The Road to Flamingo: an Evaluation of Flow Pattern Alterations and Salinity Intrusion in the Lower Glades, Everglades National Park

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Open-File Report 02-59

2002

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

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INTRODUCTION

This report describes the history of roads through the Lower Glades of Everglades National Park, Florida and their influence on salinity intrusion. The chronology that lead to this work is interesting. The U.S. Geological Survey flew a series of helicopter electromagnetic surveys over portions of Everglades National Park to map saltwater intrusion starting in 1994 (Fitterman et al., 1995; Fitterman, 1996; Fitterman and Deszcz-Pan, 1998, 2002). These surveys identified variations in the electrical resistivity that were associated with changes in ground-water quality. The patterns of ground-water quality have been traced to natural saltwater intrusion, such as the effect of tidal rivers on lowering hydrologic heads far inland, and the influence of man-made structures, such as canals and roadways on surface water flow. These latter effects are of interest as they represent variations from the natural state of affairs in the park.

Previous investigations had been done by Everglades National Park staff on the influence of some roads and canals on the near surface hydrology. This information was scattered through a number of National Park Service publications. In an effort to bring these materials together in an easily located reference, along with new data on flows through culverts beneath the main park road, this report was written.

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March 5, 2002

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1 Introduction

The main road in Everglades National Park (ENP) connects Flamingo with the Park's entrance and continues onto the coastal ridge of Dade County (Fig. 1). The current alignment of the road, an extension of State Road 9336, formerly known as State Road 27, was built in 1956 when a portion of what was then known as Ingraham Highway was replaced with a more northward section. The road has been the subject of some controversy. Some scientists have claimed that the roadbed is a barrier to natural flow to Florida Bay, while others have blocked culverts to hold fresh water back in the wetlands east of the road and north of Florida Bay. The South Florida Natural Resources Center is conducting a study to assess the current condition of the culverts and to determine the patterns of water flow in the area adjacent to the road. Information has been gathered on the road's history, the historical water levels and flow patterns. Monitoring sites have been installed to record water level, salinity and flow, which are being measured during times when water is present. In addition to the Park project, a complementary project has been undertaken by the United States Geological Survey (USGS). The USGS has been conducting investigations in the southern Everglades to assess the extent of saline-water intrusion by means of airborne electromagnetic geophysical measurements. This report condenses the information gathered to date.

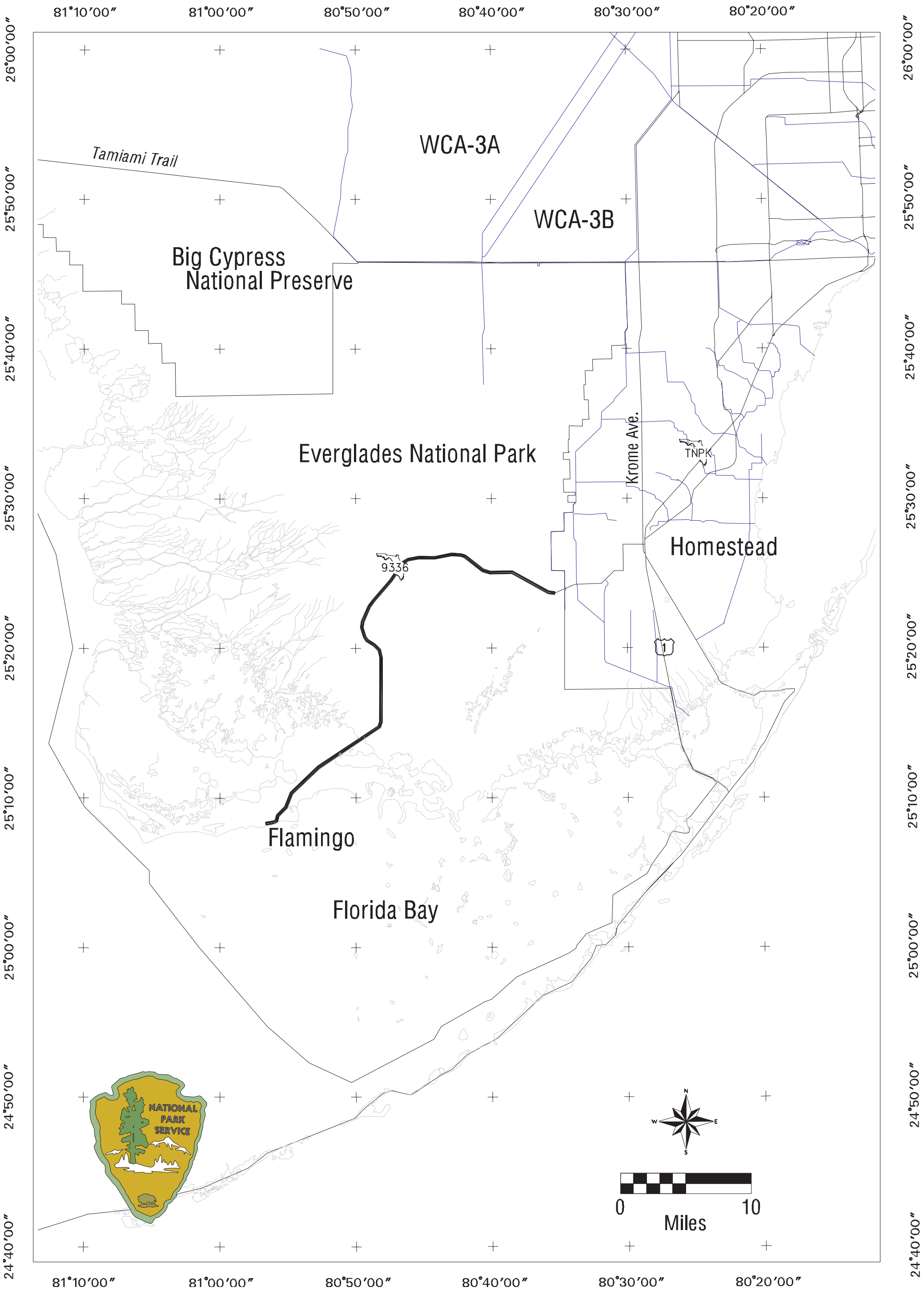

Figure 1: Location of S.R. 9336 in Everglades National Park.

2 Ingraham Highway and Homestead Canal

The Ingraham Highway was constructed between 1915 and 1919 (Fig. 2). This highway provided an overland route between Royal Palm State Park and Flamingo, a settlement on the shore of Florida Bay with access to the back-country of the Everglades. The road was built using fill from a borrow ditch, known as the Homestead canal, which followed the western edge of the road from Flamingo northward. The road, which on average was one foot above the surrounding ground elevation ([2]), frequently overtopped during the wet season, making it impassable. This highway had no culverts and effectively prevented flow except during the wet season. After the road turned eastward at the concrete bridge (Fig. 2), near the present location of the Flamingo water supply wells, the borrow ditch was located on the northside of the road. The borrow canal was open to Florida Bay. During the early decades of this century, when the drainage of the Everglades accelerated, the southern glades frequently dried out, reversing the hydraulic gradient and allowing the Homestead Canal to become a conduit for the inland flow of salt water. In addition to the free exchange of salt water through the outlet near Flamingo, saline water also entered the canal at Whiskey Creek.

Since the water level was near or above the ground surface, the road was constructed by dredging (excavating the rock by detonating dynamite in bore holes to fracture the limestone). The rock was thrown to one side and graded to make a roadbed. During the last week of December 1917, the dredge was about four and a half to five miles from Royal Palm, making slow progress towards Cape Sable, when during blasting a subaqueous cavern was uncovered ([16]). The thirty foot boom was let down and swung around, but it did not encounter

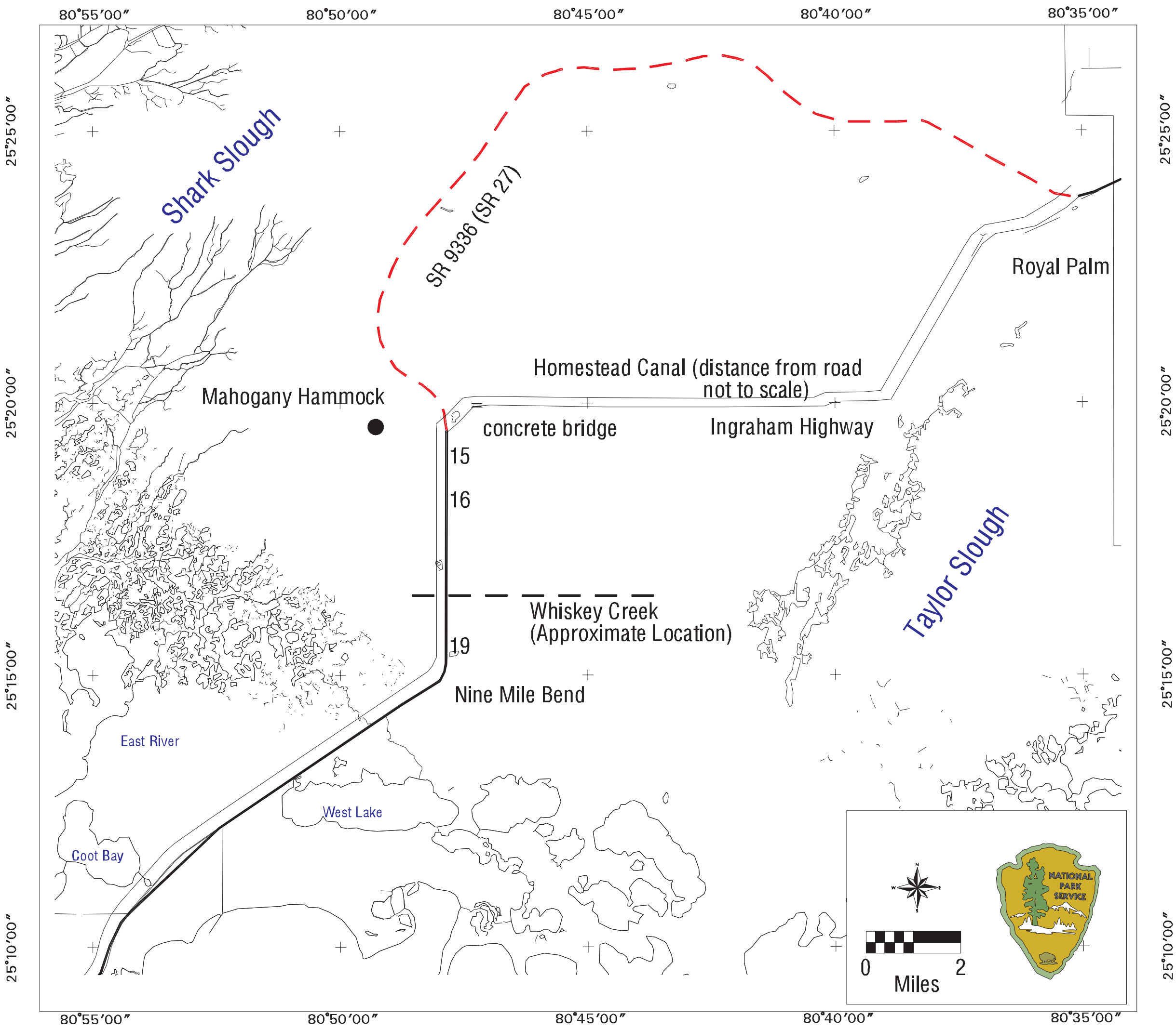

Figure 2: Alignment of old Ingraham Highway.

any obstruction. Broken pieces of stalactites, to over four feet diameter were retrieved. It is likely the dredge crossed a geologic reef remnant. Rock reef ridges exist in ENP which may serve as conduits thus altering flow patterns in the area. Upon completion of the Homestead canal and road to Flamingo, an extension of the canal was cut to Lake Ingraham in an attempt to drain the Cape Sable prairie.

During the period 1946 to 1956, water samples were collected from the canal along Ingraham Highway southwest from Royal Palm. D.B. Bogart ([14]) recognized that the canal acted as an avenue for salt-water intrusion from the estuary to the area between Whitewater Bay and Homestead. His findings were based on the chloride analysis of the samples. He concluded that in dry periods, salty water moved upstream toward ranger station at Royal Palm Park. One of the higher values collected had a chloride content of 21,000 ppm collected at Nine-mile bend on July 20, 1948. Several dams were installed in the Homestead canal in an attempt to slow salt water encroachment by regulating what had been uncontrolled flow.

The first dam was installed at station 19 (Nine-Mile Bend) in June 1950. In June 1951 a second barrier was installed in the canal at station 16, 3 miles north of station 19. A year later a third barrier was added in the canal at station 15, 1 mile north of station 16. The canal water remained relatively fresh in the reach above station 16 until the drought of 1955-56 ([11]). Data collected in May of 1956 show values of 9,420 ppm below the dam at station 16 and 4,900 ppm above the dam. Values of 82 ppm were also recorded from the old concrete bridge 2 miles north of station 15. Klein and Hartwell studied chloride levels from these stations and nearby wells. They concluded that although the general freshening of water at these sites in the 1950's may have been the result of the installation of salt-water barriers in the Homestead Canal, it was more likely due to relative higher seasonal water levels since the 1943 survey of the area around the Flamingo supply wells was made.

Construction of the new road began in 1956 and the Homestead canal was filled in from Flamingo north to the wellfield (located near culvert 76). Today, remnants of the road and canal still exist. A 10 mile section south of Royal Palm can still be traveled by service vehicles. In this section the road and canal continue to form an effective barrier for overland flow to the south. During high water the road is overtopped in several low spots as water flows south from the canal to the wetlands. A 3.4-mile section from the wellfield to the east was totally removed and can only be noticed as a slight depression. The removal of the section occured shortly after completion of S.R. 9336, to limit access to the area east of the road to help reduce poaching. The road to Royal Palm was left in place as it provided access to private property. The borrow canal north of the road is overgrown and contains a lot of organic deposit but still allows flow to occur from east to west during the wet season.

3 Construction of the New Road, S.R. 9336 (S.R. 27)

Increasing vehicle traffic in the late 1940's and early 1950's after creation of Everglades National Park necessitated improvements to the narrow and frequently inundated road to Flamingo. Re-alignment along the north side of the Long Pine Key rock ridge replaced much of the original Ingraham Highway (Fig. 3). Construction of the southern portion of what was then called S.R. 27 and is now known as S.R. 9336 began at Flamingo in 1956 and proceeded northward. During the construction of S.R. 9336 178 culverts were placed under the road from the Park entrance to Coot Bay (Fig. 3). These culverts were constructed to help reconnect the wetlands, maintain the flow of water and prevent flooding of the road during periods of high water. Simultaneously with the construction of the southern portions S.R. 9336 the Homestead canal was filled. The fill needed for the construction of the new road was obtained by digging a series of borrow pits instead of a continuous borrow canal along the side of the road.

Today, S.R. 9336 (S.R. 27) enters Everglades National Park on the Long Pine Key rock ridge, which has some of the highest elevations in the southern portion of ENP. This ridge is the terminus of the Atlantic Coastal Ridge and is made of an oolitic facies of inorganic origin. The road follows the northern edge of this ridge, until it crosses over the marl soils near Mahogany Hammock. Along its northern alignment the road heads west through pinelands broken only by a couple of transverse glades which cut through the relatively high elevations, four to five feet above sea level. Today, with sharply reduced water levels, this terminus of the coastal ridge forms a more effective barrier with the only conspicuous surface water flowing through Taylor Slough and occasionally through the smaller glades to the west that cut through the pinelands. The predominant direction of the historical surface water flow pattern in this reach is southward toward Florida Bay, at right angles to the road. The substrate is mostly rocky pinnacle limestone, Miami oolite, and where not exposed is overlain by the Perrine and Flamingo marls, an algae-based calcium carbonate

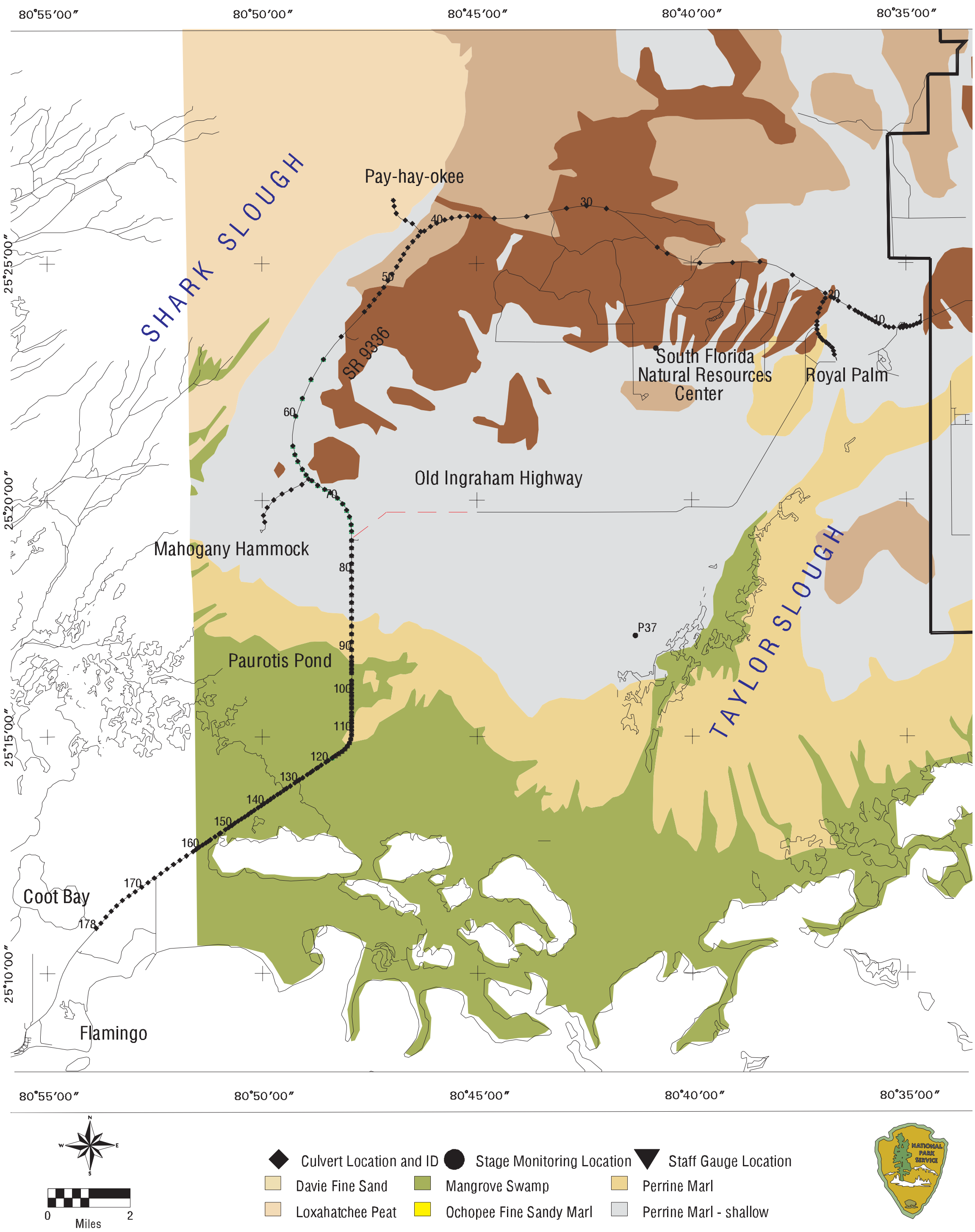

Figure 3: New road alignment. Source soil associations: [17].

deposit.

After passing the Pa-hay-okee overlook the road heads southwest, crossing mixed grass prairies and cypress domes, until it reaches the eastern edge of Shark Slough near the Mahogany Hammock overlook. The soil in this stretch is Perrine marl. South of Mahogany Hammock, the road takes a more north-south bearing, through an area dominated by prairie with hardwood hammocks scattered throughout. By now, the average elevation has dropped several feet, to one to two feet above sea level. By the time the road approaches the Nine Mile Pond turnoff (Fig. 7), the landscape has become scrub mangrove forest. Peat soils appear in the area, which tend to be thicker in the mangrove zone and water now flows more toward the southwest. This stretch of the road is close to the coast where tidal forces become more influential. The road terminates in Flamingo, where concessions and access to Florida Bay is made available by the National Park Service.

3.1 Roads connecting to S.R. 9336

Roads leading to the Park's maintenance area and visitor vista along areas along S.R. 9336 also may play a role in altering water flow. The Pine Island road leading to the maintenance area is crossed by culverts at two locations. The first location has one 24-inch culvert and the second location contains three 24-inch culverts and one 36-inch culvert adjacent to one another. Royal Palm road contains fourteen 24-inch culverts and one 36-inch culvert. The road to the South Florida Natural Resources Center contains only one 36-inch culvert. This access road serves as an additional barrier to water flowing through the small glades that cut through the pinelands north of the road. South of this road is the area known as the Hole in the Donut, an area which until June 1975 had been under cultivation. Natural vegetation, mostly short-hydroperiod marshes, have been replaced by the Brazilian pepper tree (Schinus terebinthifolius). The exotic vegetation and ground surface alterations prove to be a barrier to surface-water flow. Pay-hay-okee road has six 24-inch culverts. Mahogany Hammock road contains eight 24-inch culverts, spaced 0.2 miles apart. In addition to the main road culverts, the Pay-hay-okee Road and Mahogany Hammock road culverts were monitored for discontinuous flow and stage levels starting during the 1996 wet season. This will further help understand the flow patterns in the study area.

4 The Culverts from 1961 - 1971

Construction of the levees enclosing the Water Conservation Areas (WCA), north of ENP, the filling of WCA-3, and the excavation of ditches east of the Park shut off much of the water flow into ENP from 1962 until late 1965 when hurricane Betsy flooded the Everglades. The severe water shortages in the Park from 1961-1965 were further aggravated by the lack of rainfall, making it one of the driest times on record. The lack of water flowing into the Park had serious effects on wildlife and plant communities. Craighead estimated in 1965 that the alligator population of the eastern portion in the Everglades National Park was hardly 5% of the population in 1960. Although most of the wildlife data reported by Craighead were based on visual observations and not on systematically collected data, it became clear that the low water levels of

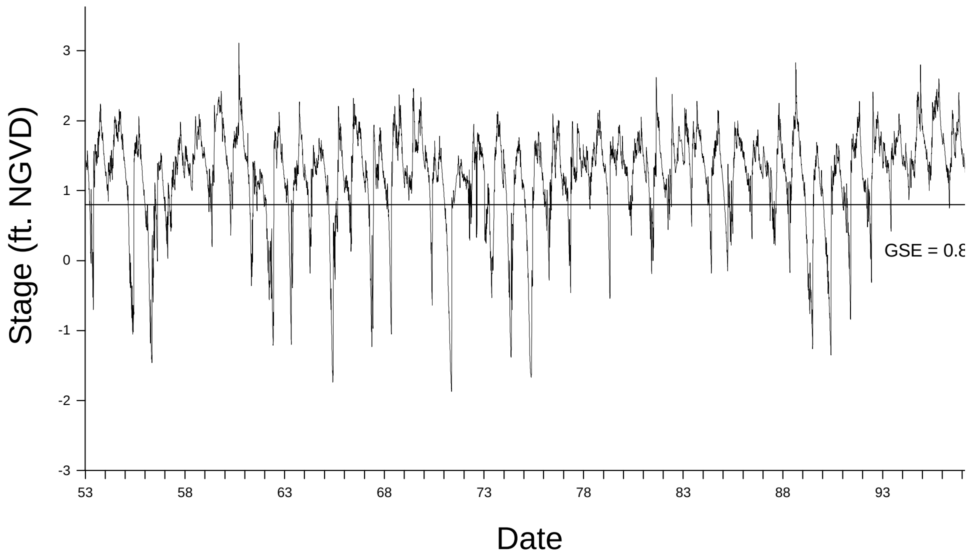

Figure 4: Period of record water levels for P37.

the early 1960's stressed every aspect of the wetlands. The low water levels of May 1962 coincided with extensive fires, burning vast areas of deep water sloughs which had been exposed. These fires also destroyed many hammocks with trees over one hundred years old.

Water levels in the southern portion of the Park regularly dipped below sea level as depicted by the hydrograph of station P37 (Fig. 4). Contour maps drawn by [9] show the spatial extent of the dry conditions. The lack of surface water flows to the southern glades, combined with the low rainfall and high evapotranspiration rates of the late dry season caused the large dryouts. These conditions were not restricted to the early 1960's, when Craighead and colleagues were doing most of their work. The lack of surface water was also endemic during the period of uncontrolled drainage prior to and into the 1940's. The lack of coastal control structures on the canals north and east of the Park

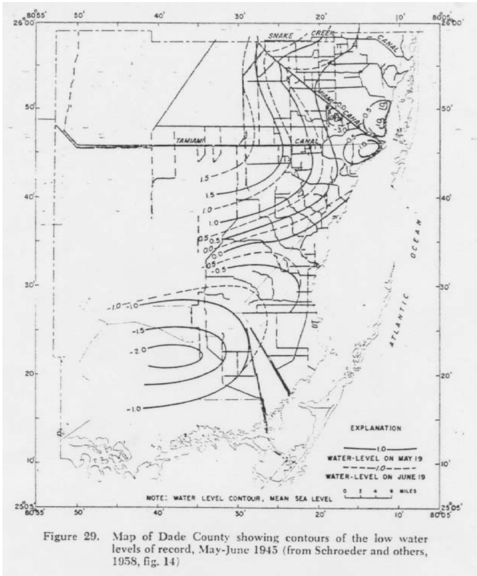

Figure 5: Water level contour map for May 1945. Source: Schroeder *et al.*, [1958]

allowed drainage to occur well into the dry season, causing overdrainage in many parts of the system. Low water levels in May 1945 were contoured by ([15]) (Fig. 5), and determined by [12] to be more severe than the 1962 conditions (Fig. 6).

During periods of low water levels, west-northwest winds blowing across Whitewater Bay create wind tides which drives salt water far into the fresh water wetlands of Everglades National Park. In one particular case it is documented that after several days of strong northwest winds with practically no fresh water in the inner mangrove zone west of S.R. 9336, salt water was driven in and banked up along the west side of the road flowing six to ten inches deep through the culverts ([3]). These storm driven waters were reported to have completely surrounded Mahogany Hammock. Lack of persistent freshwater

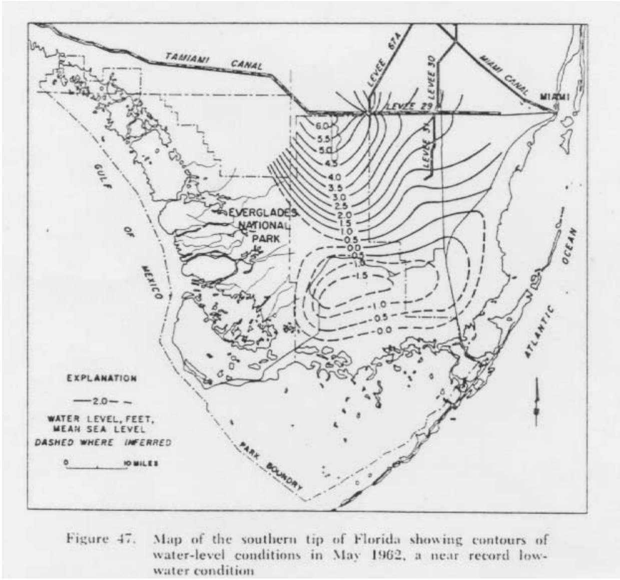

Figure 6: Water level contour map May 1962. Source: Leach *et al.*,[1972]

flow failed to flush the saltwater off the wetlands within a reasonable amount of time causing ecological changes to set in.

Based on his field observations, Craighead made a recommendation to block culverts 76 through 144 with sandbags. The proposed project was reviewed by an advisory group in 1964, and with their affirmative recommendation was authorized by the NPS Regional Director. By blocking the flow, it was hoped that fresh water could be retained in the eastern marshes south of Pumphouse Road to West Lake. The sandbagging of the culverts acts as a barrier to surface-water flows helping to retain fresh water to the east of the road and stem the water losses to the west in much the same way as the natural embankments north of Florida Bay (*i.e.* the Buttonwood strand) act as dams. Craighead in his 1967 report stated that the road embankment alone, even with the culverts open, had a considerable retarding effect on the westward flow of water immediately after heavy rains. From Craighead's papers, one can infer that he believed the general flow of water was to the west or southwest across S.R. 9336.

The culverts were blocked in November of 1964 by placing sand bags in the west end of each culvert. Three to five bags were used in each culvert. Between 1964 and 1967 the bags had to be replaced several times because the cloth would rot, alligators would move them, or high water events would wash the sandbags from the culverts. Craighead noted that all the remaining bags were flushed out after the heavy rains in June 1967. However, surveys in 1996 showed that several southern culverts were still partially blocked by the remains of sandbags. During times when there was sufficient water in the system, the blocked culverts helped retain fresh water east of the road.

Observations during the first year after blocking the culverts from November 1964 to May 1965 showed water levels remaining between 0.2 ft to 0.5 ft higher on the east side as compared to the west side of the road. This enabled the area east of S.R. 9336 to retain water further into the dry season. Only a few observations were made on both sides of the road, but Craighead's water level data clearly showed the differences between east and west. After the results of the first year were analyzed, it was felt by Craighead and others that this was an effective way to impound fresh water for wildlife use further into the dry season.

During the early 1960's the area west of the highway flooded with salt water unimpeded because of the dry glades. Marine tides combined with favorable winds pushed water from Whitewater Bay and Coot Bay into the wetlands and backed up west of the road to a depth of 0.5 to 1.0 foot ([2]). Fed by the

East River into Whiskey Creek the saline water flowed east killing fresh water flora and fauna. In addition to the natural creeks, the Buttonwood Canal allowed saline water to flow west along the highway. Coot Bay was changed from a brackish-fresh water system to a marine environment causing the loss of foraging habitat for thousands of ducks and coots.

The Buttonwood Canal extends 3.2 miles from Florida Bay to Coot Bay. Although the canal was dug beginning in 1922, the connection to Coot Bay was not made until August 1957. Objections to the connection were made by Park ecologists, but the demand for enhanced visitor experience outweighed ecological concerns. At that time a temporary earthen dike at the mouth in Flamingo was removed and the saline waters from Florida Bay were free to interchange with Coot Bay. The Homestead Canal had also been excavated along the eastern edge of Coot Bay, which allowed both Coot Bay and Whitewater Bay to contribute saline water to the canal.

5 Current Condition of Culverts

Although water level measurements continued from 1965 to 1971, little attention was paid in the following decades to the culverts below the S.R. 9336 intersection with Royal Palm Road. During the planning for the C-111 project, culverts 9 through 22 and the Taylor Slough bridge were evaluated and redesigned. Drought conditions in 1989 and 1990 again caused water levels to drop below sea level in the wetlands and hypersaline conditions prevailed in the upper estuaries of Florida Bay. No detailed investigations were made of the effects of the drought situation along the road near Flamingo. Recently, the South Florida Natural Resources Center initiated a study to re-examine the culverts and again evaluate what role the road plays in altering natural flow patterns. Observations tend to confirm that some impoundment of water on the eastern side of the road still occurs, at least in the beginning of the 1996 wet season.

To determine if there is a notable stage difference between the north/south and east/west sides of S.R. 9336 and the effect it has on the flow of water, discontinuous flow and stage measurements are being conducted. These measurements will help quantify the flow patterns that currently exist between Royal Palm Road and Mrazek Pond. Assessments on the condition of the culverts show that some of the culverts blocked by Craighead still contain sandbags on the west end of the culvert, and many of the approaches to the culverts below Nine Mile Pond are overgrown with vegetation and partially blocked with detritus which may retard flow.

5.1 More recent water level and flow measurements

Staff gauges (Fig. 7) have been installed in and near seven culverts along the main Park road and at two locations on the Pay-hay-okee overlook access road. The recorders have been installed in upstream/downstream pairs. Along with the discontinuous staff gauges (88NGVD), two stations (SR-1 and SR-2) measuring continuous stage have been installed between culverts 57 and 58. SR1 and SR2 have been operational since November 1997. Fifteen culverts have been selected for routine flow measurements along the main Park road along with two culverts on the Pay-hay-okee overlook access road and one on the road leading to Mahogany Hammock. Point velocity measurements were taken at each observation culvert using a Marsh McBirney Portable Water Current Meter beginning in 1996. These measurements are aiding in developing a representation of the flow patterns between Royal Palm and Mzarek Pond. The data confirms most of Craighead's observations. The culverts in the Pinelands predominately flow south, but are subject to periodic reversals of flow, after localized rain events. South of Pay-hay-okee there is a predominant westward flow. Discontinuous salinity measurements have been recorded during 1997 at key points between Paurotis Pond and Coot Bay.

6 Airborne Resistivity Measurements

The discussion so far has been on the history of roadways, canals and culverts, and the present conditions of culverts and flow measurements with minor mention of historical water conductivity measurements in the canals. These conductivity measurements provide some information on the extent of saltwater intrusion. We will now turn our attention to another way of assessing the extent of saltwater intrusion, which is not limited to these accessible areas.

A helicopter electomagnetic (HEM) survey, which was flown over portions of ENP by the U.S. Geological Survey to map saltwater intrusion, provides some insight into the influence of roads and canals in ENP on the hydrologic regime ([6], [4]). The survey results are presented as apparent resistivity maps which show how well the ground conducts electricity. In general, electrical conduction will increase when the ground is saturated with saline water, and will decrease when saturated with fresh water. High resistivity values corre-

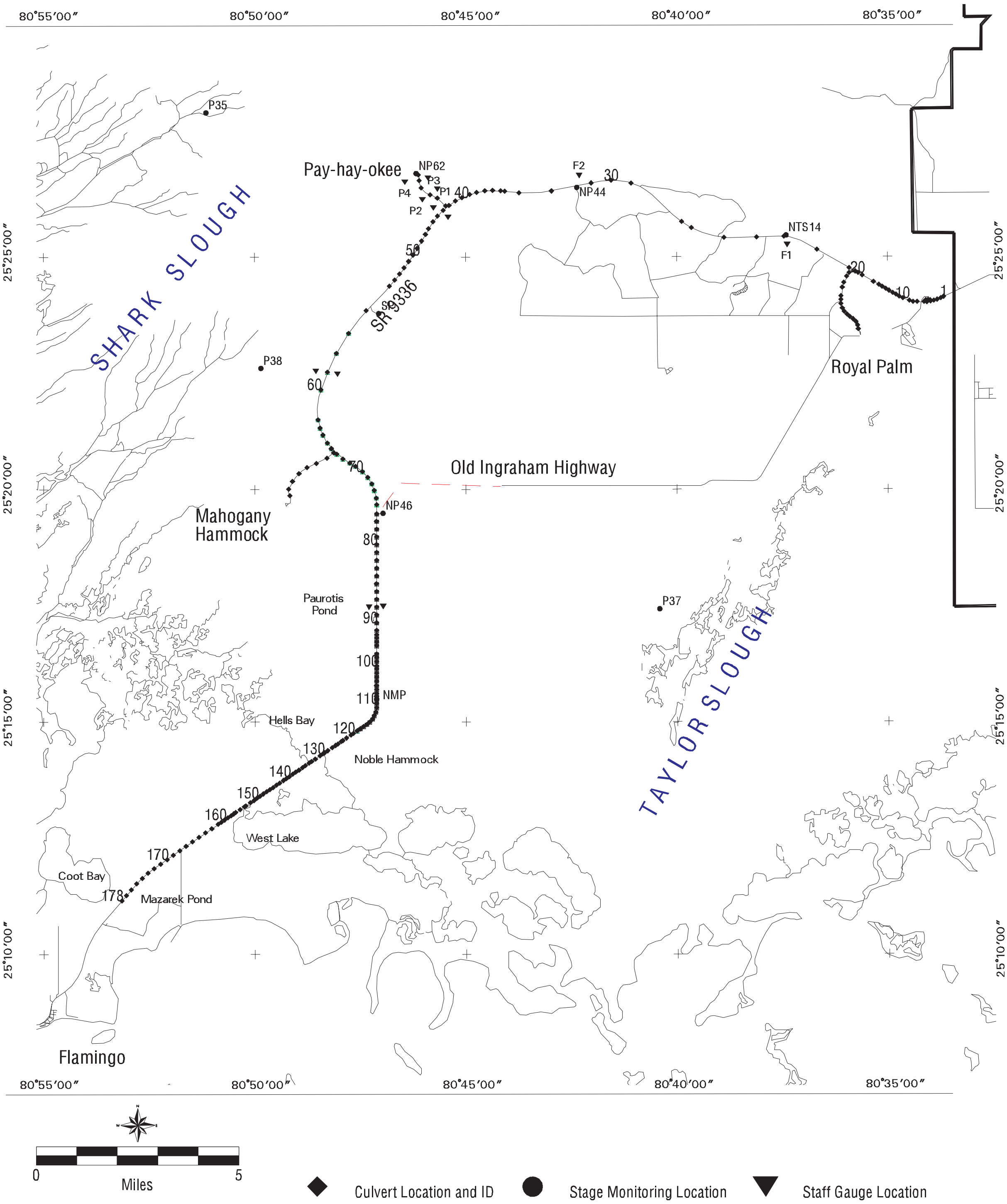

Figure 7: Staff gauges.

spond to freshwater saturated zones, while low resistivity zones are produced by saltwater saturated zones. This assumes that the porosity is fairly uniform across the area of interest. This is a good assumption in the portion of ENP surveyed, as the geology of the area is moderately uniform. The movement of saline water has been hard to trace due in part because of the difficult access to much of the area inside the ENP. With the use of HEM surveys one is able to measure the effect of saltwater intrusion in areas which are difficult or impossible to access from the ground.

Electromagnetic geophysical measurements provide a way of indirectly mapping aquifer salinity. It is well known that ground-water conductivity is directly related to the concentration of dissolved ions ([7]). The bulk resistivity of rocks saturated with a conducting pore fluid is described by Archie's Law ([1], ([10]), which states that for moderate porosity (20-40 percent) sedimentary rock, saturated with high conductivity pore fluids and devoid of clay or alteration minerals, the rock resistivity is given by: $\rho = a \times \rho_0/\phi^2$, where ρ_0 is the water resistivity (inverse of conductivity), ϕ is the porosity, and a is constant. Thus if the bulk resistivity of a region can be measured, and if the porosity is fairly uniform throughout a region, then variations in resistivity can be attributed to variations in water resistivity.

There are numerous electromagnetic techniques which can be used to determine ground resistivity ([13]). Most of these techniques make use of a transmitter loop through which a sinusoidally varying current is passed. The transmitter current produces a time varying magnetic field which induces currents in conductors in the vicinity of the transmitter loop, such as water saturated rocks. A second coil serves as a receiver which senses the magnetic field produced by the currents induced in the ground. Through an analysis of the strength of the secondary signal produced by the induced currents relative to the primary signal due to the transmitter, the resistivity of the ground can be determined ([8]).

Because of the difficult and limited access in Everglades National Park, electromagnetic geophysical measurements which can be made from an airborne platform, such as a helicopter, have a distinct advantage over ground based measurements. The U.S.G.S. has been involved in a series of helicopter electromagnetic surveys of portion of Everglades National Park designed to map the location of the freshwater/saltwater interface ([6], [4]). These surveys make use of a 10-m–long instrument pod, called a "bird," which is slung below a helicopter. The bird contains several transmitter-receiver coil pairs operating at different frequencies. The bird is flown at an altitude of 30 meters back and forth over the survey area along lines spaced 400 meters apart, with samples taken every 0.1 second (corresponding to 4–6 meters) along flight lines. The electromagnetic response is converted to apparent resistivity and gridded to produce maps.

Figure 8 shows a portion of an apparent resistivity map measured in December 1994 covering a portion of S.R. 9336 south of Pa-hay-okee to West Lake, and the western portion of Old Ingraham Highway. Apparent resistivity maps from the HEM survey show a well defined transition from high to low resistivity, as well as the influence of freshwater flowing in Taylor Slough, which pushes the transition southward in the area of maximum flow ([6], [4]). In the area along the north-south stretch of S.R. 9336 and south-westward to Flamingo, the HEM data show the influence of the road on the surface and ground-water flow patterns, as exhibited by higher resistivities to the east of the roadway. The 56 kHz apparent resistivities, shown in Figure 8, which characterizes the near surface resistivity from the surface to a depth of five to 10 meters deep. The map clearly shows changes in resistivity in the vicinity of the existing Park road and along the old alignment of Ingraham Highway.

Taylor slough brings in most of the surface water which gets added to the local precipition south of the Park road and flows in a southwesterly direction. Apparent resistivity maps from the HEM survey show a well defined transition from high to low resistivity and shows the influence of freshwater flowing in Taylor Slough which pushes the transition southward in the area of maximum flow ([6]). In the area along the north-south stretch of S.R. 9336 and southwestward to Flamingo, the HEM data show the influence of the road on the surface and ground-water flow patterns as exhibited by higher resistivities to the east of the road. The 56 kHz apparent resistivity (Figure 8), which characterizes the near surface, clearly shows changes in the conductivity in the vicinity of the existing park road and along the old alignment of Ingraham Highway, probably due to differences in pore water conductivity.

The higher resistivity areas (Fig. 8) define the southwest flowing waters of Taylor Slough and the fresher conditions in the pinelands north of old Ingraham Highway. Lower resistivity values are found north and south of the old east-west alignment of Ingraham Highway. We interpret these features as remnants of the decades when high salinity water moved up the Homestead canal during the dry season. The northward movement of the salt-fresh water interface west of the road is clearly shown by the higher conductive zone. The section of road from West Lake, near culvert 150, to the area south of

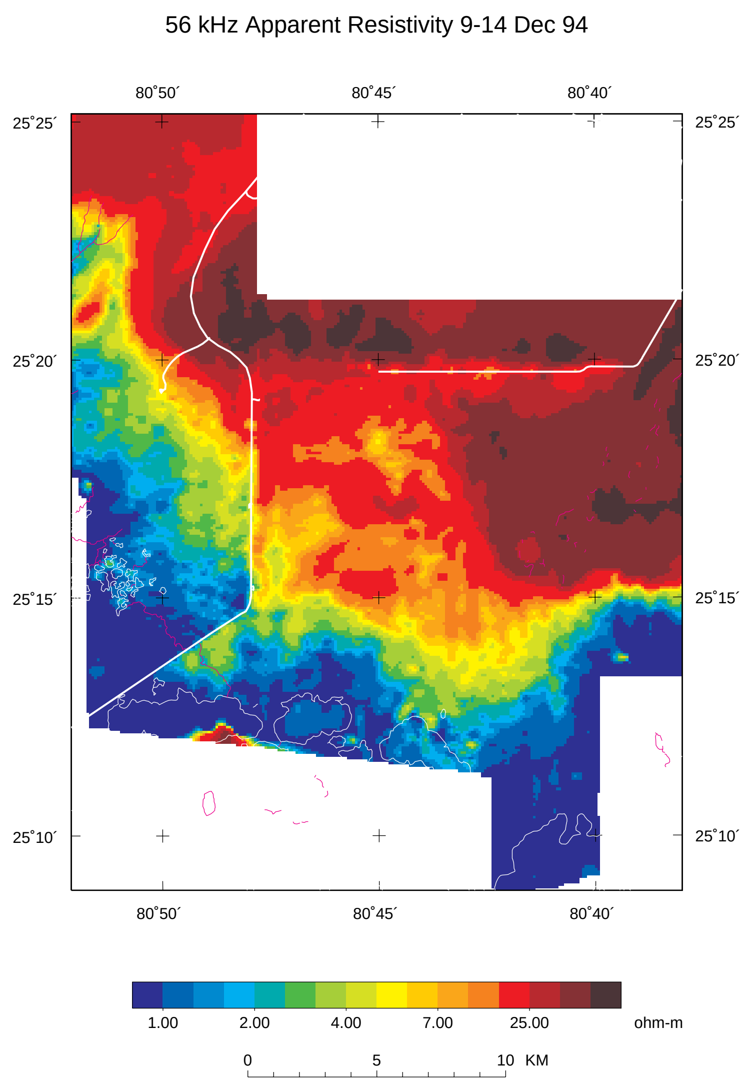

Figure 8: Resistivity of the area around the park road.

Mahogany Hammock, near culvert 70, appears to be helping to retain fresher water to the east, although it may be possible that the spatial pattern observed in these recent flights was established several decades ago and are remnants of modification of flowpatterns caused by the historical roadways. Today the volumes of fresh water required to move this interface towards the marine area may no longer be present in the system due to low water levels.

Measurements of formation resistivity and pore water conductivity in boreholes provides a means of qualitatively interpreting the HEM data. Using a series of wells across the study area to correlate the formation resistivity using an induction logger and the porewater conductivity measured in the well bore, the following relationship has been determined by regression ([5]):

$$SC[\mu\mathrm{S/cm}] = 81200\rho_f^{-1.062}[\mathrm{ohm-m}]$$

where SC is the specific conductance of the pore water, and ρ_f is the formation resistivity. While the HEM apparent resistivity map must be inverted in terms of formation resistivity as a function of depth and position to apply this correlation, its use with apparent resistivity gives a rough indication of water quality in the upper five to 10 meters.

MM-DD-YY	culv. 89	culv. 110	culv. 133	culv. 154	Paurotis	Nine mile	N.Hammock	Hells Bay	W. Lake	Mrazek Bay	Coot Bay
04-14-97					3.4	1.0	1.1	7.4	0.6	22.3	16.6
04-22-97	1.7				3.5	1.2	1.2	6.9	6.4	24.6	17.6
05-01-97						0.4	1.3	9.0	6.9	23.7	17.0
5-08-97	4.5	1.0				0.63	1.8	9.4	6.8	31.5	19.5
05-15-97	2.5				3.8	1.4	1.9	10.1	6.8	18.9	16.8
05-19-97	4.4				3.9	1.4	2	9.2	7.4	20.3	19.4
05-27-97	5.0				4.2	1.7	2.2	8.2	7.8	16.0	32.6
06-02-97	0.9	1.0	1.4	6.5	3.9	1.8	1.3	7.1	6.7	11.3	13.7
06-09-97					2.1	1.2	4.1	1.5	5.6	12.0	1.2
06-23-97			0.4	7.2	0.4	0.2	0.3	0.4	7.2	1.4	1.9
07-01-97					0.1	0.3	0.4	0.5	6.3	1.9	3.1
07-16-97	0.1	0.3	0.4	2.4	0.7	0.3	0.4	0.8	5.4	2.8	3.7
07-22-97		0.3	0.3	3.8	0.5	0.3	0.4	0.3	4.6	2.2	2.2
07-28-97	0.1	0.3	0.3	4.6	0.7	0.3	0.4	0.6	4.8	1.5	3.2
08-07-97	0.1	0.3	0.4	2.8	0.8	0.3	0.6	0.4	5.1	2.1	5.5
08-18-97	0.1	0.4	0.5	4.3	1.0	0.4	0.5	1.6	5.2	2.4	6.2
09-02-97	0.1	0.5	0.5	4.5	0.9	0.5	0.5	0.5	5.6	2.8	6.9
09-08-97	0.1	0.5	0.5	5.5	1.1	0.5	0.4	0.8	5.6	2.8	8.0
09-16-97	0.2	0.2	0.4	3.6	0.8	0.2	0.4	0.9	5.0	2.9	8.1
10-01-97	0.1	0.3	0.4	3.1	0.5	0.4	0.3	0.4	4.8	2.3	7.0
10-15-97	0.1	0.4	0.3	5.2	0.9	0.4	0.3	0.3	5.3	1.9	8.3
10-28-97	0.1	0.4	0.4	5.0	0.8	0.4	0.3	0.4	5.5	5.36	9.0

Table 1: Salinity conditions (μS/cm).

Flow dir.(+)	South	South	South	South	South	South	South
MM/DD/YY	culv. 24	culv. 31	culv. 34	culv. 41			
04/14/97	Dry	Dry	Dry	0.00			
04/21/97	Dry	Dry	Dry	0.00			
04/29/97	Dry	Dry	0.00	0.00			
05/07/97	Dry	Dry	0.00	0.00			
05/14/97	0.00	-0.84	0.00	0.00			
05/19/97	0.00	0.00	0.00	0.00			
05/27/97	0.00	0.13	1.21	0.00			
06/02/97	0.18	5.91	2.17	5.55			
06/09/97		2.34	3.61	4.68			
06/23/97	0.00	0.13	4.33	3.35			
07/01/97	0.00	0.64		1.73			
07/09/97	0.00	0.00	1.05	1.16			
07/16/97	0.00	-1.27	2.06	0.32			
07/22/97	0.00	-0.89	0.93	0.70			
07/28/97	0.00		0.85	1.33			
08/07/97	0.00	0.06	0.00	0.86			
08/18/97	0.00	0.00	0.00	0.30			
08/25/97	0.00	-1.14	3.20	0.17			
09/02/97	0.00	0.00	4.24	2.58			
09/08/97	0.00	3.54	0.00	3.34			
09/16/97	0.00	-0.33	2.53	2.85			
10/01/97	0.33	0.90	7.07	3.59			
10/15/97	0.00	1.06	1.57	2.56			
10/23/97	0.00	0.00	0.43	1.06			
10/28/97	0.00	0.00	0.06	1.59			
Positive value discharges denote south or east flows and negatives values denote north or west flows in cfs.							

Table 2: Discharge conditions

Flow dir.(+)	S. West	S. West	S. East	S. East	S. East	S. East	S. East
MM/DD/YY	P5	P6	culv. 43	culv. 56	culv. 59	culv. 63	
04/14/97	0.00		0.00	0.00	-0.59	0.00	
04/21/97	0.00		Dry	0.00	0.00	0.00	
04/29/97	0.00		0.00	0.00	0.00	0.00	
05/07/97	0.00		Dry	Dry	0.00	Dry	
05/14/97	0.00		0.00	0.00	-1.59	-0.55	
05/19/97	0.00	0.17	0.00	0.00	0.00	0.00	
05/27/97	0.26	1.30	0.00	0.00	0.00	0.00	
06/02/97	11.00		-7.12	-5.96	-16.38	-6.25	
06/09/97	11.12	11.34	8.34	-7.39	-14.50	-11.91	
06/23/97	11.00	10.68	-5.85	-5.23	-12.21	-10.25	
07/01/97	0.96		-2.70	-0.58	-5.94	-4.06	
07/09/97	7.92	7.70	-2.25	-0.79	-4.92	-3.28	
07/16/97	9.02	7.73	-2.97	-0.51	-4.88	-3.41	
07/22/97	8.64	7.54	-1.89	-1.25	-7.16	-5.28	
07/28/97	7.23	7.28	-1.46	-0.51	-4.47	-2.99	
08/07/97	6.28	5.88	-1.46	-0.50	-4.42	-1.43	
08/18/97			-0.33	-0.06	-1.10	-0.33	
08/25/97							
09/02/97	9.58	9.36	-4.83	-1.74	-5.36	-2.35	
09/08/97	9.43		-3.40	-1.10	-6.74	-5.06	
09/16/97	8.64	8.48	-1.86	0.00	-2.87	-1.84	
10/01/97	10.05	10.05	-3.79	-0.29	-4.84	-2.91	
10/15/97	8.17	7.23	-1.64	-0.09	-3.37	-1.64	
10/23/97	5.97	6.60	-1.32		-2.02	-0.91	
10/28/97	6.44	5.50	-3.10	0.00	-1.60	-0.32	
Positive value discharges denote south or east flows and negatives values denote north or west flows in cfs.							

Table 3: Discharge conditions

Flow dir.(+)	East	N. East	East	East	East	S. East	S. East	S. East
MM/DD/YY	M5	culv. 68	culv. 76	culv. 89	culv. 110	culv. 133	culv. 154	culv. 176
04/14/97	0.00	0.00	0.00	0.00	Dry	D	Dry	Dry
04/21/97	0.00	0.00	0.00	Dry	Dry	D	Dry	Dry
04/29/97	0.00	0.00	0.00	Dry	0.00	D	Dry	Dry
05/07/97	0.00	0.00	Dry	0.00	0.00	0.00	Dry	Dry
05/14/97		-0.15	0.00	0.00	Dry	0.00	Dry	Dry
05/19/97		0.00	0.00	0.00	Dry	0.00	Dry	Dry
05/27/97	0.00	0.00	0.00	Dry	Dry		Dry	Dry
06/02/97			-3.35	-1.54		-0.12	0.00	Dry
06/09/97		-9.94	-4.80	-4.08				
06/23/97	1.17	-13.70	-8.94	-11.47	-2.13	-3.79	Dry	Dry
07/01/97	0.95	-4.07	-2.99	-6.32		-2.02	-2.47	0.00
07/09/97	1.03	-3.16	-1.14	-3.29	-0.18	-1.58	-0.01	0.00
07/16/97	1.65	-3.11	-1.73	-1.78	0.03	-1.18	0.10	0.00
07/22/97	0.24	-6.74	-2.29	-4.25				0.00
07/28/97	0.20	-1.48	-1.37	-4.67	-2.31	-0.21	Dry	
08/07/97	0.43	-0.43	-1.58	-3.01	0.00	-1.12	0.00	0.00
08/18/97		-0.15	-0.75	-2.00	-0.30	-0.33	Dry	Dry
08/25/97								
09/02/97	0.23	-2.91	-1.15	-2.11	-0.12	-0.31	0.00	0.00
09/08/97	0.69	-3.78	-1.96	-2.69	-0.07	-0.83	-0.30	Dry
09/16/97	0.41	-2.53	-1.37	-2.58	-0.49	0.00	0.00	0.00
10/01/97	0.18	-2.69	-1.44	-4.11	-0.71	-1.58	-0.61	0.00
10/15/97	0.70	-0.77	-0.59	-3.05	0.00	-1.73	0.00	Dry
10/23/97	0.64	0.00	-0.34	-0.95	0.00	-0.30	0.00	Dry
10/28/97	0.41	0.00	-0.22	-1.26	-0.02	-0.51	0.00	0.00
Positive value discharges denote south or east flows and negatives values denote north or west flows in cfs.								

Table 4: Discharge conditions

MM/DD/YY	TS(S)	TS(N)	F1	N14	F2	P44	P1	P2	P3
04/14/97						1.9		2.06	2.13
04/21/97						1.74			1.98
04/29/97						2.6			1.95
05/07/97		2.74		2.87	2.8	2.78			
05/14/97		3.06		4.42	4.62	4.6		2.2	2.11
05/19/97		3.42		4.03	4.34	4.38	2.32	2.26	2.16
05/27/97	3.71	3.71	4.68	4.8	4.5	4.55	2.67	2.47	2.45
06/02/97	4.14	4.24		5.67		5.31	3.46	3.1	3.36
06/09/97	4.48	4.64	5.5	5.71	5.02	5.17	3.65	3.22	3.58
06/23/97	4.71	4.94	5.46	5.48		4.81	3.79	3.38	3.7
07/01/97	4.36	4.42	5.21	5.25		4.64	3.53	3.21	3.48
07/09/97	4.18	4.24	4.98	4.98		4.53	3.4	3.17	3.36
07/16/97	4.04	4.1	5.02	5.08	4.86	4.79	3.51	3.24	3.44
07/22/97	4.51	4.69	5.22	5.24	4.78	4.7	3.5	3.24	3.4
07/28/97	4.38	4.48	4.19	5.15	4.62	4.55	3.44	3.2	3.38
08/07/97	4.54	4.72	5.07	5.09	4.4	4.31	3.38	3.18	3.32
08/18/97	4.45	4.55	4.75	4.74	4.42	4.32	3.34	3.14	3.34
08/25/97	4.6	4.8	5.25	5.28	4.79	4.75	3.55	3.29	3.48
09/02/97	4.75	4.98	5.37	5.43	4.94	4.84	3.76	3.42	3.69
09/08/97	4.79	5	5.41	5.43	4.81	4.7	3.76	3.42	3.7
09/16/97	4.74	4.94	5.28	5.33	4.77	4.69	3.71	3.4	3.74
10/01/97	4.79	4.96	5.42	5.45	5.01	4.86	3.98	3.56	3.91
10/15/97	4.12	4.18	4.84	4.81	4.56	4.44	3.68	3.44	4.64
10/23/97	3.9	3.92		4.12	4.4	4.15	3.56	3.36	3.56
10/28/97	3.59	3.6		3.83		3.88	3.45	3.34	3.39
Stage is in feet NGVD.									

Table 5: Stage conditions

MM/DD/YY	P4	P62	43(S)	43(N)	SP	59(S)	59(N)	P38	89 E	89 W
04/14/97		2.24			2	1.66	1.65	1.28		0.49
04/21/97		2.1			1.62	1.36	1.38	1.21		0.54
04/29/97		2.08			1.71	1.46	1.46	1.15	0.73	0.9
05/07/97		1.94			1.28	0.85		0.97	0.86	0.86
05/14/97		2.2	2.37		2.19	1.82	1.75	1.14	0.98	0.98
05/19/97		2.18		2.4	2.07	1.52	1.53	1.11	0.98	0.97
05/27/97	2.36	2.39		2.58	2.12	1.52	1.55	1.11	0.72	0.72
06/02/97	3	3.04	3.62	3.32	3.15	3	2.2	1.82		
06/09/97	3.2	3.59	3.74	3.4	3.51	2.96	2.98		1.92	1.82
06/23/97	3.41	3.49	3.62	3.49	3.04	2.86	2.48	2.35	2.2	1.92
07/01/97	3.25	3.29	3.39	3.35	2.63	2.35	2.22		1.9	1.64
07/09/97	3.18	3.22	3.32	3.26	2.59	2.32	2.2	2.1	1.71	1.52
07/16/97	3.23	3.28	3.43	3.34	2.63	2.09	1.92	2.17	1.74	1.49
07/22/97	3.23	3.28	3.42	3.36	2.71	2.41	2.22	2.08	1.9	1.66
07/28/97	3.21	3.26	3.31	3.29	2.57	2.27	2.18	2.07	1.76	1.52
08/07/97	3.2	3.22	3.28	3.25	2.57	2.2	2.14	2.02	1.72	1.52
08/18/97	3.16	3.18	3.22	3.2	2.52	2.15	2.13	2.04	1.52	1.38
08/25/97	3.28	3.33	3.46	3.38	2.56	2.18	2.15	1.96	1.56	1.35
09/02/97	3.43	3.46	3.66	3.54	2.84	2.36	2.24	2.12	1.63	1.4
09/08/97	3.4	3.48	3.55	3.5	2.81	2.27	2.24	2.2	1.71	1.56
09/16/97	3.43	3.47	3.5	3.47	2.72	2.28	2.25	2.14	1.72	1.57
10/01/97	3.58	3.66	3.68	3.62	2.87	2.48	2.41	2.35	1.92	1.72
10/15/97	3.45	3.5	3.5	3.5	2.77	2.34	2.3	2.2	1.68	1.52
10/23/97	3.36	3.33	3.4	3.38	2.61	2.22	2.2	2.1	1.55	1.44
10/28/97	3.34	3.33	3.32	3.3	2.53	2.12	2.1	2.05	1.35	1.4
Stage is in feet NGVD.										

Table 6: Stage conditions

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