1996-2006 provides insight of the hydraulic connection between surface water, the surficial aquifer, and the Floridan aquifer in the Gold Head area (Figure 4-7). There was a good correlation between water well levels and lake levels/precipitation with the best model resulting in an adjusted R squared of 0.8465 when the independent variables were – Pebble Lake water levels, rain at Gold Head - annual, rain at Gold Head - August, and weighted rain – June, July, August. A regression of Pebble Lake levels relative to rainfall at Gold Head, rain - (June, July, August), and rain-August resulted in an adjusted R squared of 0.708 with two outliers removed (standard error of 3.61) and adding temperature as a variable degraded all the models. When running the same three independent variables of rain relative to lake levels at Little Lake Johnson and Big Lake Johnson with the same outliers removed (based on studentized residuals), the result was an adjusted R squared of 0.560 and 0.447, respectively. Covariance plots between the Gold Head U.S.G.S. Floridan well and Pebble Lake, Big Lake Johnson, and precipitation at Gold Head Park indicate a positive relationship (Figure 4-8). The scatter plots of bivariate distribution of the U.S.G.S. well versus Pebble Lake and the U.S.G.S. well versus precipitation in August at Gold Head Park indicate the strongest positive relationship. Well level data was obtained from

September gauging which may help explain the relationship of August rain at Gold Head to U.S.G.S well levels.

During this study, a lake sounding survey (utilizing a canoe, Lowrance 480m sonar unit, and Garmin 76 CSx GPS unit) was performed on Lake Sheeler and Deer Lake (Figures 4-9 and 4-10). Depths were compared to the 1936 lake soundings completed by the Department of the Interior (Figure 4-2 transposed through GIS to Figures 4-11 and 4-12) during construction of the Gold Head Park and results indicate the lake bottom configurations are very similar. Lake levels are several feet lower in 2008 compared to 1936, subsequently changing the lake edge positions (Figures 4-13 and 4-14). The lack of surficial drainage into the lakes and absence of silt and clay within surficial sediments has allowed the lake bottom configurations to remain relatively unchanged over a seventy-year period.

Surface mining of clean white sand was begun in the 1960's and continues today in a large open pit immediately west of Pebble Lake in the Gold Head Branch State Park. This has most likely contributed to lowering of the surficial water table in the area although surface water diversion projects (up to several million gallons a day) to help resupply the Keystone Heights area south-southwest of the park could have also impacted the Gold Head region. Reduced rainfall in the recent past has dropped water levels considerably with drought conditions in 2000-2002 causing local officials to divert significant amounts of water from Lake Magnolia southward toward the Keystone Heights region. Based on the regression analysis of Pebble, Little, and Big Lake Johnson relative to rainfall, it is possible that Pebble Lake is more susceptible to periods of drought since it is considerably smaller (less storage capacity) and lost its surface supply from the small steephead spring that previously supplied it. Time series plots indicate Pebble Lake has greater water level variation than Lake Johnson. Seepage lakes commonly fluctuate more than drainage lakes (Figure 4-15).

The steepness of the ravine slopes suggest that the surficial water table has been intercepted and during drilling of the exploratory borehole near the steephead wall there was no saturation present within the sediments until forty one feet below land surface (approximately the same depth of the principal springs at the steephead wall base). The piezometric surface of the Floridan aquifer at Gold Head probably fluctuates and coincides with that of the surficial water table. The soil conditions near the steephead at Gold Head Branch State Park consist of approximately fifty feet of clean ancient beach sand resting upon reworked carbonates, thereby allowing rapid infiltration of precipitation and subsurface movement of groundwater toward discharge features such as sink lakes and the steephead ravine. There was no confining or semi-confining layer encountered during the subsurface investigation of the steephead. The borehole drilled near the Gold Head steephead wall during this investigation did not encounter the Hawthorne and it may have been weathered away by erosional processes associated with multiple sea transgressions and regressions. The steepness of the ravine slopes suggest that the surficial water table has been intercepted and during drilling of the exploratory borehole near the steephead wall there was no saturation present within the sediments until forty one feet below land surface (approximately the same depth of the principal springs at the steephead wall base).

A down-the-hole falling-head hydraulic conductivity test was performed (Figure 4-16) in natural soil (fine sand), approximately one hundred and fifty feet NNE of the ravine headwall utilizing a four inch I.D. PVC casing driven four feet into the ground and surcharged for two hours until the rate of water level drop had stabilized. Utilizing a modified form of Darcy's equation; $K = d_t^2 L \ / \ d_c^2 t \ * \ \ln (h_o / h)$

where; d_t = I.D. of casing L = length of sample h_o = initial head

d_c = I.D. of soil sample t = time h = final head

A drop of 1.0 inches over one hour was measured and a hydraulic conductivity value of 7.6 feet per day or 2.68 x 10^{-5} cm/sec was calculated. This value falls within the normal range for hydraulic conductivity in fine sand of 10^{-5} – 10^{-3} cm/sec (Fetter, 1980).

In the Gold Head area, the surficial aquifer is hydraulically connected to the Floridan aquifer and surface water – lakes. The geohydrological system is a complex balance of water through-flow in the subsurface and the more distant surface water features are from the center of the recharge zone, the more sensitive they become to severe drought, prolonged periods of heavy rain, and man-made influences. The water levels of seepage lakes are more variable than drainage lakes and smaller seepage lakes have greater variability than larger seepage lakes due to less storage capacity and other factors. The water quality within the Etonia basin is generally very good and the clean, ancient beach sand in the Gold Head area provides an excellent natural filter for precipitation before it reaches the Floridan aquifer. Protection of this precious resource is increasingly important as development quickens its pace and communities are often in dispute over water rights.

4.2 Trees and Climate

The two most powerful hurricanes (Category Five) to impact the Gold Head area within the last one hundred years occurred in 1960 - Donna and 1964 – Dora. The tree-ring widths from these years and the two subsequent years was average, indicating no direct relationship of tree growth to these hurricanes. Since the local soils are almost entirely sand (approximately fifty foot thickness) resting on top of limestone, extreme precipitation events infiltrate into and through the subsurface relatively quickly.

Obtaining the best available precipitation and temperature data is critical to tree ring studies and fortunately there is rain data for the Gold Head Branch State Park from 1992 to the present. The period from 1946 to 1991 required extensive investigation combining data from numerous stations to determine the best possible precipitation chronology. After modeling many combinations of data, the best aggregate of rain data (from 1946-1991) assembled utilized Camp Blanding (1946-1957), Starke (1958-1987), and Silver Lake, Camp Blanding, Penney Farms (1988-1991) data. An isocontour map of annual Florida precipitation illustrates the east-west trend of equal amounts of rain in the Gold Head/Camp Blanding area, thereby supporting model results compared to Jacksonville, Gainesville, or Palatka precipitation data. Temperature data available near the study area is restricted to Gainesville (University and Airport) and Jacksonville which was combined for the period between 1946-2006 and subsequently dissected to find key months during the growing season. The North Florida area receives a significant amount of rain during the months of June, July, and August and these months proved key to the growth response measured within the sampled hickory trees at Gold Head. The months of May and September were also analyzed although they indicated a negative affect on the explanation of growth with the exception of precipitation outliers of 7" inches or more of rain during either May or September. These outliers were weighted (eleven total from 1946-2006) into four groups – 7-8" (1966, 1976, 1983) – 1.25X weight, 10" (1950, 1969, 1975, 1978) – 1.5X weight, 14-16" (1959, 1979, 1988) – 1.75X weight, and 20" (2004) – 2.0X weight, and improved the models slightly. Temperature values for annual average, summed June, July, and August averages, and August average produced the best models and this correlated with the same precipitation variables that produced the best models. Analyses of growth trends in longleaf pine (pinus palustrus) and slash pine (pinus elliottii) by Foster, 2001 in central Florida found a positive relationship between slash pine and water availability in mesic flatwoods only during the months May-September with a negative response to water availability for all other months. During this study, temperature consistently proved to have a more important relationship to tree ring residuals compared to precipitation. Since the hickory trees analyzed are located near the base of the steephead wall, the root system of the trees extends downward into a saturated zone that is likely supplying water 365 days a year throughout the life of the tree. So, precipitation amounts aren't as critical to the plants' growth as temperature and other factors. If temperature values were available from Gold Head and a much longer period of precipitation data from the Gold Head Park, a significantly better climate/growth correlation might have been possible.

Time series plots of rain and temperature variables, tree ring width residuals, and lake levels were analyzed and lag plots of autocorrelation and cross-correlation for residuals, precipitation, temperature, and lake levels indicate collinearity between precipitation and temperature exists. Time series plots for annual precipitation (1946-2006) and rain during June, July, and August illustrates a strong interrelationship (Figure 4-17) although time series temperature plots for the same periods did not correlate nearly as well. August is a key month for the growing season in this region and plots of both precipitation and temperature indicate a good relationship between August and the months of June, July, and August combined. Lag plots of autocorrelation for rainfall indicate an alternating positive and negative correlation with increasing lag. Autocorrelation lag plots for temperature and tree ring width residuals indicate a decreasing positive correlation as lag increases.

The best temperature model incorporated temperature data from (June, July, August – summed and averaged) X (temperature – annual average) X (temperature - August), which also is the same configuration of precipitation data that produced the best rainfall models. Combining these three temperature variables with (rain – annual average) X (rain - June, July, August – summed and averaged) X (rain – August) consistently produced the best models to explain the climate signal stored within the tree rings from core # 4 (Figures 4-18 and 4-19) obtained from the hickory tree near the base of the steephead wall. The climate signal from 1946-2006 was difficult to interpret from the hickory trees in the ravine and the best model (residuals from tree-ring widths – temperature; annual average and precipitation; annual) produced a multiple adjusted R squared of only 0.075 although this value was considerably better than other models. Removing outliers from the n=61 observations models usually reduced the explanatory power of the models – adding additional variables and removing 6-8 outliers either degraded the model or improved it by only .002 adjusted R squared. Humidity, sunshine, and localized climatic variables are affecting plants growing within the steephead ravine at Gold Head Branch State Park. If precipitation was recorded at Gold Head for a longer period, and temperature and humidity data was available locally, the model results might have improved considerably over a sixty-year period. Examining the period from 1992-2006 produced relatively good results to explain the climate signal from the tree rings after four successive outliers (based on studentized residuals) were removed. Beginning with n=16, four outliers were removed and the weighted rain variable added to produce an adjusted R squared of 0.842, resulting in the best model fitting the tree ring residuals to precipitation and temperature.

The tree core analyses indicates precipitation during the months of June, July, and August (Figure 4-20), (particularly August) is important to the growth of hickory trees in the Gold Head Park region although temperature during this growth period is critical for optimal propagation of the species. Time series analyses indicates collinearity between rain and temperature and since groundwater provides a significant source of water for plants in the Gold

Head ravine, temperature plays an important role during the growing season. Temperature values for annual average, summed June, July, and August averages, and August average produced the best models and this correlated with the same precipitation variables that produced the best models.

During this study, temperature consistently proved to have a more important relationship to tree ring residuals compared to precipitation. Since the hickory trees analyzed are located near the base of the steephead wall, the root system of the trees extends downward into a saturated zone that is supplying water 365 days a year throughout the life of the tree. So, in this area, precipitation amounts are not as critical to the plants' growth as temperature and other factors.

Sheeler Lake is one of the oldest lakes in the southeast United States since the late Wisconsin period was very dry and water levels were considerably lower before 8,500 years ago. Sheeler Lake contains the oldest record of the mass occurrence of broad-leaved forest in the southeastern United States at the end of the late Wisconsin glacial period (Watts, 1980). Lake sediments contain a continuous pollen record dating back to 24,000 years ago and at the end of the Wisconsin glacial period (approximately 14,000 years ago) there was a warming trend with an increase in precipitation. The mesic forest declined in the area approximately 12,000 years ago as pine and oak began to dominate the forest. Few limestone sink lakes in Florida and southern Georgia have long, uninterrupted records of sedimentation. The relatively shallow lakes were mostly dry before 8,500 years ago because the water level in the Floridan aquifer within the Ocala limestone was significantly lower during the dry, late Wisconsin period. The location of Sheeler Lake near the center of a stable major groundwater recharge zone allowed the lake to continuously hold water and create a pollen record spanning 24,000 years. The Gold Head region was less susceptible, historically, to sustained drought conditions due to its location near the center of a major recharge zone for the Floridan aquifer. If Lake Johnson was not supplied with surface water by the Gold Head Branch stream, it might be experiencing considerably lower lake levels than currently exists.

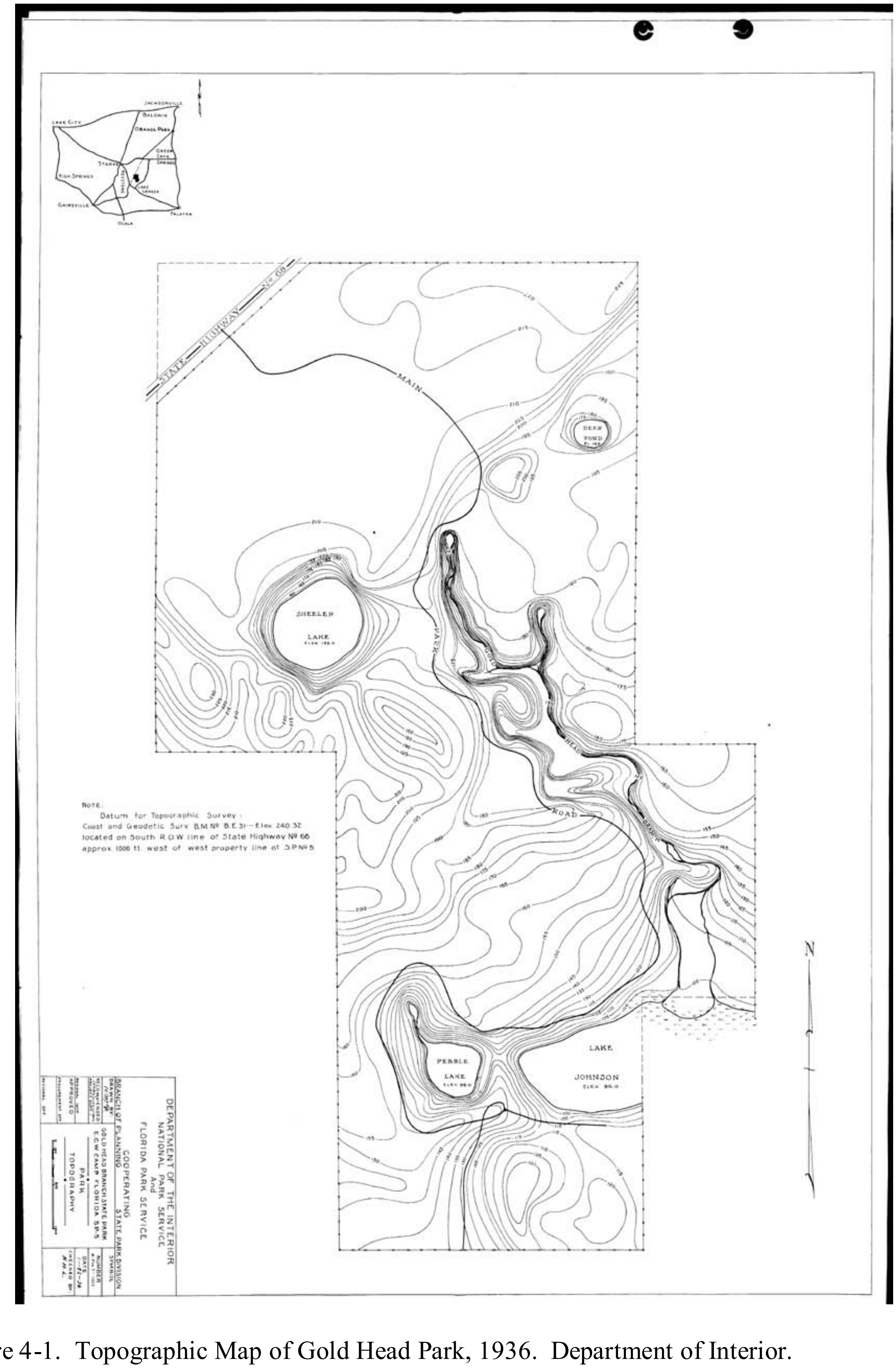


Figure 4-1. Topographic Map of Gold Head Park, 1936. Department of Interior.

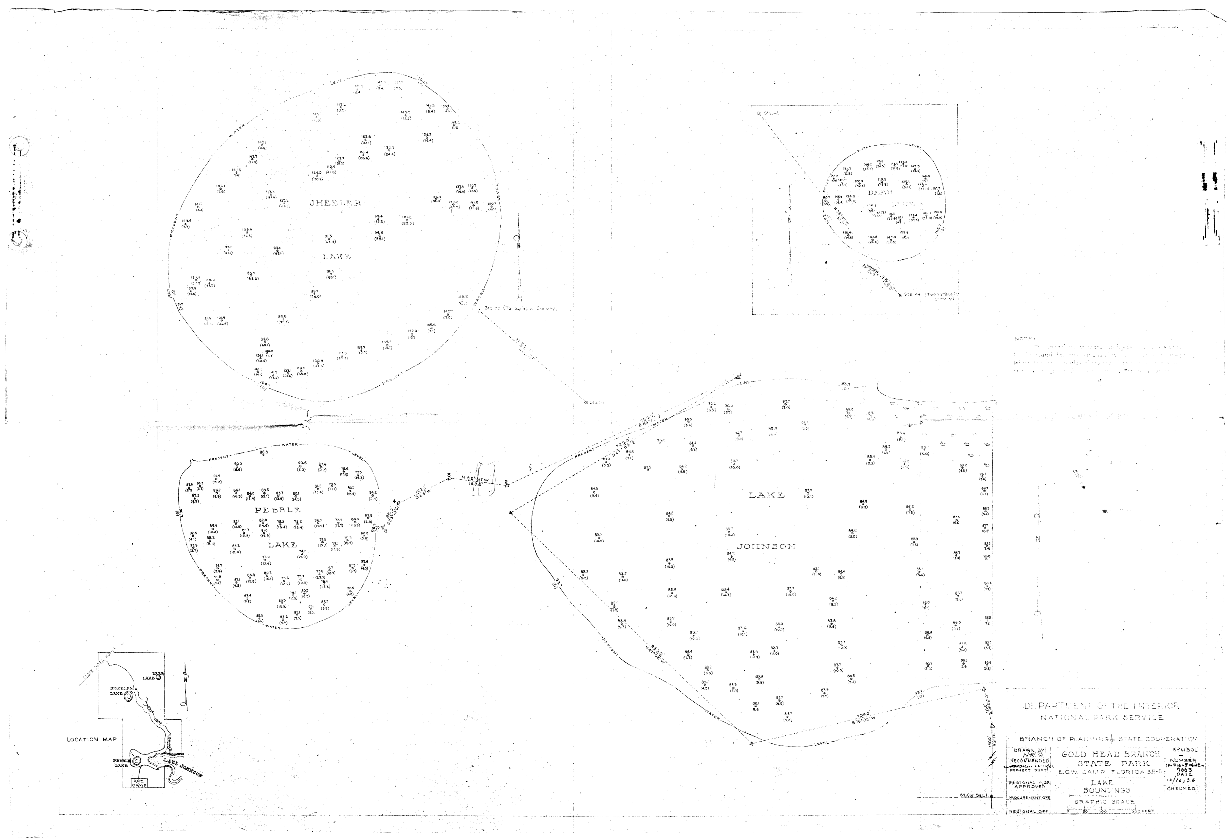


Figure 4-2. Lake Soundings, 1936. Gold Head Park, Department of Interior. (Zoom to 500% for depth and elevation data).

Figure 4-3. Confluence of two tributaries from spring discharge near steephead headwall.

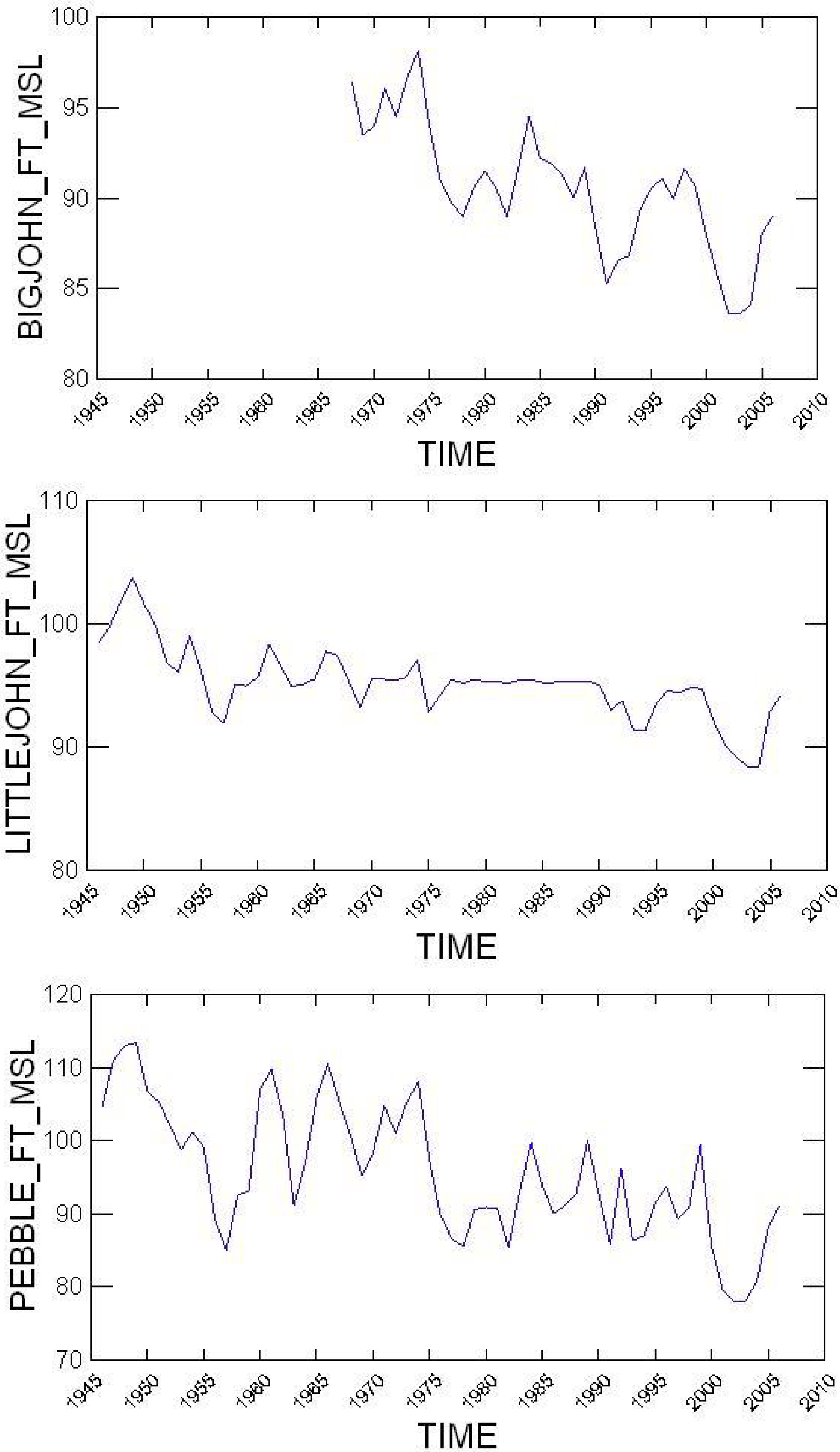


Figure 4-4. Time series plots – lake levels; Big Lake Johnson, Little Lake Johnson, Pebble Lake (raw data obtained from St. Johns River Water Management District-SJRWMD).

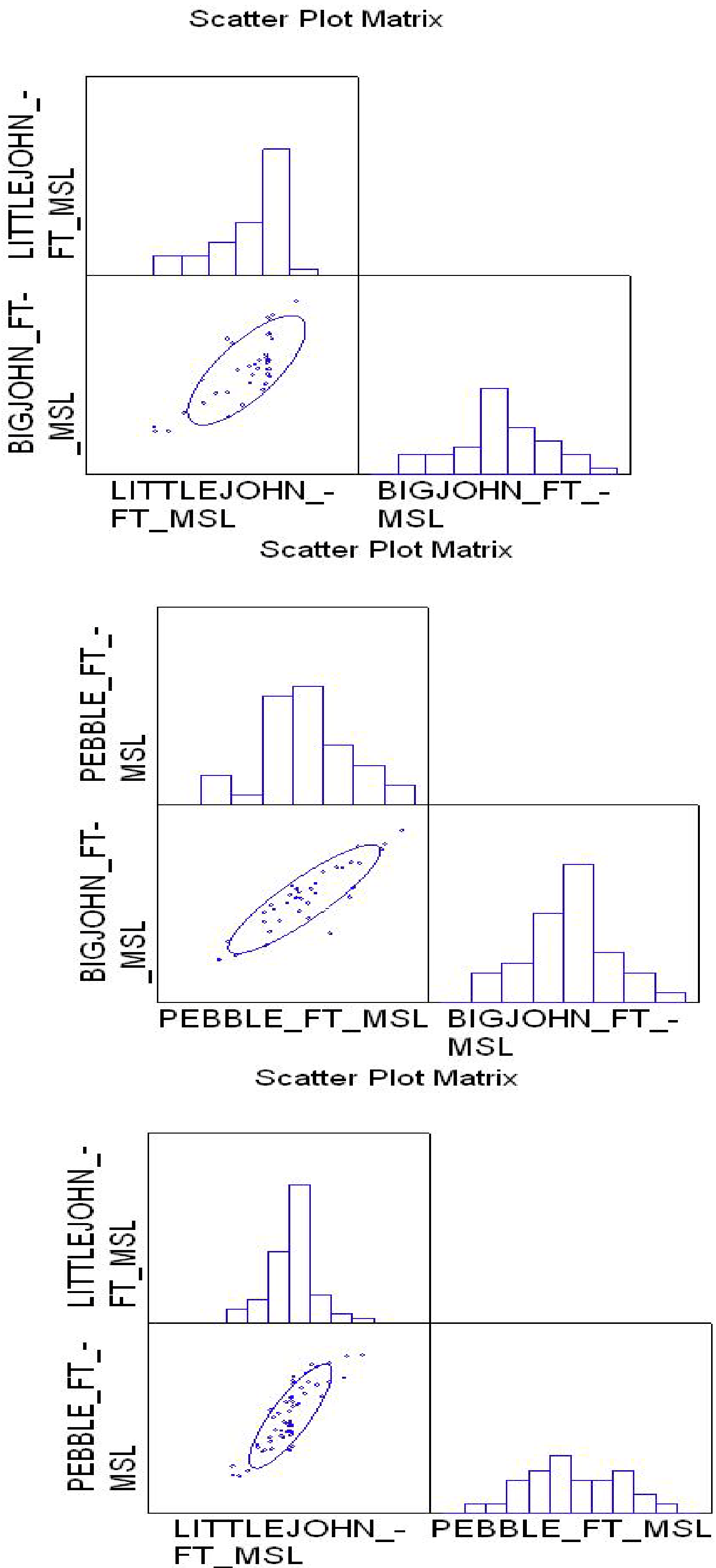
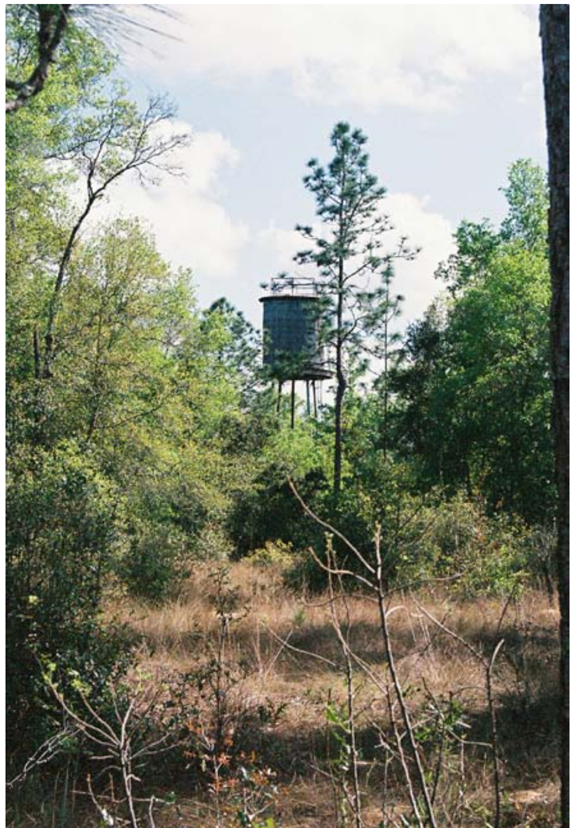


Figure 4-5. Covariance plots of lake levels (feet msl) – Big Lake Johnson, Little Lake Johnson, Pebble Lake.



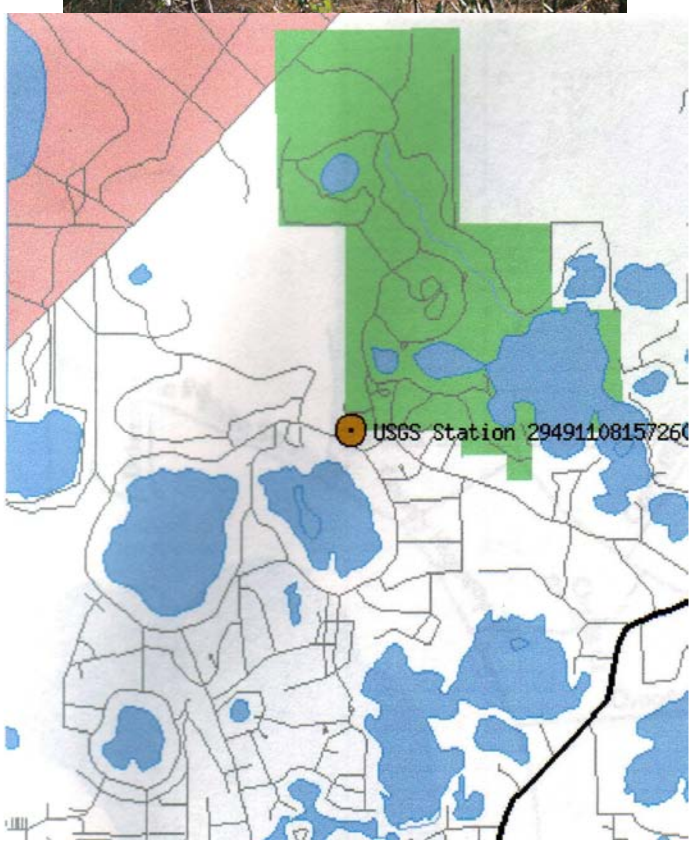

USGS Station 294911081572606

Figure 4-6. Water tower constructed in 1930's by CCC. Supply well in SW corner of Gold Head Park.

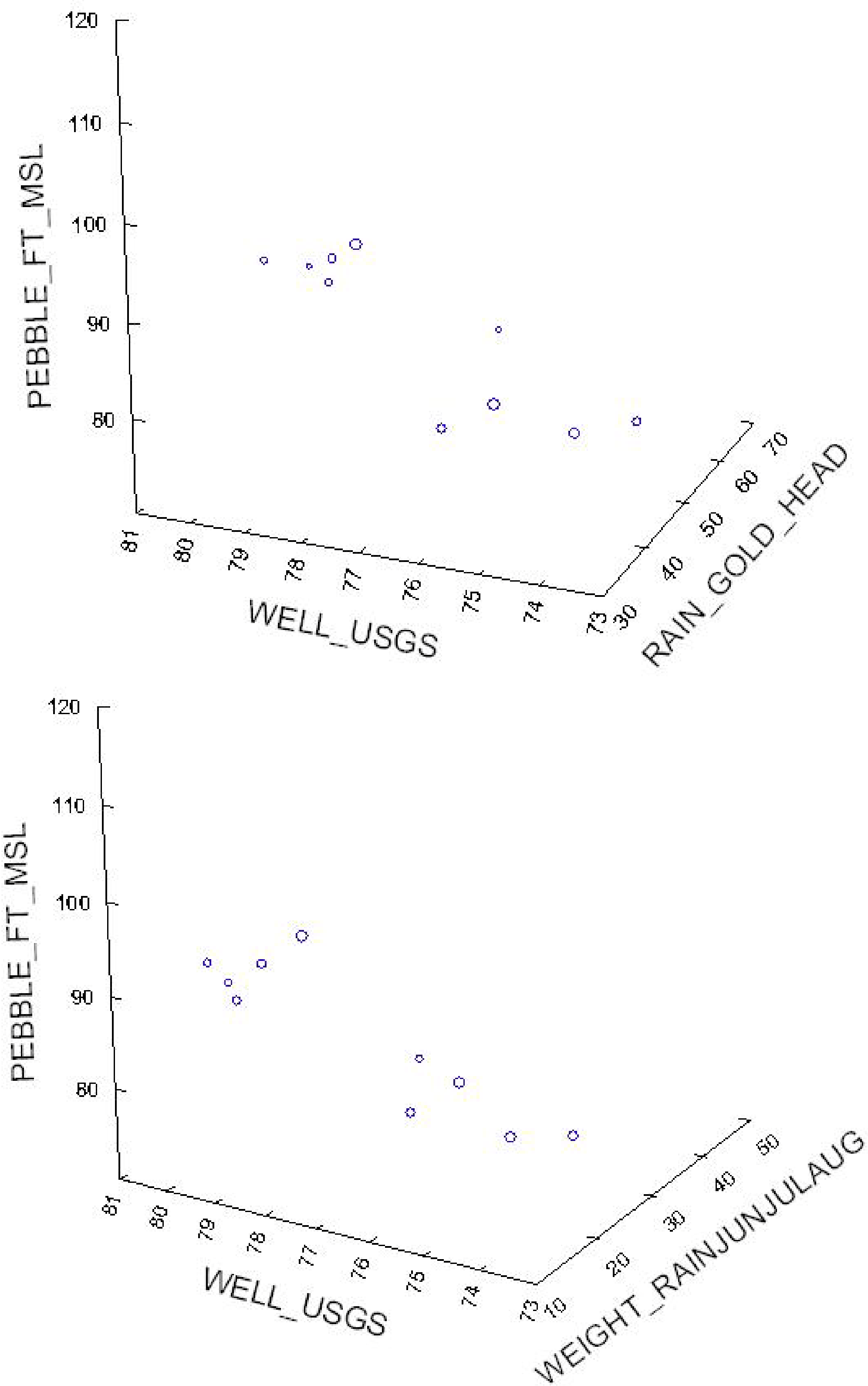


Figure 4-7. Three dimensional scatter plots of lake levels and Floridan well levels (feet msl) compared to precipitation (inches).

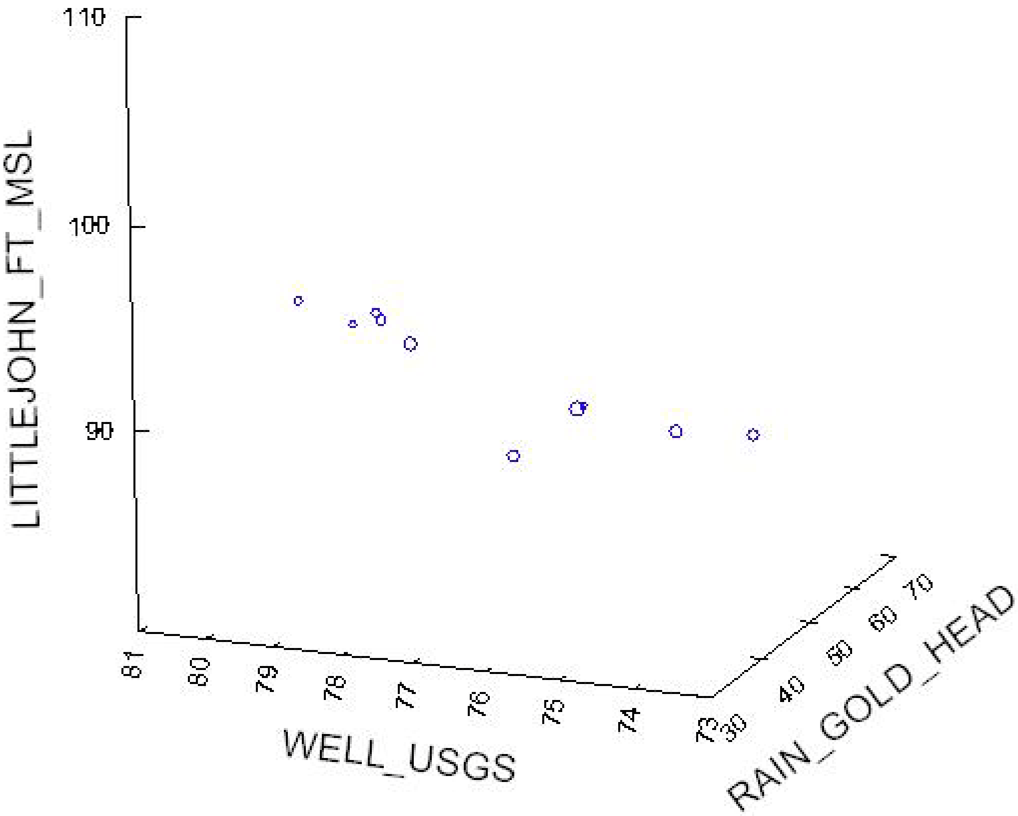


Figure 4-7. Continued

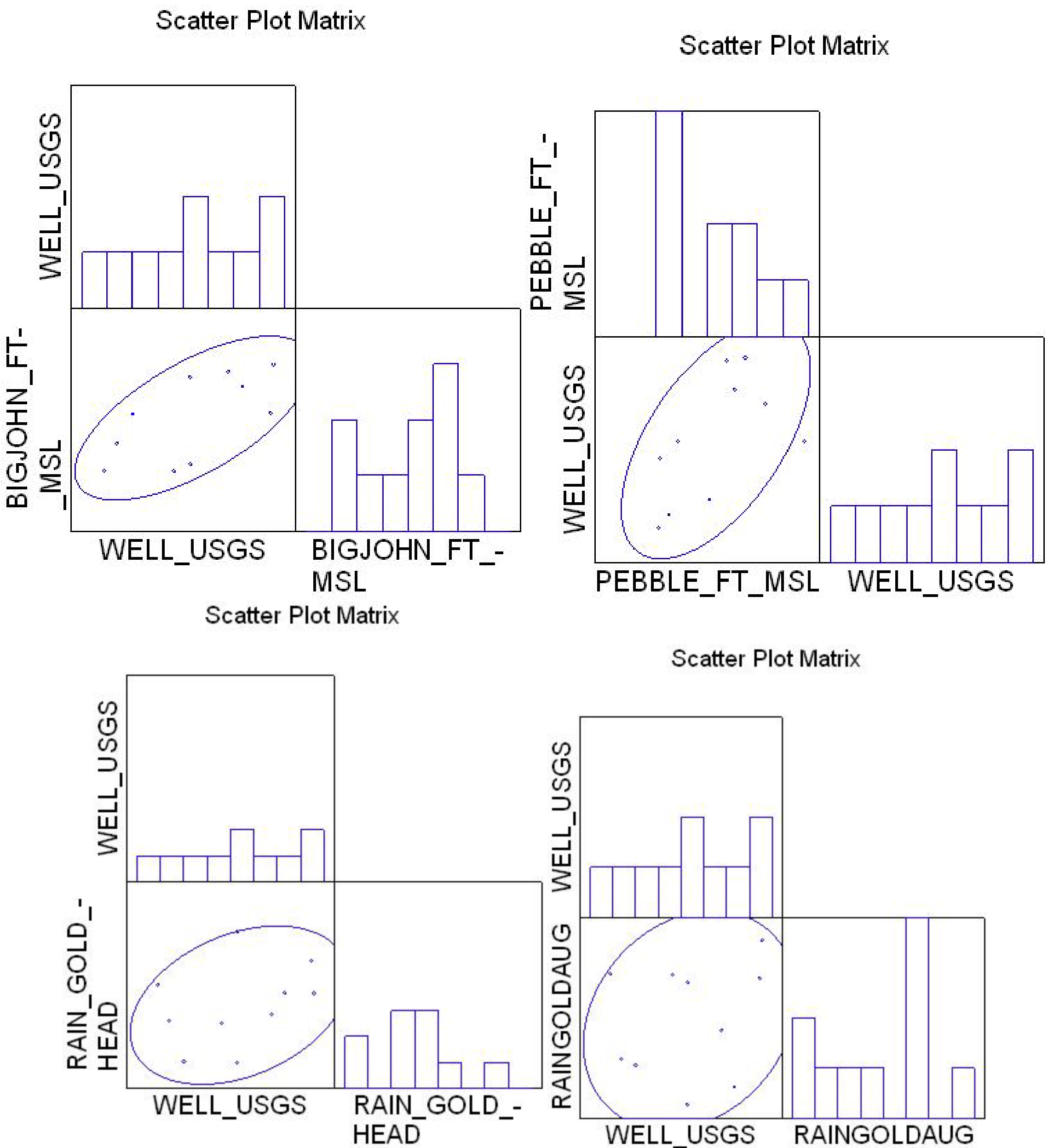


Figure 4-8. Covariance plots of U.S.G.S. Floridan well levels (feet msl) versus Big Lake Johnson and Pebble Lake levels (feet msl), annual rain and August rain (inches) at Gold Head Park (raw data-SJRWMD).

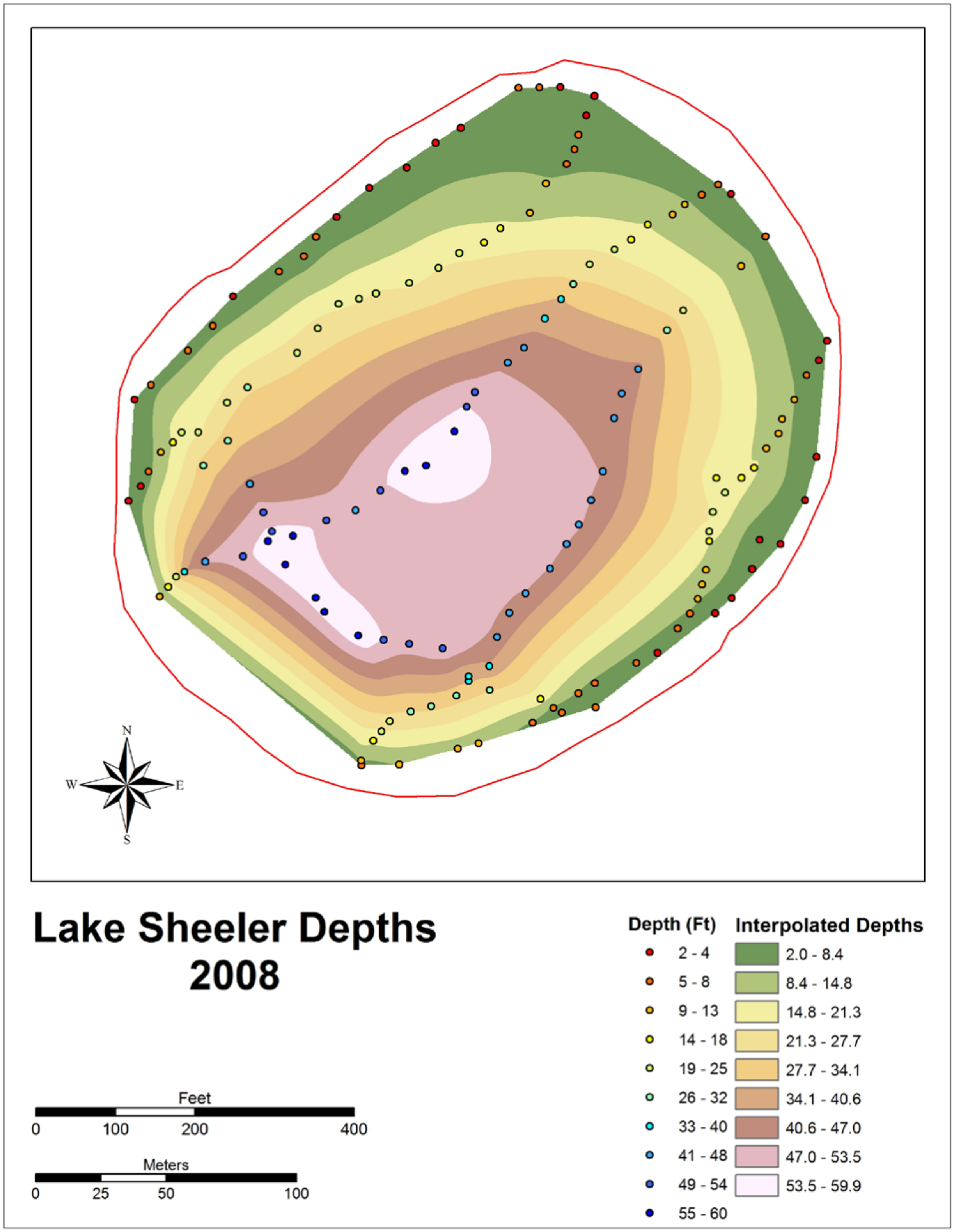


Figure 4-9. Lake Sheeler water depths, 2008.

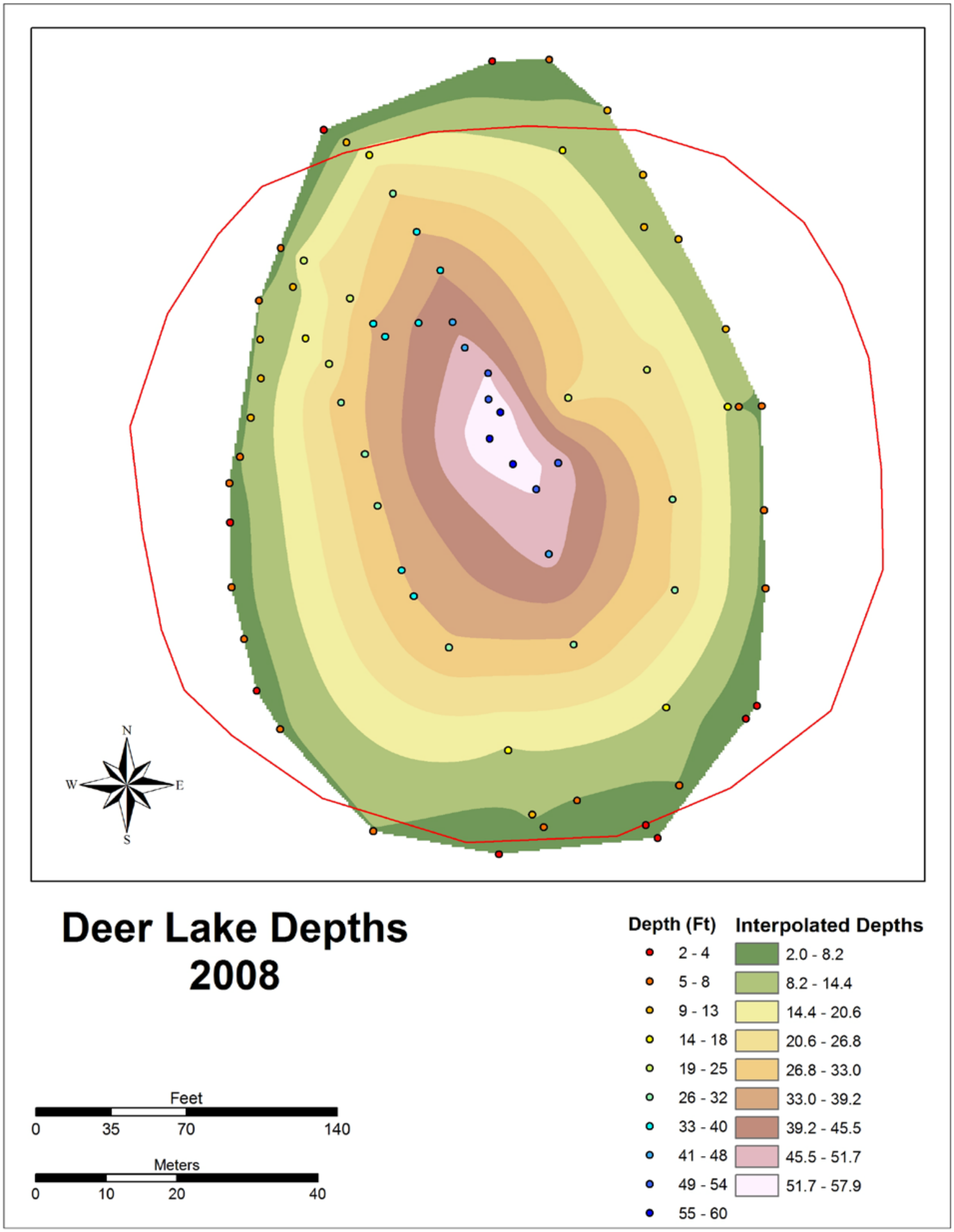


Figure 4-10. Deer Lake water depths, 2008. Data values extend beyond edge of lake due to GPS accuracy limitations and lack of shoreline around edge of Deer Lake

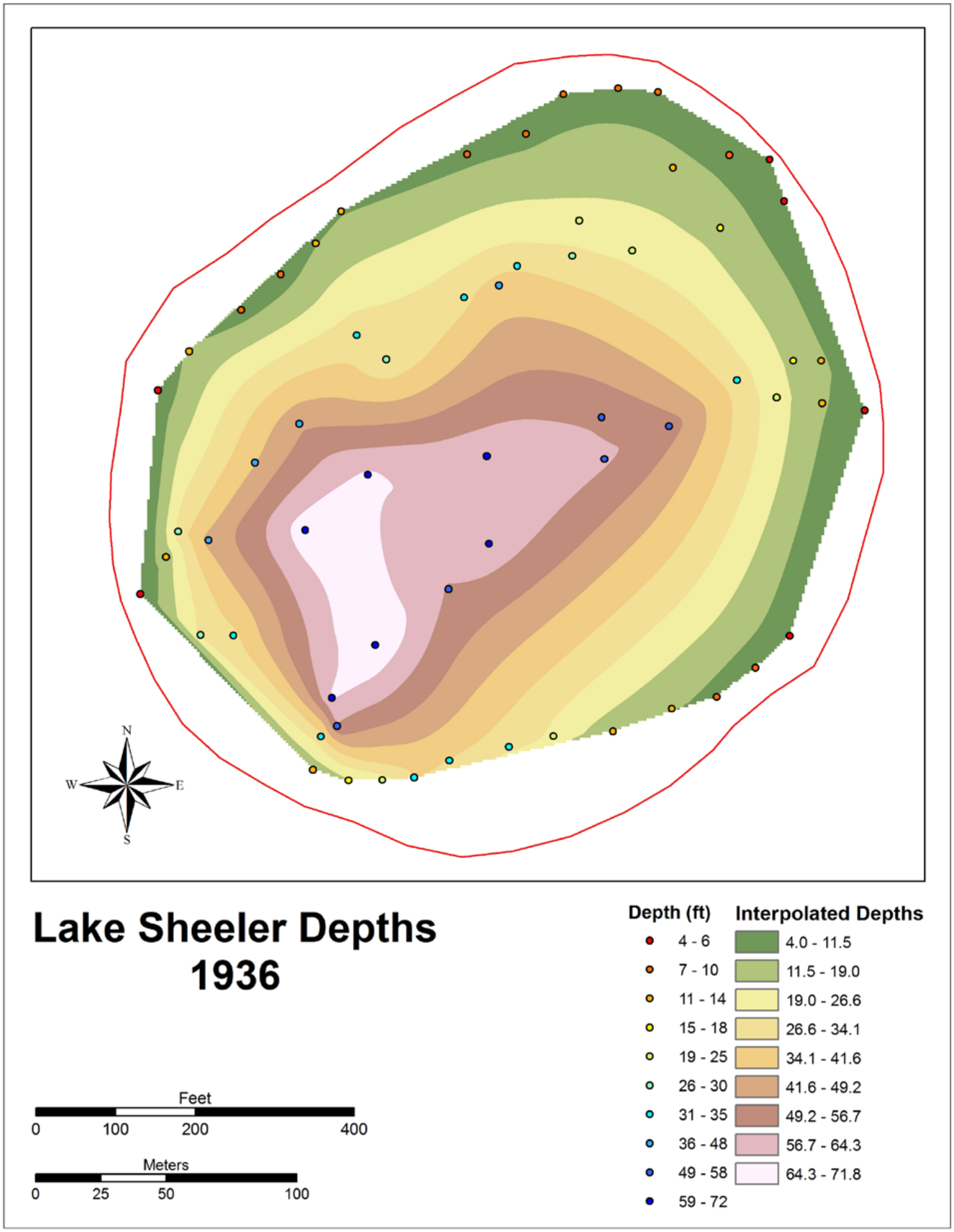


Figure 4-11. Lake Sheeler water depths, 1936 (plotted from Department of Interior map).

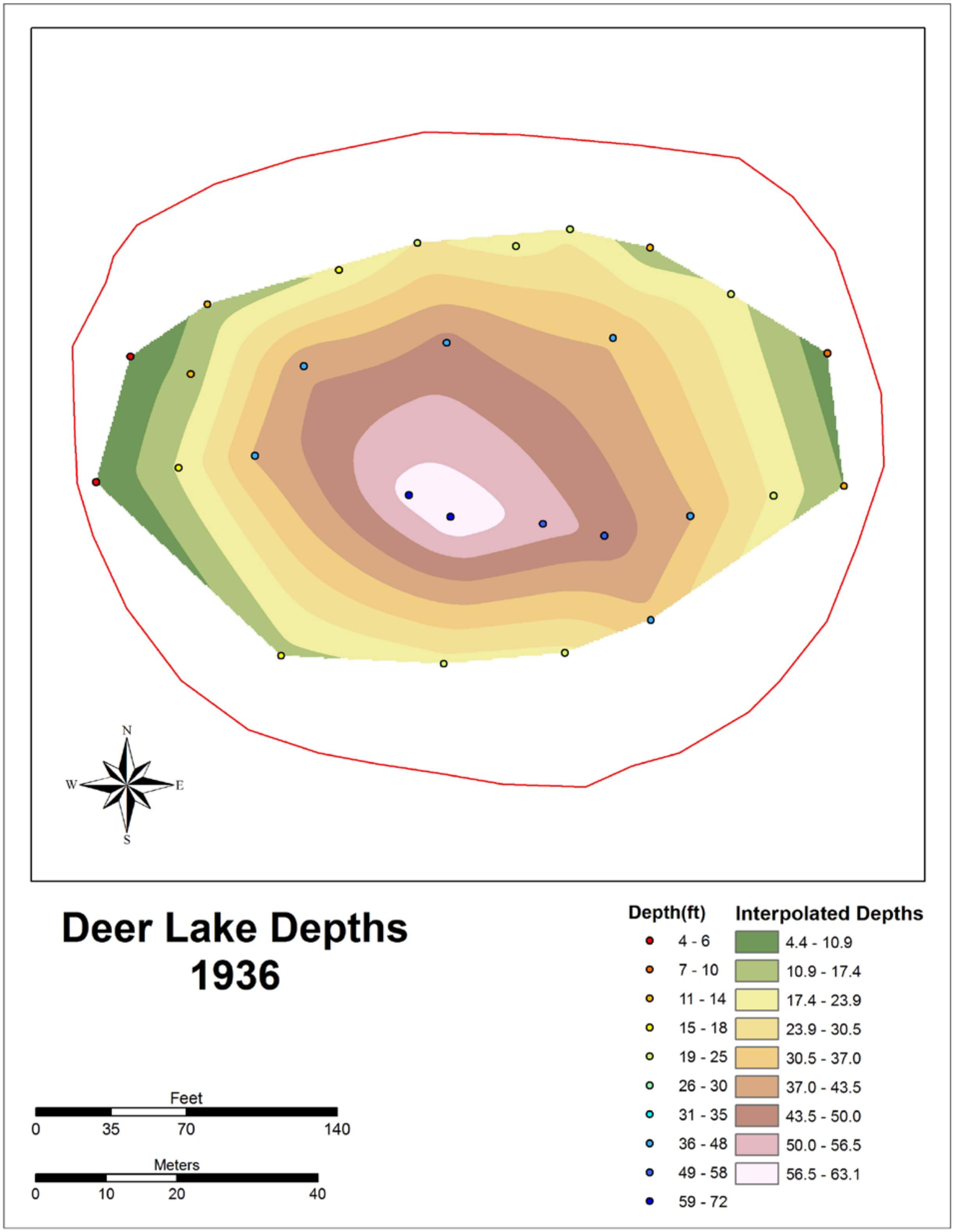


Figure 4-12. Deer Lake water depths, 1936 (plotted from Department of Interior map).

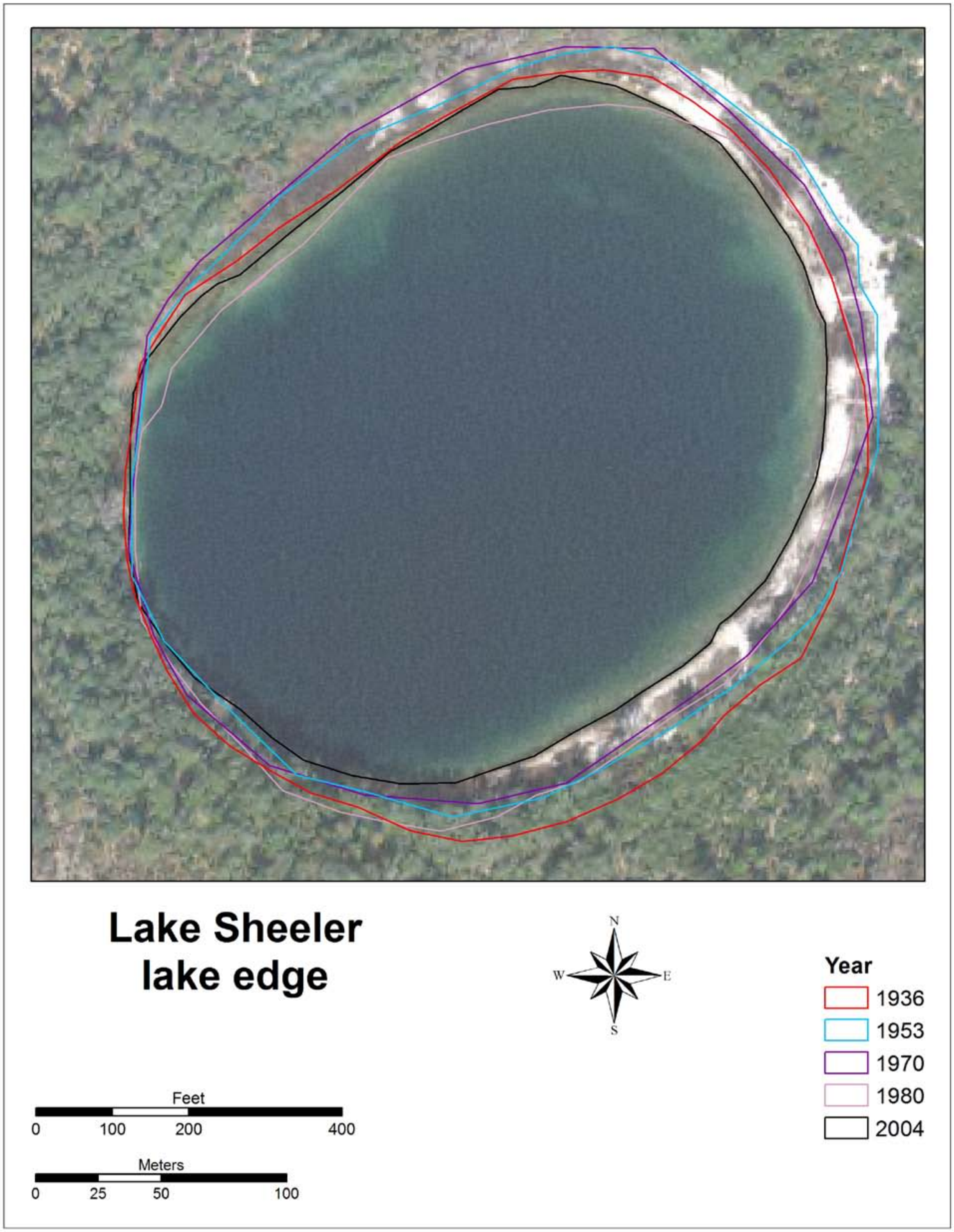


Figure 4-13. Lake Sheeler water edge, 1936-2004 (change from 1953 –2004 digitized from aerial photographs).

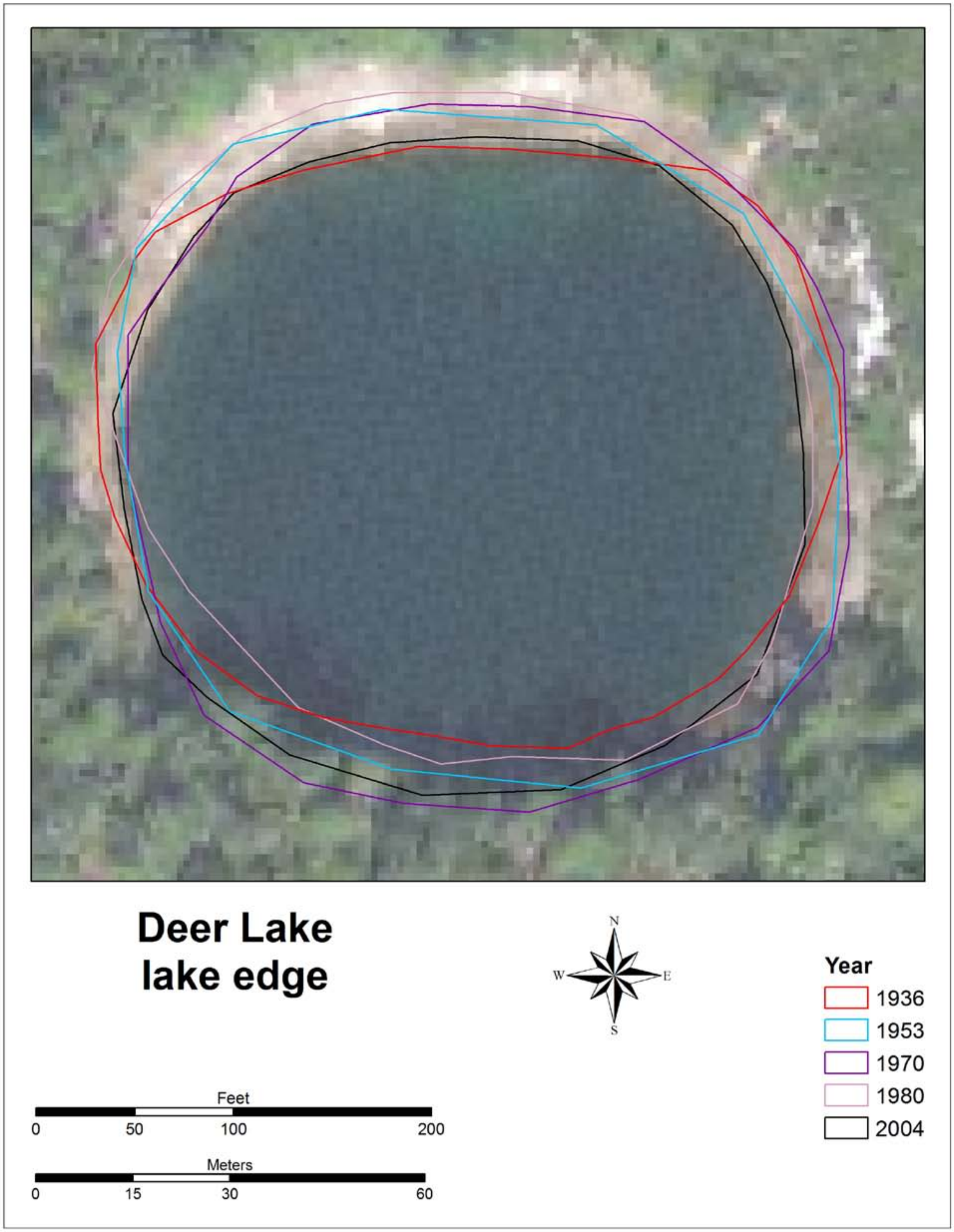


Figure 4-14. Deer Lake water edge, 1936-2004 (change from 1953-2004 digitized from aerial photographs).

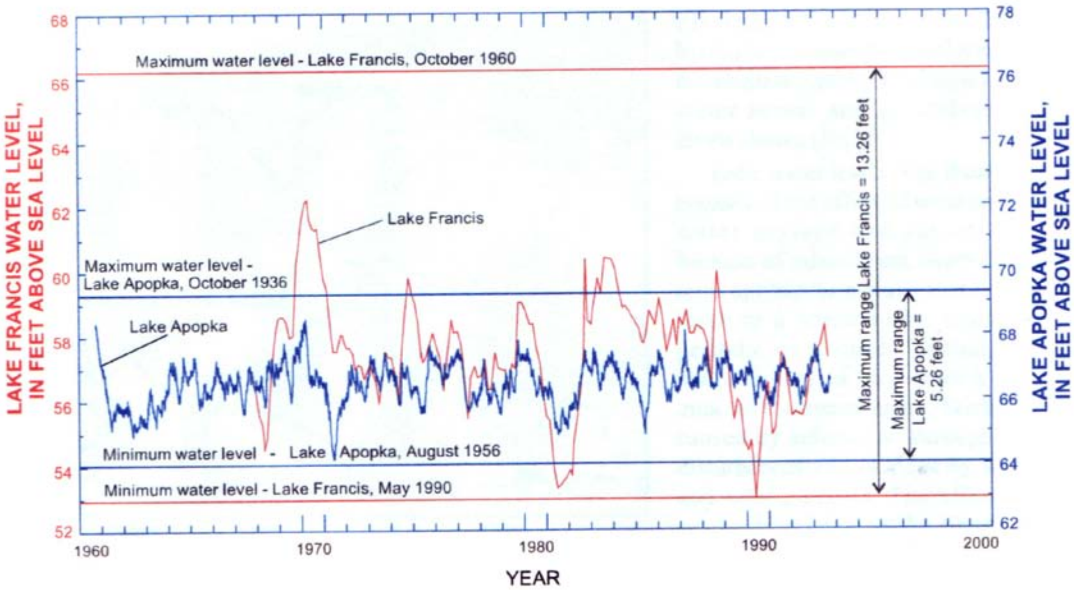


***Figure 20.** Water-level fluctuations in a drainage lake (Lake Apopka) and a seepage lake (Lake Francis).*

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Figure 4-15. Water level fluctuations in a drainage lake (Lake Apopka and a seepage lake (Lake Francis). The seepage lake time series illustrates greater variation but with less frequency in variation (Schiffer, 1998).

Figure 4-16. Soil infiltration test in progress – Note; PCV casing marked inside for water level measurement and clay packed around base of casing to prevent breach of seal.

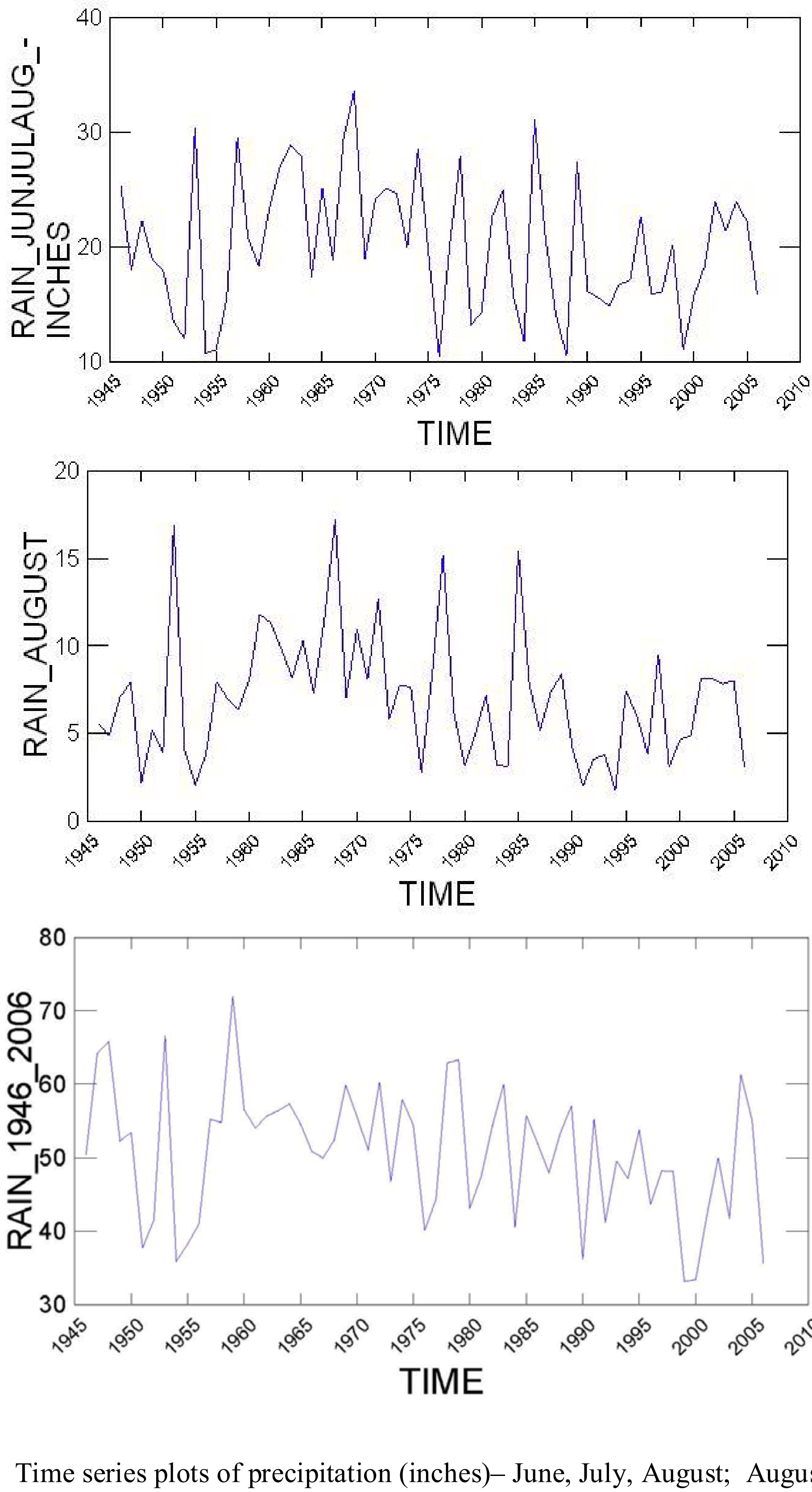

Figure 4-17. Time series plots of precipitation (inches)– June, July, August; August; Annual rain from 1946-2006.

Figure 4-18. Hickory tree at the steephead headwall – core #4. Note – overlook platform in bottom left of photograph, which is approximately fifty feet above base of headwall.

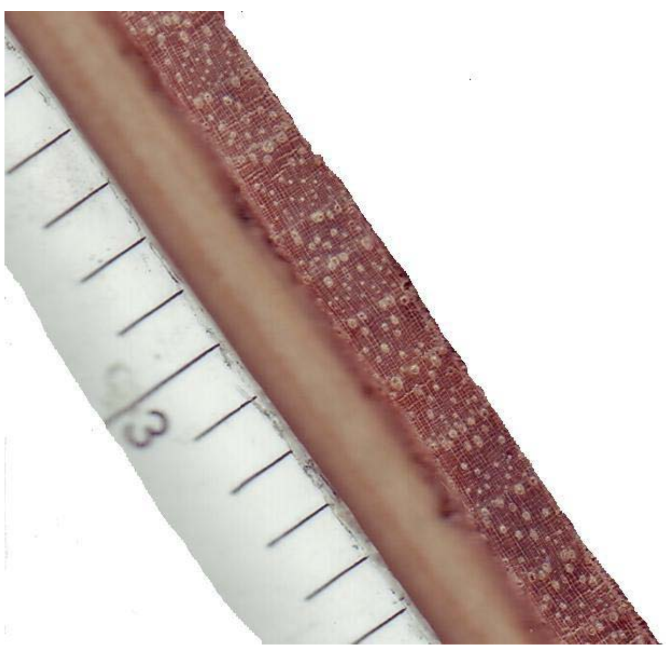

Figure 4-19. Hickory tree core #4. Note large vessels formed during spring growth period – 1.2” segment.

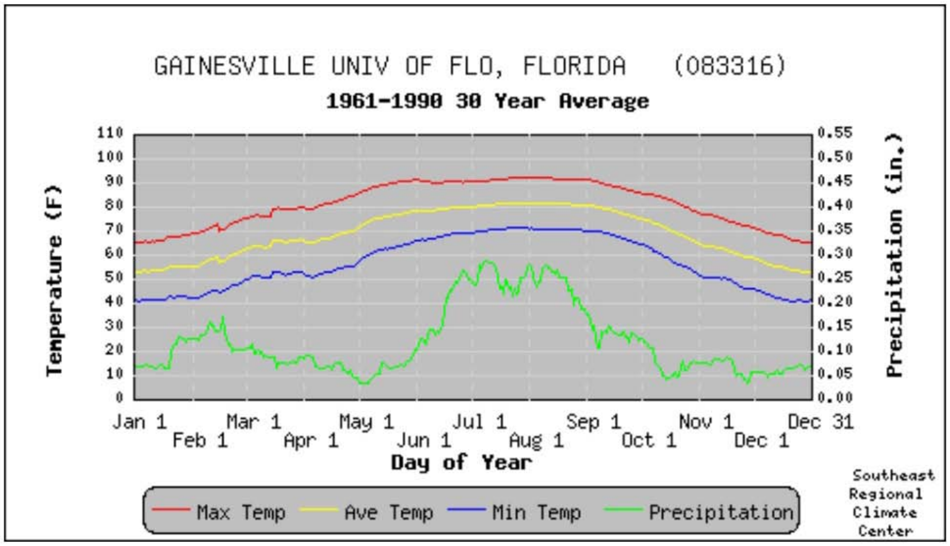

Figure 4-20. Precipitation and temperature averages for 30-year period at the University of Florida, Gainesville, Florida.

CHAPTER 5
CONCLUSIONS

5.1 Contributions of Study

Groundwater outflow and sapping features may be more difficult to identify on Earth than on Mars where the effects of sapping haven't been altered by rainfall runoff and other processes. Microcosmic sapping features on beaches share many characteristics with Mars sapping features and other examples of groundwater outflow found in Florida, Colorado, Holland, New Zealand, and other locations. This suggests some common processes are operating to form groundwater sapping features. Headward erosional development of drainage systems is usually a result of excess infiltration capacity of surficial soils with little or no associated surface runoff, structural or stratigraphic subsurface control of discharge through restricted downward percolation, and topographic influences relative to the water table and groundwater outflow. In regions of groundwater sapping, the capacity of soils to accommodate relatively rapid movement of water towards the discharge features is critical towards formation of a sapping drainage network with headwall extension/retreat. The steephead ravine in Gold Head Branch State Park is an unusual geomorphological feature that has advanced headward by undercutting of the ancient reworked marine and fluvial sediments. It is possibly tens of thousands of years old and has advanced at a relatively slow rate of anywhere from a few inches per century to several feet during and after events such as hurricanes, fires, and heavy sustained rain. The steephead has formed as a result of highly permeable soils and consistently abundant groundwater in a relatively stable geohydrological environment that is hydraulically interconnected. Lake levels in the Gold Head area have, historically, fluctuated with sustained periods of drought and heavy rain, although the lakes' existence near the center of a significant recharge zone has contributed to a buffering of impact by severe drought and regional lowering of water levels. Lake levels analyzed during this study contributed to an understanding of localized groundwater flow and complex processes occurring in the subsurface.

Based upon the subsurface investigation during this project, the steephead ravine at Gold Head Branch Park, that was formed by undercutting of sand in the headwall area, does not have a significant confining nor semi-confining layer present in the shallow subsurface that restricted downward movement of groundwater. The surficial aquifer, lake system, and Floridan aquifer are interconnected in a flow-through system and the regional mounded recharge zone has provided sufficient groundwater to continue driving development of the steephead ravine during a period lasting tens of thousands of years. The investigation by Schumm, et al., 1995 in the Florida panhandle involved drilling at the steephead headwall of two ravines to a depth below the base of the steepheads and they found no low-permeability horizons present. As the infiltration capacity of a terrain increases, the importance of surficial drainage in the development of drainage networks decreases. This study has contributed to the understanding of unusual natural processes occurring when high infiltration rates and abundant groundwater are present in an important recharge zone for the Floridan aquifer.

5.2 Limitations of Investigation

The study of the origin and development of steepheads in Florida involves reconstructing natural processes occurring over a period of thousands of years. Rainfall, temperature, and lake level data is only available for a relatively short period of time and inferences to the distant past should be tempered with caution. The rate of development of steephead terrains is difficult to interpret although the activities of man such as groundwater withdrawal and surface water diversion, urban development, and surface mining can have synergistic affects upon the steephead ravine and its natural balance. A greater understanding of the geohydrology of the Gold Head Branch Park ravine area would be possible if a study was undertaken to include a larger region.

5.3 Future Research

Experimental studies of spring-sapping channels seem to reproduce very well steephead ravine evolution, although analysis of current geohydrological conditions within this environment would benefit from an extensive network of piezometers to accurately measure changing groundwater levels over extended periods. Groundwater flow in three dimensions could be investigated between the steephead ravine and nearby lakes. The relationship and possible impact of the sand mining pit upon water levels within the Gold Head Branch Park might be investigated through mapping and analyses of groundwater levels between Pebble Lake and the sand mine utilizing groundwater piezometers and ground penetrating radar. The Gold Head region has been affected by previous severe drought conditions and further investigation will contribute to preservation of a unique environment.

The relationship of trees to climate and growing conditions within the Gold Head ravine is a complex system that seems to consider temperature as an important factor, since water supply during drought conditions is often provided through the subsurface. Future research to improve explanatory models might include measurement and/or inferential determination of additional variables such as humidity, sunshine/cloudiness, and competition effects within an extremely diverse environment.

APPENDIX A
TEST BORING LOG AND LOCATION MAP

STANDARD PENETRATION TEST

Project: Gold Head Branch State Park
Location: S.R. 21, Six miles NNE of
Keystone Heights, Florida
*Approx. 50 ft. N of steephead wall
Geologist on Site: Glenn Hermansen

Date: April 20, 2007
Drilled By: Central Florida Geotechnical; Matt Heron and Brad Alford
Boring Designation: B-1
Water Table (ft. bls): 41 feet below land surface
Type of Sampling: Split-barrel sample tube
Sheet # 1 of 2

DEPTH (ft.)	SAMPLE	BLOWS Per 6" increment	N blows (ft.)	DESCRIPTION
0	1	2,2		Light brown fine sand, trace fines
	2	2,1,2,2	3	
5	3	2,2,1,2	3	
	4	3,2,4,3	6	
	5	6,5,6,8	11	Brown fine sand, trace-some fines
10				
	6	8,11,14,15	25	SAA (same as above)
15				
20	7	10,11,13,15	24	SAA (fine-medium sand)
	8	6,8,9,10	17	SAA
25				
30	9	6,8,10,12	18	SAA - moist
35	10	9,12,17,22	29	Light gray fine-medium sand, trace phosphates

STANDARD PENETRATION TEST Project: Gold Head Branch State Park Location: N29 50' 31.5" W81 57' 13.2" ±7 meters Geologist on Site: Glenn Hermansen	Date: April 20, 2007 Drilled By: Central Florida Geotechnical; Matt Heron and Brad Alford Boring Designation: B-1 Water Table (ft. bls): 41 feet below land surface Type of Sampling: Split-barrel sample tube (two ft.) Sheet #: 2 of 2

DEPTH (ft.)	SAMPLE	BLOWS Per 6" increment	N blows (ft.)	DESCRIPTION
35	11	19,18,16,16	34	Light gray fine-medium sand, trace phosphate
	12	12,16,16,18	32	SAA
40	13	6,13,16,18	29	SAA, Water @ 41 feet below land surface
	14	20,20,28,25	48	SAA
45	15	20,25,31,31	56	SAA
	16	26,33,30,31	63	SAA
	17	27,27,28,40	55	SAA
50	18	7,19,29,40	48	SAA ____________53 ft.
	19	17,19,25,33	44	Light gray-brown slightly silty fine sand
55	20	20,28,20,20	48	Light gray slightly silty fine sand, trace shell, carbonates
	21	13,4,4,3	8	SAA w/ increasing fines; slightly clayey to clayey
	22	17,8,3,6	11	sand with carbonates – saturated @ 56-60 ft. bls
60	23	2,3,7,11	10	Drilling rod fell to 63.5 ft. w/ bit
	24	4,4,2,3	6	Sampled from 63.5 –65.5 ft.
65	25	7,7,18,16	25	Rod fell to 66 ft. – sampled 66-68 ft. bls Boring terminated at 68 feet below land surface
70				

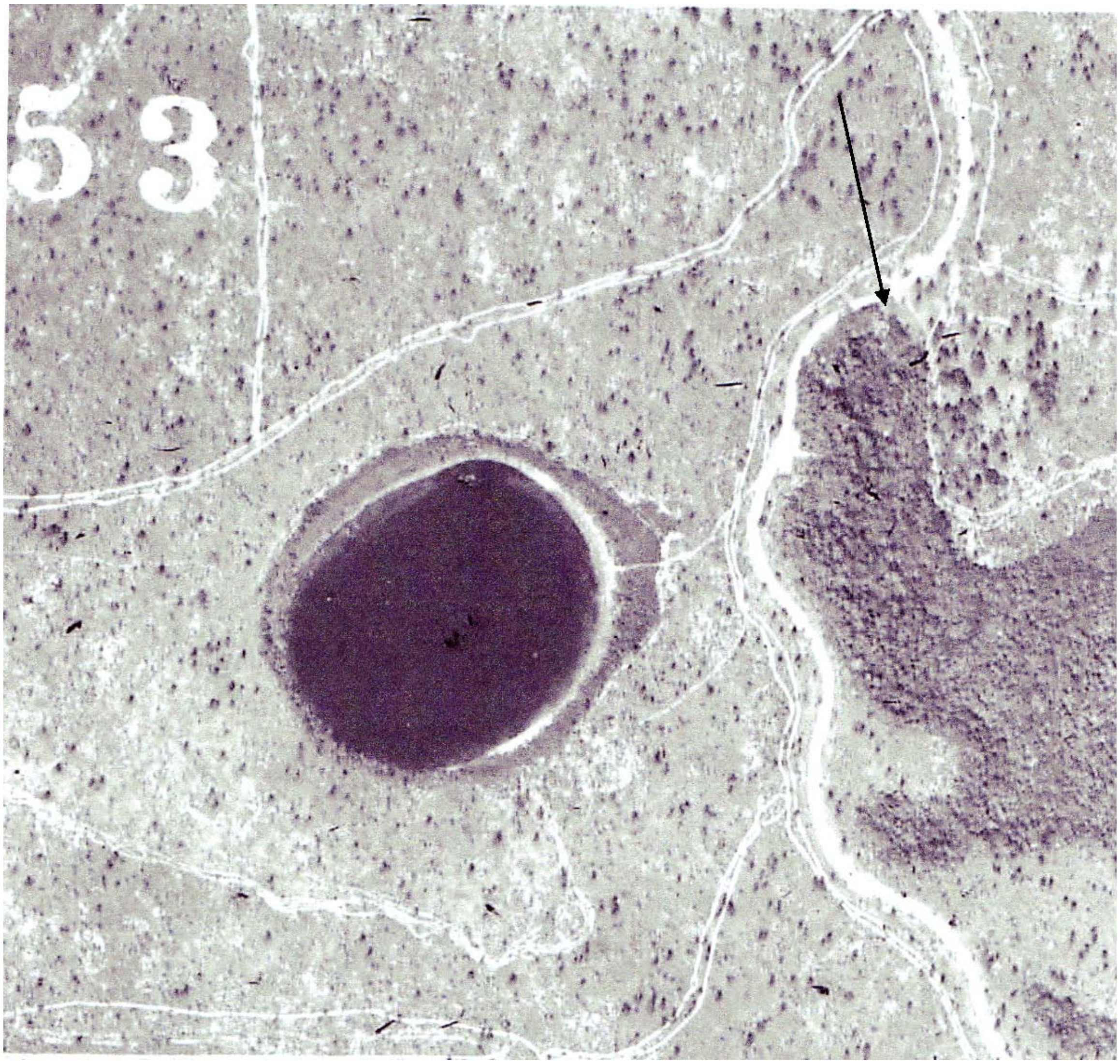

Figure A-1. 1953 Aerial photograph of Sheeler Lake and upper section of ravine. Arrow indicates location of test boring at steephead headwall. Trees clearcut except within ravine.

APPENDIX B
STATISTICAL DATA

YEAR	DTH__4	NES_PR_	LD_HEAD	LAND_	RAIN_MELROSE	RAIN_1946_2006	RESIDUALS4	RAIN_GAINESVILLE	TEMP_YEAR_AVG
1946	0.1			50.35		50.35	0.012344634	53.93	71.27
1947	0.11			64.21		64.21	0.021680736	75.85	69.39
1948	0.08			65.77		65.77	-0.013809404	58.46	71.86
1949	0.12			52.25		52.25	0.026842947	63.18	72.1
1950	0.11			53.38		53.38	0.007796628	46.73	70.65
1951	0.07			37.71		37.71	-0.030009625	55.97	70.72
1952	0.05			41.51		41.51	-0.035502031	42.14	70.68
1953	0.06			66.64		66.64	-0.043254061	73.3	70.7
1954	0.09			35.89		35.89	-0.011885856	35.24	70.37
1955	0.09			38.26		38.26	-0.010309822	42.72	70.5
1956	0.06			40.99		40.99	-0.032117909	47.98	70.25
1957	0.06			55.18		55.18	-0.034398252	56.7	70.82
1958	0.11					54.78	0.016773671	59.86	68.36
1959	0.09					71.96	0.002639057	61.14	70.43
1960	0.08				63.42	56.48	-0.014265472	62.94	69
1961	0.08				51.46	53.95	-0.015350799	47.75	67.72
1962	0.06				49.58	55.64	-0.035668315	46.71	68.04
1963	0.06				49.03	56.32	-0.023417971	37.27	67.41
1964	0.09				70.25	57.3	-0.00399414	76.95	68.55
1965	0.09				51.93	54.52	-0.001003717	64	69.06
1966	0.06				57.11	50.78	-0.032978089	54.7	67.56
1967	0.13				53.69	49.91	0.034776207	52.54	68.9
1968	0.16					52.41	0.068828866	49.83	67.46
1969	0.09					59.82	-0.001327006	53.55	68.13
1970	0.19					55.49	0.09508795	60.53	68.88
1971	0.11					50.99	0.025156093	50.34	68.81
1972	0.13					60.25	0.037483752	67.78	68.97
1973	0.11					46.73	0.014037261	50.6	68.61
1974	0.13					57.88	0.034978263	50.51	68.62
1975	0.08					54.32	-0.016199433	51.6	69.09
1976	0.11					40.1	0.008529801	48.11	66.21
1977	0.11					44.29	0.014429826	33.56	67.24
1978	0.13					62.93	0.040560771	49.2	67.09
1979	0.13					63.28	0.03001924	59.82	67.21
1980	0.09	51.53				43.07	-0.011695346	41.56	68.36
1981	0.11	41.68				47.36	0.020029653	35.25	67.62
1982	0.06	58.9				54.36	-0.02930645	61.13	69.85
1983	0.17	60.05				59.95	0.07020975	65.35	66.32
1984	0.17	41.89				40.56	0.070827463	39.25	70.06
1985	0.09	42.96				55.67	-0.004259699	49.83	69.41
1986	0.13	51.47				51.87	0.036721714	52.31	69.79
1987	0.13	53.17				47.86	0.025071764	46.63	68.17
1988	0.13	32.99				53.22	0.026838307	61.21	67.58
1989	0.13	36.05				57.02	0.029343797	40.47	68.87
1990	0.09	40.39				36.16	-0.005916555	42.33	70.52
1991	0.06	48.6				55.21	-0.040223227	50.97	69.76
1992	0.08		41.14			41.14	-0.01540853	54.28	67.9
1993	0.09		49.48			49.48	-0.006782508	43.65	68.04
1994	0.05		47.1			47.1	-0.042972316	48.89	69.51
1995	0.13		53.7			53.7	0.031191163	51.22	68.97
1996	0.1		43.59			43.59	0.003835205	54.65	68.25
1997	0.04		48.17			48.17	-0.056216752	58.22	69.56
1998	0.1		48.08			48.08	-0.004835868	45.62	71.09
1999	0.08		33.15			33.15	-0.024703089	38.34	69.38
2000	0.09		33.38			33.38	-0.009634379	34.35	68.17
2001	0.06		42.16			42.16	-0.035142971	42.14	69.1
2002	0.05		49.94			49.94	-0.049911484	55.33	69.14
2003	0.04		41.68			41.68	-0.048590595	46.62	68.65
2004	0.05		61.29			61.29	-0.042227597	58.37	69.17
2005	0.08		54.99			54.99	-0.023409933	49.98	68.96
2006	0.1		35.62			35.62	0.000694683	35.43	69

RAIN_SEPT	RAIN_JUNJULAUG_INCHES	RAIN_AUGUST	RAIN_JULY	RAIN_JUNE	TEMP_JUNJULAUG_AVG	TEMP_AUG_	PEBBLE_FT_MSL
5.68	25.42	5.55	9.16	10.71	79.83	80.32	104.6
9.98	18.03	4.88	8.01	5.14	79.32	80.71	110.96
6.36	22.3	7.07	12.88	2.35	80.77	80.6	112.96
6.36	18.86	7.95	4.51	6.4	80.64	80.39	113.38
14.37	17.96	2.2	14.42	1.34	81.36	81.95	106.71
5.12	13.5	5.21	5.92	2.37	81.82	83.11	105.36
6.46	12	3.88	4.39	3.73	82.9	81.92	102.1
5.15	30.4	16.85	8.61	4.94	80.76	80.34	98.76
6	10.76	4.1	5.25	1.41	82.25	83.8	101.2
8.75	11.05	2.05	6.44	2.56	80.53	82.37	99.08
3.77	15.53	3.87	3.49	8.17	80.91	82.24	89.24
7.95	29.5	7.95	12.45	9.1	80.66	80.44	85.04
0.8	20.83	6.99	9.67	4.17	81.14	81.31	92.5
7.51	18.36	6.36	5.85	6.15	80.56	81.24	93.12
9.25	23.3	8.1	9.37	5.83	80.58	81.35	106.96
3.14	26.96	11.81	5.88	9.27	80.36	81.05	109.82
4.29	28.88	11.34	9.87	7.67	80.68	80.95	103.67
8.02	27.9	9.81	8.02	10.07	80.85	82	91.16
4.11	17.39	8.2	6.06	3.13	80.38	80.39	96.94
6.01	25.14	10.31	6.83	8	79.11	80.87	105.86
7.89	18.83	7.28	5.24	6.31	79.15	80.35	110.46
1.68	29.44	11.64	10.36	7.44	79.05	80	105.38
1.46	33.58	17.21	11.29	5.08	80.32	80.9	100.78
9.68	18.95	7.04	9.66	2.25	81.59	80.71	95.11
4.39	24.25	10.93	7.71	5.61	81.61	82.35	98.25
2.3	25.09	8.11	7.57	9.41	80.38	80.94	104.75
1.08	24.68	12.71	4.05	7.92	79.03	80.55	101.05
4.54	20	5.83	5.45	8.72	80.71	80.47	105.25
7.77	28.5	7.77	14.48	6.25	78.74	79.85	108.06
10.94	19.51	7.65	5.07	6.79	80.66	81.16	97.32
5.12	10.51	2.79	2.75	4.97	79.28	79.66	89.67
4.85	20.24	8.49	5.4	6.35	81.92	81.82	86.54
2.32	27.9	15.15	6.71	6.04	80.67	80.77	85.52
15.92	13.24	6.27	4.3	2.67	79.81	80.35	90.54
4.72	14.3	3.15	6.25	4.9	82.31	83.06	90.88
5.42	22.64	4.99	10.14	7.51	82.8	80.77	90.74
5.9	24.94	7.17	11.08	6.69	82.06	82.05	85.38
7.28	15.74	3.23	3.25	9.26	80.39	82.23	93.06
5.77	11.81	3.13	6.19	2.49	79.58	80.81	99.66
4.14	31.06	15.42	7.49	8.15	80.19	79.82	93.91
3.22	20.99	7.92	6.57	6.5	80.71	80.21	89.99
4.09	14.08	5.19	5.73	3.16	81.33	82.34	91.14
15.16	10.58	7.34	2.59	0.65	79.53	80.37	92.62
5.36	27.38	8.4	11.51	7.47	80.22	80.32	100
1.46	16.15	4.18	5.57	6.4	80.5	80.87	92.72
4.33	15.59	2.02	6.09	7.48	80.11	80.61	85.82
4.16	14.89	3.56	3.53	7.8	80.18	79.39	96.22
5.3	16.76	3.79	6.73	6.24	81.03	81.89	86.36
2.55	17.12	1.78	2.53	12.81	79.63	78.68	86.96
4.5	22.66	7.44	4.91	10.31	80.84	82.08	91.46
1.42	15.89	6.01	5.15	4.73	80.08	79.58	93.76
3.59	16.1	3.81	4.99	7.3	80.16	81.29	89.2
11.52	20.16	9.48	6.58	4.1	83.14	82	90.78
5.5	11.03	3.12	3.32	4.59	80.85	82.15	99.47
4.37	15.71	4.65	3.8	7.26	80.5	80.82	85.44
9.12	18.33	4.89	6.12	7.32	80.41	81	79.49
4.75	24.02	8.19	7.45	8.38	79.49	79.56	77.94
2.2	21.4	8.14	6.8	6.46	79.74	80.05	78.1
20.15	24.01	7.85	6.24	9.92	81.22	80.79	80.76
4.67	22.21	8.03	6.82	7.36	81.41	82.42	88.01
4.13	15.76	3.05	5.82	6.89	80.64	82.21	91.21

LITTLEJOHN_FT_MSL	BIGJOHN_FT_MSL	SHEELER	RAINGOLDAUG	WEIGHT_RAINJUNJULAUG	WIDTH_2	RESIDUALS2
98.41				25.42	0.13	0.028196721
99.79				18.03	0.19	0.088196721
101.89				22.3	0.12	0.018196721
103.71				18.86	0.16	0.058196721
101.61				26.94	0.1	-0.001803279
99.91				13.5	0.1	-0.001803279
96.89				12	0.18	0.078196721
96.03				30.4	0.18	0.078196721
99.01				10.76	0.12	0.018196721
96.21				11.05	0.08	-0.021803279
92.79				15.53	0.14	0.038196721
91.91				29.5	0.15	0.048196721
95.03				20.83	0.08	-0.021803279
94.99				32.13	0.11	0.008196721
95.65				23.3	0.15	0.048196721
98.35				26.96	0.13	0.028196721
96.59				28.88	0.17	0.068196721
94.91				27.9	0.1	-0.001803279
95.1				17.39	0.12	0.018196721
95.5				25.14	0.07	-0.031803279
97.76				23.54	0.06	-0.041803279
97.4				29.44	0.08	-0.021803279
95.34	96.39			33.58	0.08	-0.021803279
93.2	93.48			28.43	0.08	-0.021803279
95.56	93.98			24.25	0.09	-0.011803279
95.51	96.06			25.09	0.08	-0.021803279
95.37	94.47			24.68	0.08	-0.021803279
95.65	96.67			20	0.1	-0.001803279
97.08	98.17			28.5	0.09	-0.011803279
92.86	93.97			29.27	0.1	-0.001803279
94.18	90.91			13.14	0.1	-0.001803279
95.46	89.73			20.24	0.1	-0.001803279
95.2	88.97			41.85	0.1	-0.001803279
95.46	90.56			23.17	0.09	-0.011803279
95.28	91.49			14.3	0.07	-0.031803279
95.28	90.59			22.64	0.09	-0.011803279
95.2	88.93			24.94	0.04	-0.061803279
95.4	91.59			19.68	0.08	-0.021803279
95.48	94.57			11.81	0.08	-0.021803279
95.22	92.19			31.06	0.08	-0.021803279
95.24	91.89			20.99	0.06	-0.041803279
95.31	91.26			14.08	0.06	-0.041803279
95.33	90			18.52	0.11	0.008196721
95.35	91.68			27.38	0.12	0.018196721
95.05	88.3			16.15	0.09	-0.011803279
92.99	85.25			15.59	0.07	-0.031803279
93.79	86.57		3.56	14.89	0.07	-0.031803279
91.39	86.81		3.79	16.76	0.07	-0.031803279
91.3	89.34		1.78	17.12	0.12	0.018196721
93.49	90.51		7.44	22.66	0.09	-0.011803279
94.57	91.09		6.01	15.89	0.13	0.028196721
94.4	89.95		3.81	16.1	0.15	0.048196721
94.81	91.61		9.48	20.16	0.11	0.008196721
94.72	90.66		3.12	11.03	0.1	-0.001803279
92.18	87.9		4.65	15.71	0.1	-0.001803279
90.22	85.71	149.78	4.89	18.33	0.1	-0.001803279
89.22	83.64	149.29	8.19	24.02	0.11	0.008196721
88.44	83.6	146.46	8.14	21.4	0.04	-0.061803279
88.4	84.12	148.61	7.85	28.02	0.09	-0.011803279
92.9	88	152.19	8.03	22.21	0.08	-0.021803279
94.24	89.04	154.16	3.05	15.76	0.09	-0.011803279

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