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**GPS Surveying of Estuarine Sites and Water Level Gages in
the Lower Suwannee River Watershed**

by

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Summary

Population increases in Florida are compelling water management district managers to evaluate the impact of freshwater withdrawal and drinking water supply projects on flood plain and down-river estuarine resources. In 1997 the Suwannee River Water Management District and the U.S. Geological Survey (USGS) undertook a study of Suwannee River discharge variations and the impact on the flood plain ecosystem in Levy and Dixie counties.

Elevation plays an important role in the frequency and duration of flooding in river and estuarine plant communities. Scientists conducted leveling surveys to determine elevations in their study areas. However, the vegetation monitoring transects in the Lower Suwannee River Refuge were difficult to access with traditional leveling methods. As a result, Differential Global Positioning System (DGPS) vertical surveys were conducted by the USGS for sites in the Lower Suwannee Refuge. One orthometric height was established for each study site with DGPS surveying techniques. Traditional surveys were conducted to complete elevation data for each transect. This report presents the methods and results of the GPS surveys for vegetation monitoring transects and water level gages in the Lower Suwannee River Refuge. The results are reported as orthometric heights ± 0.03 meters NAVD88 (North American Vertical Datum 1988).

Introduction

The USGS conducted a DGPS survey in 1998 in the Lower Suwannee River basin. The GPS survey secured centimeter-level orthometric heights (NAVD88) for sites in the estuarine portion of the flood plain in Dixie and Levy counties, Florida (Figure 1). The survey was conducted by USGS Geologic Division (GD) in cooperation with USGS Water Resources Division (WRD), Tallahassee, and the Suwannee River Water Management District (SRWMD). GPS surveying was employed to establish centimeter-level benchmarks for each site, linking transects to each other, to existing water level gages, and to WRD elevation surveys further up river. The GPS approach was preferred over traditional leveling techniques because of site inaccessibility.

The GPS survey employed a rapid static approach with a base station in constant operation while a roving antenna moved from one site to another. The base stations were previously established as part of a coastal network for the estuarine marshes (Marth et al., 1995; Raabe et al., 1996). The roving antenna provided a portable link to the base station across rough or inhospitable terrain. The USGS surveyed DGPS centimeter-level vertical positions for vegetation transects in the emergent and forested Lower Suwannee estuarine area. Orthometric heights for water level gages in the Lower Suwannee River were also established.

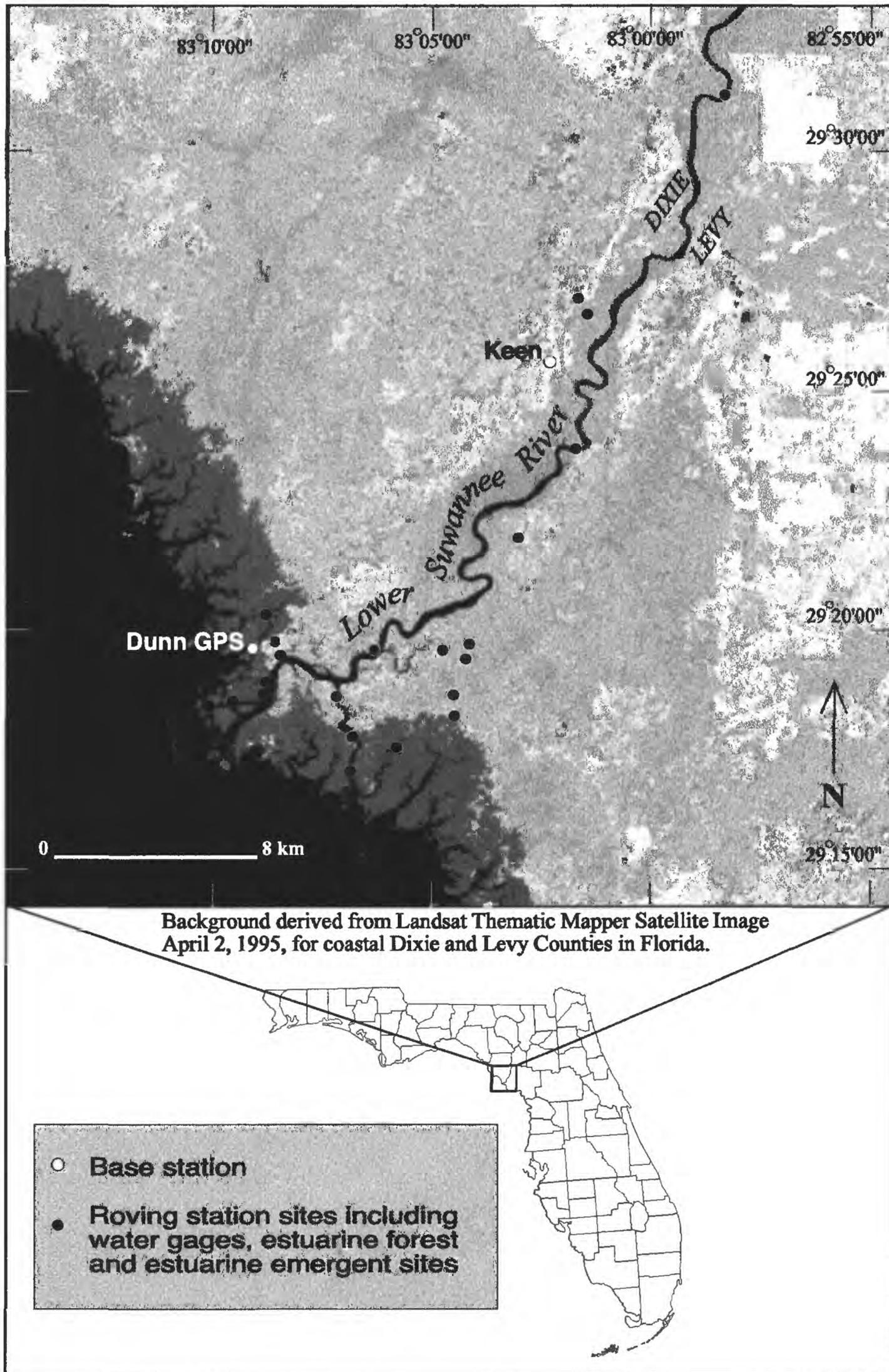


Figure 1. Location of GPS survey sites in the Lower Suwannee River basin.

The elevations obtained in the survey are used by researchers working in the Suwannee River watershed. Hydrologists use gage heights to link the water level gage network together. The survey established benchmark elevations at one end of each vegetation transect in both forested and emergent habitats. Once the benchmark was established, traditional leveling was employed to secure relative elevations throughout the site. Transect elevations enhanced vegetation surveys by providing a connection between vegetative response, river discharge, and flooding cycles. The elevations for monitored transects were completed by the investigators with traditional surveying methods. The estuarine forested sites are being monitored by WRD, and the estuarine emergent sites are being monitored under contract.

Background

DGPS surveying is now a commonly accepted method for obtaining orthometric heights (Milbert and Smith, 1996) and standard methods for GPS surveying of vertical positions have been established (Federal Geodetic Control Committee, 1989; 1995). The USGS in St. Petersburg, Florida, has carried out centimeter-level vertical surveys for other purposes and established a network of highly accurate base stations along Florida's Big Bend coast (Raabe et al., 1996). Two of these base stations are located in the Lower Suwannee River watershed.

While elevations for sites in the lower portion of the Suwannee River basin study were established with the DGPS methods, elevations in the remainder of the upper basin were derived from traditional surveying techniques and were obtained from the National Geodetic Survey (NGS) database (Helen Light pers. comm., 1998). It is understood that some discrepancies still exist between traditionally leveled benchmarks and the elevations derived from DGPS surveying but is fairly consistent at ± 2 -3 cm (Ronnie Taylor pers. comm., 1999). The National Geodetic Survey office in Florida is attempting to establish a larger and more comprehensive set of GPS benchmarks and adjustment techniques for Florida. In the meantime, traditionally leveled benchmarks continue to be mixed with DGPS derived elevations with attendant problems. Road improvements and faulty records have also obscured errors in placement, location, and elevation.

Caution is advised when expecting correspondence between elevations derived from different sources and different datums. Florida Department of Environmental Protection (FDEP) and Department of Transportation (DOT) still employ the National Geodetic Vertical Datum 1929 (NGVD29). While the older datum has been replaced nationally with the current North American Vertical Datum 1988 (NAVD88), state agencies have not yet made the adjustment in their mapping activities. The basic difference between NGVD29 and NAVD88 is the difference between theoretical gravity values and observed gravity and a paucity of data points in Florida (Zilkoski, 1990). Thorough discussions of the NAVD88 adjustment and problems in Florida can be found in Zilkoski et al. (1992) and Shrestha (1992). Conversions from one vertical datum to another introduce an additional ± 4 cm at the 95% confidence interval (Milbert et al., 1994), and errors are cumulative.

Methods

Three steps are critical to quality GPS vertical surveys: 1) survey planning and field logistics, 2) survey execution, and 3) post-processing of the data. Cooperation from all parties made this a successful campaign. SRWMD and WRD participated in the planning, field logistics, and survey execution by providing information, transportation, manpower, access, and navigation to the sites.

Survey Planning and Field Logistics

Approximate dates of operation, obstruction diagrams, site locations, and constraints were considered in the planning phase. Several iterations of mission planning were required until time blocks were allocated to each site, allowed sufficient travel time between sites, and insured adequate visibility and availability of satellites for the required precision. Four or more satellites were mandatory for concurrent viewing from both the base station and the roving antenna. The configuration of the jointly viewed satellites also affected the precision of the measurements.

Options for site occupations in this survey were charted and preferred time frames with alternatives were selected. Contingency plans were discussed, and field crews were ready to take alternative steps when or if conditions changed. Mobility required a combination of trucks and water craft to move from one site to another. Field crews consisted of a base station operator, a driver, and the roving antenna carrier. An additional surveyor accompanied the forested estuarine site visits to facilitate traditional leveling to the forest transect.

The base stations used in the current survey (Figure 1) were established in a DGPS network in 1994-5 (Raabe et al., 1996). Keen, L210, is on County Road (CR) 349 near the cemetery. The elevation for L210 is used as published in the NGS database, 4.590 m NAVD88, and confirmed by Raabe et al. (1996). Dunn GPS, L201, is a replacement for L200 at the end of CR 349. L200 was destroyed during road improvement. The new GPS elevation established for Dunn GPS is 1.351 m NAVD88. Previously established obstruction diagrams for the base stations were field-checked for validity. Appendix 1 contains a description of Dunn GPS location and leveling.

Site locations were provided by WRD (Figure 1). Each site was evaluated for accessibility, method of transportation for access, and time required to move between sites. GPS surveys require an open view of the sky for satellite tracking. An obstruction diagram was established for all but the estuarine emergent sites, for which we assumed 360° visibility 10° above the horizon. Illustrations of water level gages were provided by SRWMD where accessibility, visibility, and positioning of the GPS receiver was an issue. WRD provided obstruction diagrams for the estuarine forest sites.

A combination of Ashtech Z-12 and Z-Surveyor receivers were used in the survey. A fixed-height tripod, choke ring antenna, and Z-12 receiver operated as the base station with data logged to a laptop that was continuously monitored. A marine antenna mounted on a portable mono-pole and a Z-Surveyor receiver operated as the roving unit with a bipod for stability (Figure 2). Both the base and roving units logged data at 10 second intervals.

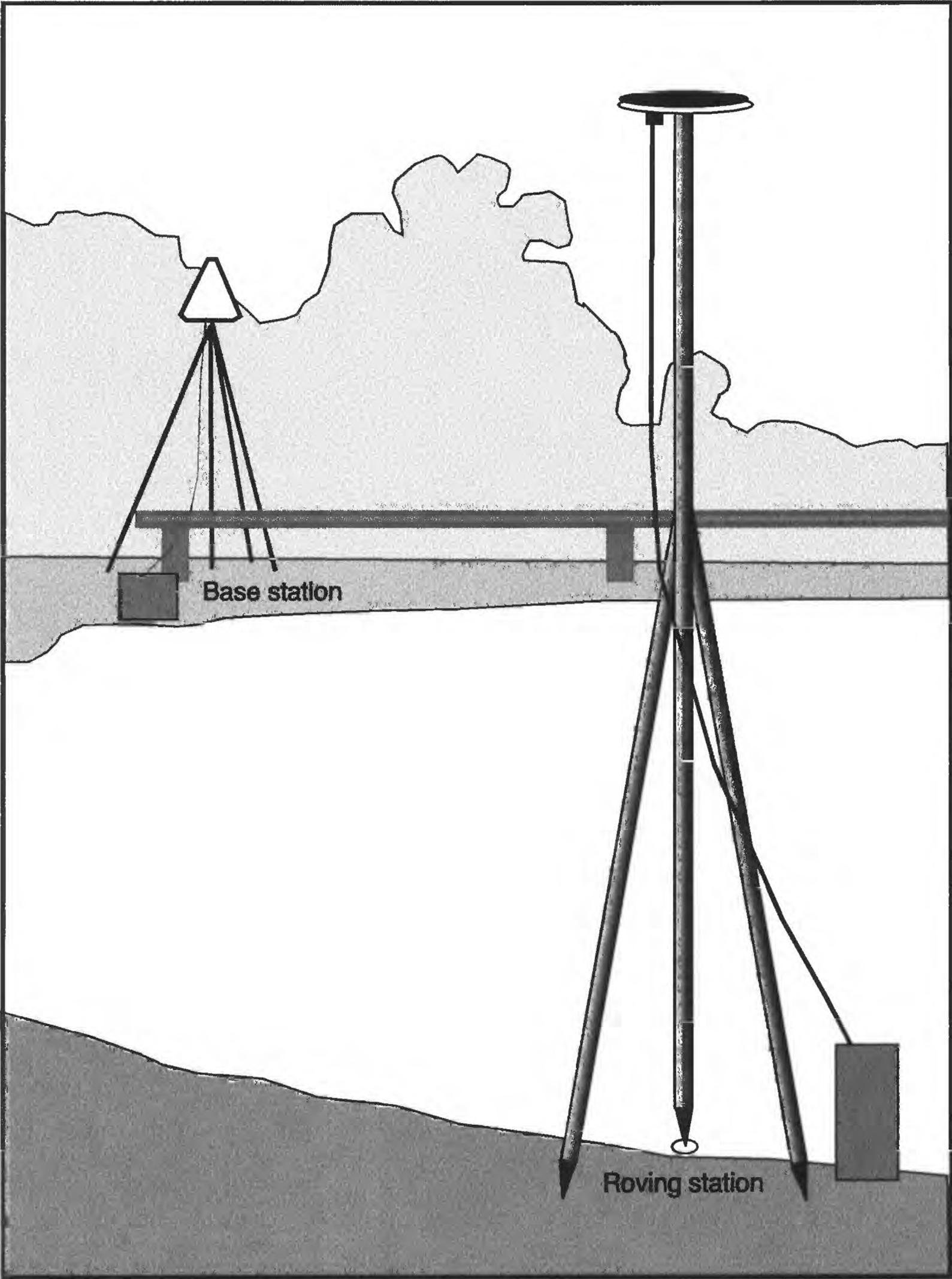


Figure 2. Base station on fixed tripod and portable roving antenna.

Survey execution

Two attempts were made to secure the elevations of the gages and transects. The first attempt on January 26-28, 1998, was aborted due to equipment failures and errors. Successful surveys were conducted in April 1998. Julian days, in the format *J*____, are used in the GPS data collection format. The DGPS surveys for the Lower Suwannee marsh and water gage sites were conducted April 20-21, *J110-J111*, by the GD team, and by Rob Mattson and John Good of SRWMD (Table 1). The DGPS survey for the estuarine forest sites was conducted April 29-30, *J119-J120*, by the GD team, and by Helen Light and Lori Lewis of WRD, and Erik Lewis of SRWMD (Table 2).

Table 1. GPS occupation of Lower Suwannee sites April 20-21, 1998.

<i>Site #</i>	<i>Occupation (min)</i>	<i>Notes</i>
DAY 1 J110		
AA99	15 (initialized) *	Angler's Resort Benchmark
AA16	2	Upper West Pass marsh transect - steel rod in PVC
AA15	2	Middle West Pass marsh transect - steel rod in PVC
AA14	2	Lower West Pass marsh transect
AA19	2	Salt Creek, top of PVC casing
AA19	2 (re-occupy)	Salt Creek, top of PVC casing
AB19	2	Salt Creek, steel rod in PVC
AA15	2 (re-occupy)	Middle West Pass marsh transect
AA01	2	Lower West Pass gage, steel rod
AA20	2 *	Dan May Creek marsh transect
AA20	10 (re-occupy) *	Dan May Creek marsh transect
AA03 †	3 *	Lower East Pass gage
AA17 †	2 *	Lower East Pass marsh transect
AA18	2 *	Upper East Pass marsh transect
AA99	2 (re-occupy) *	Angler's Resort benchmark
AA99	15 (re-initialize) *	Angler's Resort benchmark
DAY 2 J111		
BB99	15 (initialize) *	Angler's Resort benchmark
BB03 †	2 *	Lower East Pass gage
BB20	2 *	Dan May Creek marsh transect
BB17	2 *	Lower East Pass marsh transect
BB18	2 *	Upper East Pass marsh transect
BB05	2	Upper East Pass gage – aluminum bracket on concrete piling
BB05	2 (re-occupy)	Upper East Pass gage
BB04	2	Gopher River gage – base of gage box interior
BB45	2 *	Treasure Camp boat ramp - "x" scratched in concrete
BB45	2 (re-occupy) *	Treasure Camp boat ramp - "x" scratched in concrete
BB02	2	Upper West Pass gage – aluminum bracket holding pole to piling; orange (A)
BB92	2	Upper West Pass gage – nail on wood deck sprayed orange (B)
BB18	2 (re-occupy) *	Upper East Pass marsh transect
BB99	4 (re-occupy) *	Angler's Resort benchmark
BB99	15 (re-initialize) *	Angler's Resort benchmark

Table 2. GPS occupation of Lower Suwannee sites April 29-30, 1998.

<i>Site #</i>	<i>Occupation (min)</i>	<i>Notes</i>
DAY 3 J119		
CC80	15 (initialize)	Survey nail (#1) in road across from Dunn GPS (Appendix 1)
CC81	3 **	Keen High Water Mark; nail in road
CC45	10 *	Treasure Island Boat Ramp ("x")
CC45	2 *	Treasure Island Boat Ramp (nail on "x")
CC11	5	Sandfly transect, survey nail on stake
CC12	5	Gopher River; nail on stake in open marsh area
CC30	5	McCormick Creek; nail on stake
CC13	5	Barnett Creek transect; nail on stake
CC09	5	Alternate Sandfly; nail on stake
CC09	10 (re-occupy)	Alternate Sandfly
CC30	5 (re-occupy)	McCormick Creek
CC08	5	Turkey Island transect; nail on stake
CC45 †	5 (re-occupy) *	Treasure Island Boat Ramp; nail on "x"
CC81	5 (re-occupy) **	Keen High Water Mark; nail in road; level to nail in tree
L210	5 *	Keen BM L210-L210 baseline repeat
CC99	5 *	Angler's Resort benchmark
CC80	10 (re-initialize)	Re-initialize on survey nail near DunnGPS
DAY 4 J120		
DD81	10 (initialize) **	Keen High Water Mark; nail in road
DD06	10	New Clay Landing; nail in boat ramp wall
DD45	10 **	Treasure Island Boat Ramp; nail on "x"
DD07	10	Keen Transect; nail in stake in open area
DD81	10 (re-initialize)	Keen High Water Mark; nail in road

* Indicates multiple-day occupation of vector (base station to site).

** Multiple-day occupation of position, but different base station.

† Unsuccessful or erroneous data collection during site occupation.

Base station **L201** was occupied for the first three days, *J110*, *J111*, and *J119*. **L210** served as the base location for the fourth day, *J120*. Positions occupied on *J110* were prefixed with "A," *J111* with "B," *J119* with "C," and *J120* with "D".

The base station was set up to record all day on an Ashtech Z-12 with a laptop for data logging due to memory limitations of the Ashtech receivers. Initialization of the roving unit was conducted nearby for 15 minutes. The roving antenna was moved to each subsequent site for a 2-5 minute occupation. Final re-initialization was conducted at the end of the day at the initialization site. If loss of lock on satellites occurred during transport, then the next station was subsequently occupied 5-10 minutes. The battery of the roving unit typically lasted approximately 5 hours. Once a new battery was installed, the rover was re-deployed at the location occupied prior to the exchange.

Two to five sites were re-occupied during the course of each day for verification and accuracy evaluation. Sites were also re-occupied on subsequent days. Re-initializations, re-occupations, and multiple-day occupations are noted in Tables 1 and 2. Comparisons of the length of vectors from re-occupations provide an additional check for errors and accuracy.

Post-processing and Results

Post-processing of the field data was completed with Ashtech post-processing software, PNAV version 2.5, using Forward and Backward survey processing for the PL1-code/PL2-code/PL2-phase and CAL1-phase wave measurements (Ashtech, 1994). Ashtech's Prism software was used for adjustment analysis to examine the overall network fit of the vectors. Data was examined for cycle slips, high PDOP, high vector residuals, a high network standard error, or fewer than 6 satellites. Valid surveys must have low position dilution of precision (PDOP), preferably < 5. Vectors with high PDOP, less than 5 satellites, or high standard deviations were eliminated from final calculations of ellipsoid heights.

Ellipsoid heights were converted to orthometric heights using the NAVD88 datum and the Geoid96 geoid model. Final orthometric heights in meters are shown in Table 3.

Table 3. DGPS-derived orthometric heights.

<i>Site</i>	<i>NAVD88 (m)</i>	<i>NGVD29 (m/ft)</i>	<i>Latitude & Longitude NAD83</i>	
Angler's Resort Benchmark	1.070m	1.268m/4.16ft	29 19 48.030	83 08 35.547
<i>Suwannee River Delta Marsh Transect Sites:</i>				
Upper West Pass Marsh Transect	0.414m	0.612m/2.00ft	29 18 56.443	83 08 46.857
Middle West Pass Marsh Transect	0.218m	0.417m/1.37ft	29 18 31.579	83 09 34.365
Lower West Pass Marsh Transect	0.200 m	0.399m/1.30ft	29 18 25.790	83 10 7.788
Lower East Pass Marsh Transect	0.359m	0.557m/1.82ft	29 17 9.565	83 06 45.492
Upper East Pass Marsh Transect	0.529m	0.727m/2.39ft	29 17 52.801	83 06 41.516
Salt Creek Marsh Transect A	0.427m	0.625m/2.05ft	29 20 18.592	83 08 49.459
Salt Creek Marsh Transect B	0.246m	0.444m/1.45ft	29 20 18.591	83 08 49.458
Dan May Creek Marsh Transect	0.319m	0.516m/1.69ft	29 17 40.956	83 05 40.364
<i>Lower Suwannee River Gage Sites:</i>				
Lower East Pass Gage	<i>orthometric height not available</i>			
Upper East Pass Gage	2.014m	2.212m/7.26ft	29 18 41.903	83 07 8.709
Gopher River Gage	3.735m	3.932m/12.90ft	29 19 40.909	83 06 14.507
Upper West Pass Gage A	1.895m	2.093m/6.86ft	29 19 28.097	83 08 27.428
Upper West Pass Gage B	3.016m	3.214m/10.55ft	29 19 28.422	83 08 27.631
Lower West Pass Gage	0.224m	0.422m/1.38ft	29 18 42.839	83 08 51.793
<i>Lower Suwannee River Estuarine Forest Sites:</i>				
Treasure Camp Boat Ramp	1.844m	2.040m/6.69ft	29 23 47.413	83 01 34.012
Sandfly Transect	1.203m	1.399m/4.59ft	29 19 48.858	83 03 59.036
Gopher River	0.783m	0.980m/3.21ft	29 19 37.616	83 04 37.787
McCormick Creek Marsh site	0.837m	1.034m/3.39ft	29 18 19.246	83 04 20.133
Barnett Creek Transect	0.815m	1.012m/3.32ft	29 18 44.379	83 04 20.417
Alternate Sandfly Site	1.284m	1.480m/4.85ft	29 19 29.703	83 04 6.866
Turkey Island Transect	1.953m	2.149m/7.05ft	29 21 57.401	83 02 54.711
Keen High Water Mark	3.607m	3.805m/12.48ft	29 26 51.745	83 01 36.286
New Clay Landing	2.398m	2.598m/8.52ft	29 31 5.274	82 58 12.646
Keen Transect	1.550m	1.748m/5.73ft	29 26 31.995	83 01 20.483

Accuracy of the NAVD88 orthometric heights is ± 3 cm at the 95% confidence interval. Conversion to NGVD29 with VERTCON software is provided in meters and in feet for users still employing the older datum. The conversion to NGVD29 adds an additional error of ± 4 cm at the 95% confidence level (Milbert et al., 1994). Again, errors are cumulative. Horizontal positions are given as latitude and longitude in North American Datum 1983 (NAD83). The World Geodetic System 1984 (WGS84) coordinates provided by the GPS system are almost identical to NAD83 (Langley, 1992; Shrestha et al., 1993).

No trend was detected between GPS-derived heights and traditional leveling (Appendix 2). While traditional leveling heights vary slightly from GPS-derived heights, the difference does not exceed the expected error range of $\pm 2-4$ cm. We are confident that the GPS-derived elevations are congruent with the elevations obtained along the Upper Suwannee River from traditional leveling techniques.

Replication of site occupations were conducted to provide verification and validation of elevations and vector lengths between the base station and individual sites. The length of vectors occupied on same and subsequent days are shown in meters in Table 4. Vector lengths between replicated site occupations show an acceptable range in variation. Repeat vectors were from 10 - 18,000 m in length, yet consistently differ by less than 4 cm on repeat occupations. Repeat vectors with high standard deviations in both forward and backward processing and other data errors were eliminated from the analysis.

Note that the variation in vector length should not be interpreted solely as an error in vertical placement. The length of a vector between the base station and the site includes variation in both horizontal and vertical placement of the position in question.

A second base station, Keen, **L210**, was occupied on the fourth day, **J120**, to minimize vector length between base station and sites occupied by the roving antenna (Figure 1). As a result, while rover site occupations may have been repeated on **J120**, vector lengths are not comparable from "D" sites to "A," "B," or "C" sites. As an additional check, base to base vectors were observed between the two base stations on **J119** and **J120**. Comparison of these vector lengths with a previous vector observation in 1998 is included in Table 4. The three 15 km vectors vary by less than 2 cm for overall survey reliability. The orthometric height obtained for the Keen benchmark, **L210**, from this survey is 4.590 m NAVD88. This height corresponds exactly with the published NGS position (Appendix 1).

Discussion

Orthometric heights (NAVD88) were established for 22 locations in the 1998 DGPS survey with ± 3 cm accuracy at the 95% confidence interval. The horizontal and vertical location of the Lower East Pass gage mark was not secured in this survey due to data errors during both occupations of the site.

WRD installed a brass plate in the town of Suwannee at the Angler's Resort. The benchmark is on the patio behind the store alongside the canal (Figure 3). This site was occupied several times by the roving antenna during the first three days for initialization. While the benchmark is not essential to the vegetation surveys, it does provide an

additional and accessible vertical benchmark with centimeter-level accuracy in the town of Suwannee.

Several occupied sites are not retrievable, nor repeatable. They were temporary positions that served as markers for the traditional leveling conducted by the investigators of the monitored transects. Caution should be exercised in surveying from any of the sites described as "nail on stake" or "nail in road," beyond the initial surveying conducted immediately following the GPS survey. Those sites, which are described as steel rod in poly vinyl chloride (PVC) casing, may be relatively stable for some time in the future. The water level gages may be considered stable barring major storms or boat impact. A nail on concrete at a boat ramp may also be considered stable for some time into the future.

Table 4. Vector length variation from multiple occupations.

<i>Base Station to Site #</i>	<i>Vector1 (m)</i>	<i>Vector2 (m)</i>	<i>Vector3 (m)</i>	<i>Difference (m)/ Between days (m)</i>
AA99	924.156	924.175	924.177	0.021
BB99	924.169	924.174	924.169	0.005/0.018
CC99	924.159			
AA15	2180.785	2180.746		0.039
AA18	5122.032			
BB18	5122.037	5122.006		0.031/0.028
AA19	1330.992	1330.995		0.003
AA20	6672.035	6672.046		0.011/0.006
BB20	6672.041			
BB05	3662.013	3661.997		0.016
BB45	14445.632	14445.643		0.011
CC45	14445.605	14445.606		0.001/0.038
CC09	8130.653	8130.659		0.006
CC30	8143.526	8143.551		0.025
CC80	10.732	10.733	10.738	0.006
CC81	18063.476	18063.491		0.015
DD81	2485.417	2485.420		0.003
L201-L210 <i>J119</i> 1998		15696.333		
L201-L210 <i>J120</i> 1998		15696.340		
L201-L210 <i>J356</i> 1997		15696.323		0.017

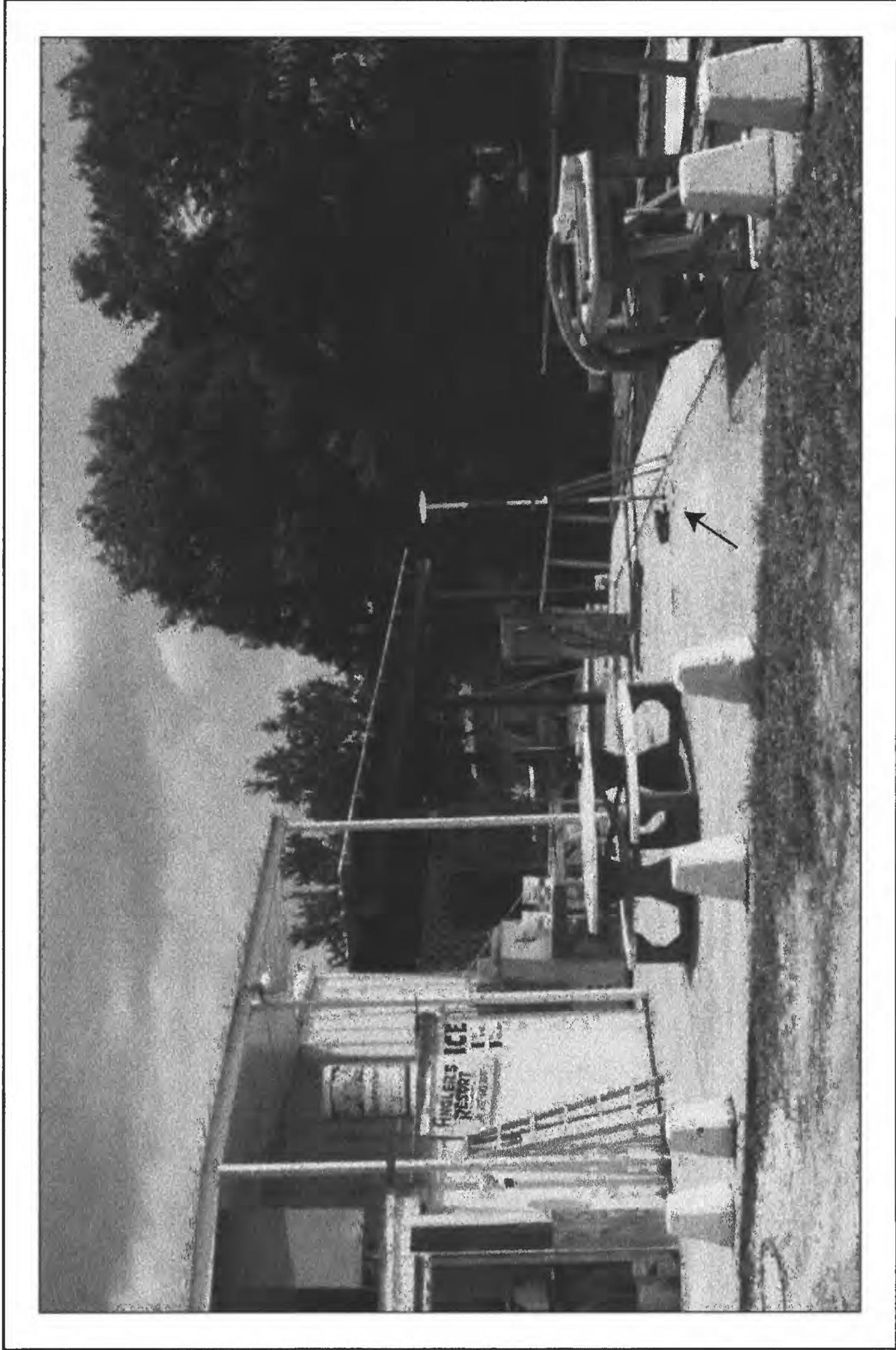


Figure 3. Angler's Resort benchmark located on patio between boat canal and Angler's Resort store on County Road 349 in Suwannee, Florida.

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Appendix 1

Establishment of New Benchmark, Dunn GPS 1997

Base stations for DGPS surveying must be clear of overhead and vertical obstructions for adequate satellite tracking. In 1994 the Dunnary RM3 benchmark was relocated to a nail using a laser level with closure at ± 0.0006 m (Marth et al., 1995). The new location permitted satellite tracking with a GPS antenna. This position was occupied in the Big Bend GPS network as **L200** (Raabe et al., 1996). Road improvements in the intervening years destroyed the adjusted position of **L200**.

Late in 1997 a new monument, Dunn GPS 1997 was established nearby, beyond the impact of road activities. Steel rebar was driven to refusal and encased in a cement footing. A USGS brass benchmark was installed on the rebar just below ground surface, and stamped Dunn GPS 1997. The new location is at the end of CR 349 in Suwannee.

To locate the benchmark, begin at Old Town in Dixie County, Florida. Turn south on CR 349 from US 98/27A. Continue on CR 349 until it ends at Barbree Circle in the town of Suwannee. The benchmark is installed behind the left, or south end of the guard rail. It is 0.4 m behind or southwest of the southernmost guard rail post and 2.0 m east of riprap along the Salt Creek canal (Figure 4). It is covered by 0.05-0.08 m of sandy soil. Two sabal palms form a clump of vegetation 1 m northwest of the benchmark. Another larger sabal palm stands several meters southwest of the benchmark.

The site should be stable for some years. The guard rail and a flashing red light were installed due to motorists driving over the edge into the Salt Creek canal. Although there is some potential for a large storm surge to erode the canal, a pile of riprap along the canal's edge does provide some protection.

The position was laser-leveled to benchmarks Dunnary, RM2, and RM3 in the Barbree Circle with a loop closure of 0.0026 m. The Dunnary benchmarks are not suitable for GPS surveying due to excessive overhead obstructions.

Elevation of the new benchmark was established with DGPS surveying. The station was occupied in 1997 and 1998 with simultaneous occupations of previous networked benchmarks, Keen, Barrow 2, and FLGS 35 (Raabe et al., 1996). See Table 5 for horizontal and vertical positions of benchmarks utilized in this survey. An adjustment of vectors between Dunn GPS 1997 and the established benchmarks secured the new GPS-derived orthometric height of **1.351** m NAVD88, and a horizontal position of **29 19 38.548 83 09 08.046** (NAD83). Vertical precision is 1 ppm at one sigma with a standard deviation of less than 0.02 m vertical. For data collection purposes, Dunn GPS 1997 is referred to as **L201**.

Table 5. Horizontal and vertical control

<i>Published Designation</i>	<i>Survey Site #</i>	<i>Horizontal and Vertical Order</i>	<i>Latitude/Longitude (NAD83)</i>	<i>Pub. Orthometric Height NAVD88 (m)</i>
Dunn GPS	L201	unpublished	29 19 38.548 083 09 08.046	*1.351
Keen	L210	1H, 2V	29 25 39.15126 083 02 16.61863	4.590
Barrow 2	L220	BH, 1V/HARN	29 28 29.04147 082 49 43.77412	12.895
FLGPS 35	L230	BH	29 09 51.31877 082 38 24.33711	*10.766

* Unpublished GPS-derived orthometric height

Several survey nails were installed nearby and laser-leveled as backup due to the history of alterations in the area (Figure 5). Table 6 presents the leveling relationship to Dunn GPS and the derived orthometric heights for each nail.

Table 6. Orthometric height of nails

<i>Nail</i>	<i>Leveled difference to Dunn GPS (m)</i>	<i>Derived Orthometric Height (m)</i>
Nail #1	-0.166	1.185**
Nail #2	+0.581	1.932
Nail #3	-0.127	1.223
Nail #4	-0.214	1.137
Nail #5	+0.078	1.429

** Nail #1 was also included in the GPS survey on Day 3 as CC80. The GPS-derived height of 1.161 m NAVD88 is -0.024 m from the leveled elevation of 1.185. This negative 2-3 cm difference is congruent with data presented in Appendix 2.

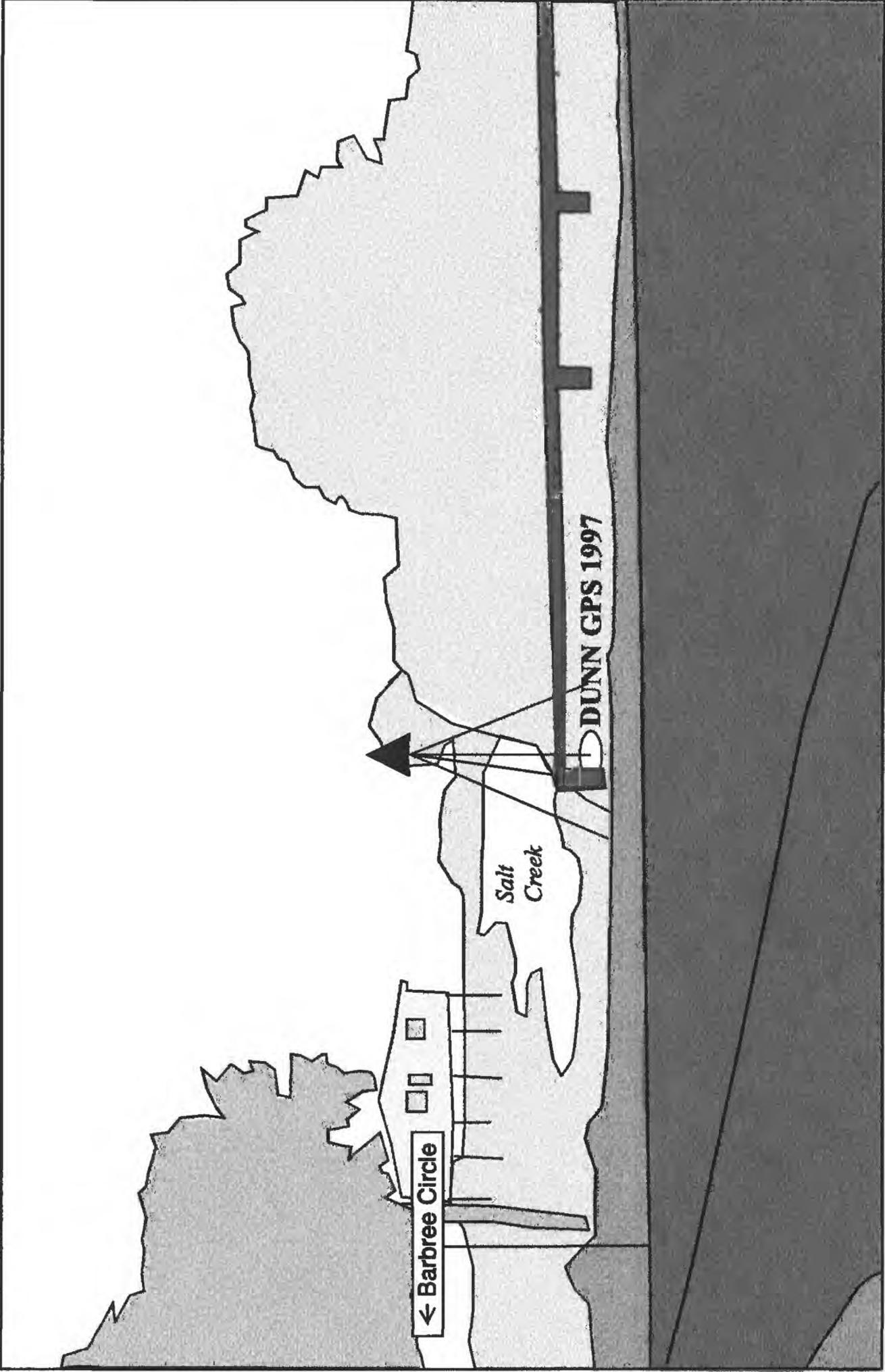
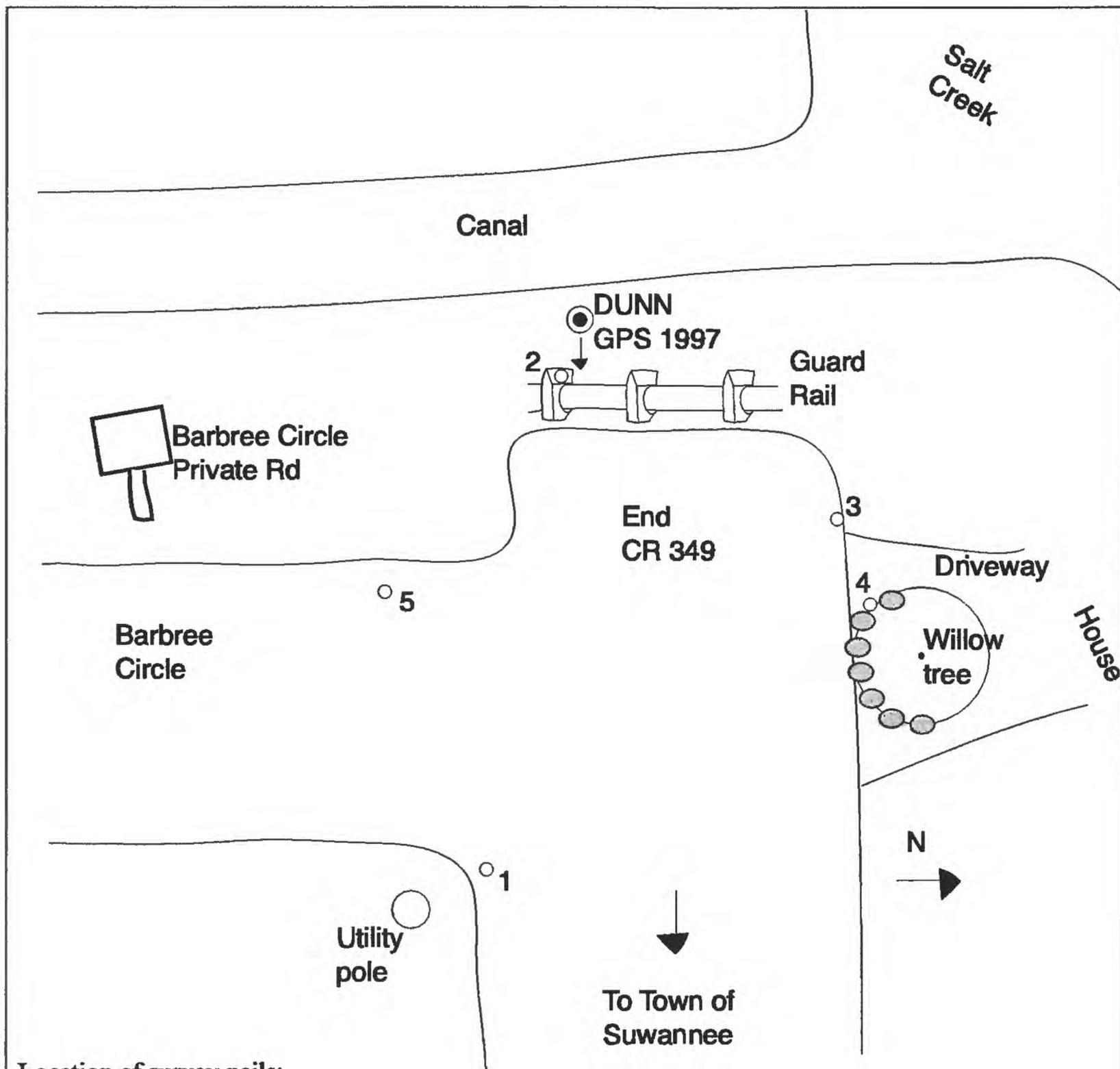


Figure 4. Location of Dunn GPS 1997 at the end of County Road 349 in the town of Suwannee, Florida.



Location of survey nails:

1. Located to the left at turn onto Barbree Circle on edge of pavement ~15 ft west from utility pole.
2. Located on top of southern-most post of guard rail - in front (northeast) of benchmark (18").
3. Located east of northern-most guardrail post ~ 12.5 feet.
4. South of willow tree ~24.5 ft - next to second piling from left on asphalt driveway - last house on right.
5. Edge of pavement - Barbree Circle ~26.5 ft NE of private road sign.

Location of Base Station (Dunn GPS):

1. Located 18" behind far left guard rail post.

Figure 5. Location of survey nails and Dunn GPS 1997 at end of County Road 349.

Appendix 2

GPS-Derived Heights versus Published Heights

Surveying with GPS satellites requires overhead visibility. Several published benchmarks were located in the vicinity of the survey, but were not suitable for GPS survey occupation because of overhead obstructions. What follows is a brief discussion of the relation between the published adjusted NAVD88 orthometric heights and heights derived from leveling to GPS-occupied sites.

Three benchmarks, Dunnary, Dunnary RM2, and Dunnary RM3, are located on Barbree Circle in Suwannee. Each of the published benchmarks were recovered and laser-leveled to the new Dunn GPS benchmark located in the open area nearby. Table 7 presents the published orthometric height of the original benchmark, the leveling difference to Dunn GPS, and the height of the benchmark as derived from Dunn GPS. The difference between the published height and the derived height is negative 2-3 cm in all three cases. Our leveling between the three published benchmarks establishes Dunnary 1 cm higher in relationship to both RM2 and RM3. This could explain the minor difference in the final comparison with Dunn GPS.

SRWMD leveled from benchmark, A 15 FLDNR, to the Gopher River gage with a difference of 4.07', or 1.241 m. The derived elevation of A 15 FLDNR from the Gopher River gage presents a height difference of +0.034 m. Traditional leveling methods were also employed to establish the relationship between the Treasure Camp boat ramp GPS location and a nearby tidal station, 872 7512 A Tidal. The resulting difference between the published height and the height derived from the GPS position is +0.017 m.

The comparisons presented here show \pm 2-4 cm difference between the published NAVD88 height and the height as leveled to the GPS-derived height at a nearby satellite observation position. Considering the cumulative sources of error from both an adjusted NAVD88 published height and the GPS-derived error range, these differences are well-within reason. While these results do not offer a consistent adjustment between GPS-derived and leveled survey heights, they do provide additional assurance of the overall survey accuracy and reliability.

Table 7. Comparison of published and derived heights

<i>Benchmark and Nearby GPS Position</i>	<i>Published BM Orth. Ht. (m) NAVD88</i>	<i>GPS-derived Ht. of nearby GPS position</i>	<i>Leveled difference (m)</i>	<i>Derived Height from GPS and Leveling</i>	<i>Difference (m) from Published Height</i>
Dunnary to Dunn GPS	1.778	1.351	+0.041	1.758	-0.020
RM2 to Dunn GPS	2.213	1.351	+0.830	2.181	-0.032
RM3 to Dunn GPS	1.305	1.351	-0.077	1.274	-0.031
A 15 FLDNR to Gopher River gage	2.528	3.735	+1.241	3.769	+0.034
872 7512 A Tidal to Treasure Camp boat ramp "x"	1.924	1.844	+0.097	1.941	+0.017