

SURVEYOR'S REPORT

**Specific Purpose Survey of Wells and Ground Elevations at
Tree Island 3AN1
Broward County, Florida**

**South Florida Water Management District's
Purchase Order numbers 4500003040 and 4500014815**

**Keith and Schnars project number 16434.00,
Tasks 22169 and 22191**

Report Date: September 24, 2007

Submittal: First

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SURVEYOR'S CERTIFICATION

I hereby certify that this Specific Purpose Survey meets applicable portions of the Minimum Technical Standards set forth by the Florida Board of Professional Surveyors and Mappers in Chapter 61-G17, Florida Administrative Code. This report is prepared for the sole and specific use of the South Florida Water Management District and is not assignable.

KEITH and SCHNARS, PA.
L.B. number 1337

By:



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Professional Surveyor and Mapper
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Date of Survey:
September 11, 2007

PURPOSE

This survey was performed to determine elevations on wells and other features at four well cluster sites in the vicinity of Tree Island 3AN1 for the South Florida Water Management District (SFWMD). Additionally, at each well site and at a total of 188 regularly spaced locations, elevations of the surface of the muck and of the rock surface beneath the muck were measured.

LOCATION OF PROJECT

Tree island 3AN1 is located in western Broward County, Florida, approximately 2 miles north of Interstate 75 (Alligator Alley) at its point of closest approach to the site, and about 40 miles west of the east coast of Florida in Fort Lauderdale.

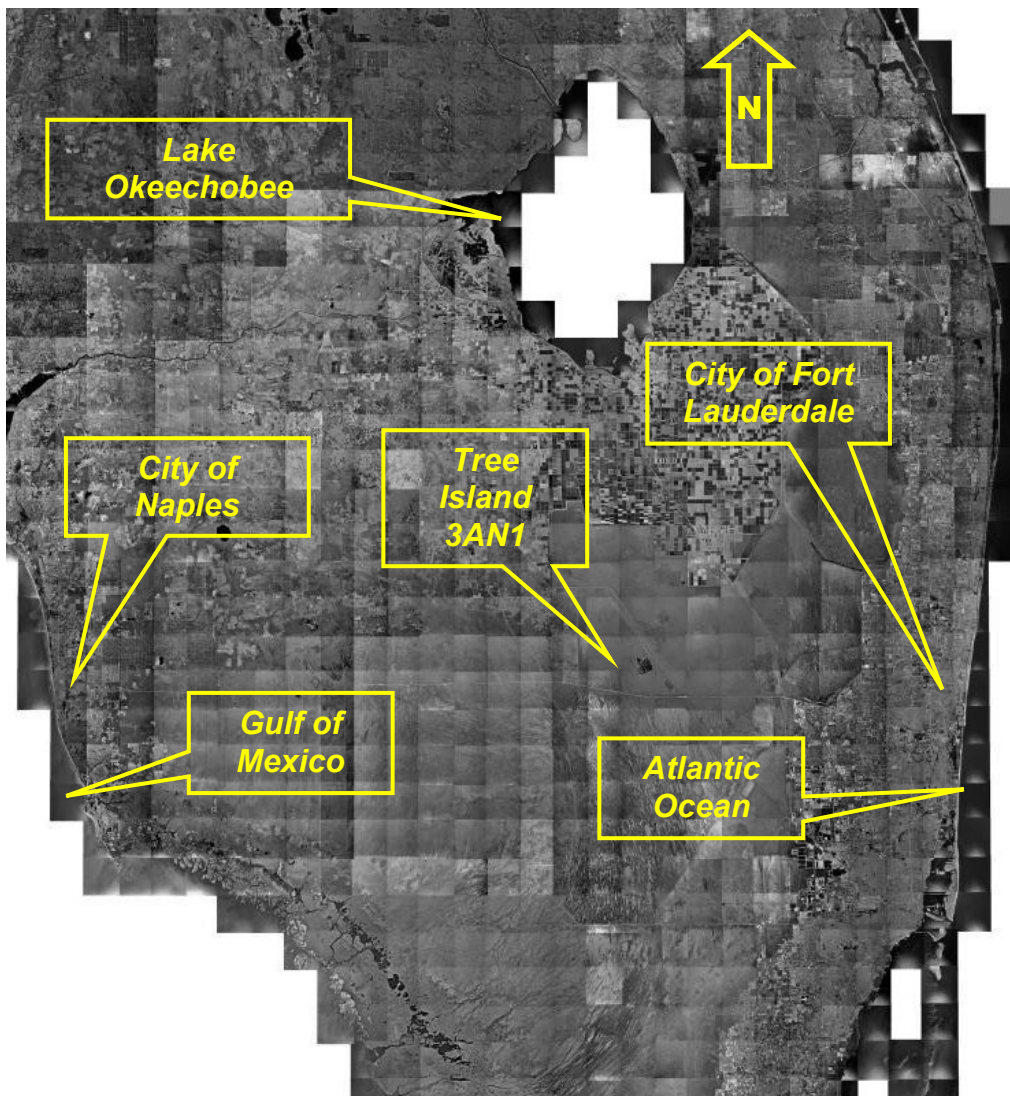


Figure 1: Location of Tree Island 3AN1 in southern Florida

Source of photograph: <http://terraserver.microsoft.com>, downloaded September 2007.

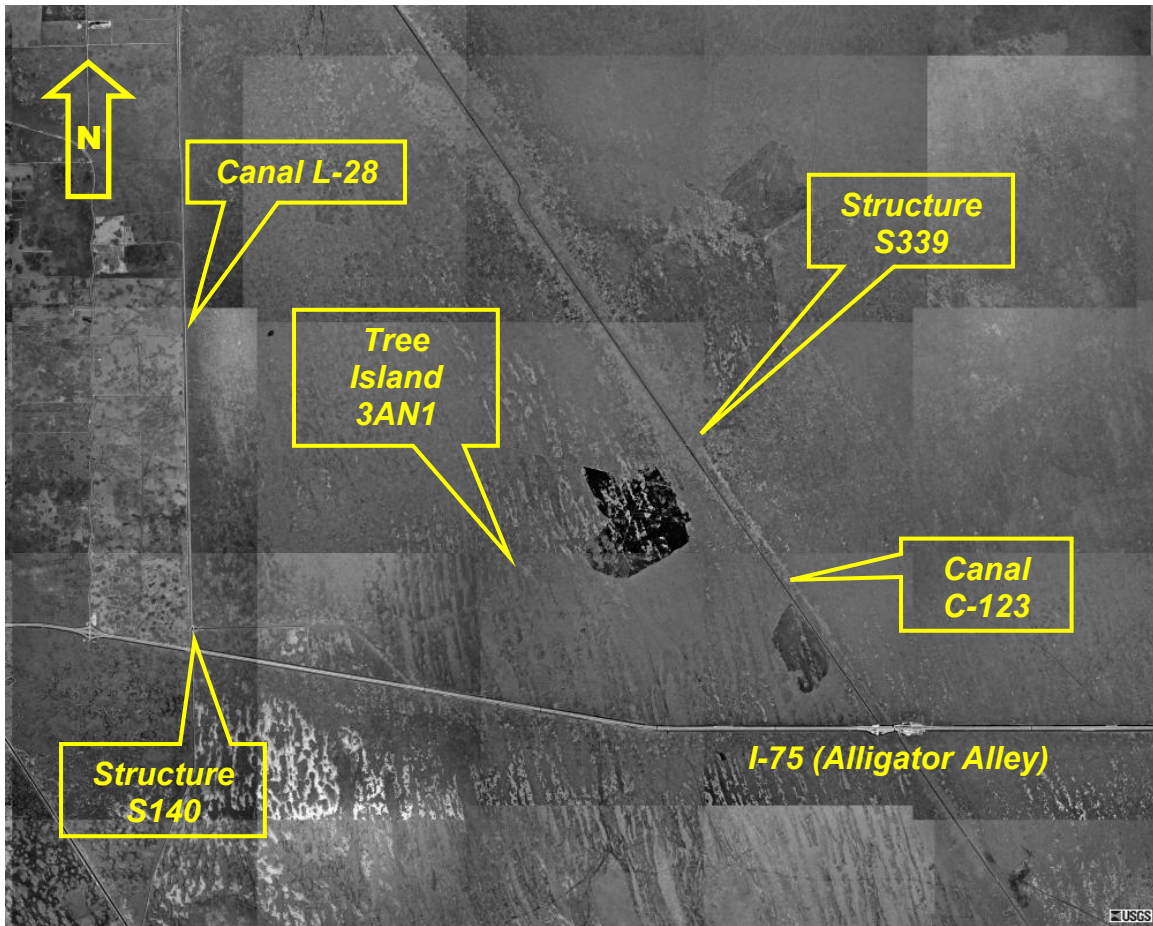


Figure 2: Location of Tree Island 3AN1 (larger scale view)

Source of photograph: <http://terraserver.microsoft.com>, downloaded September 2007.

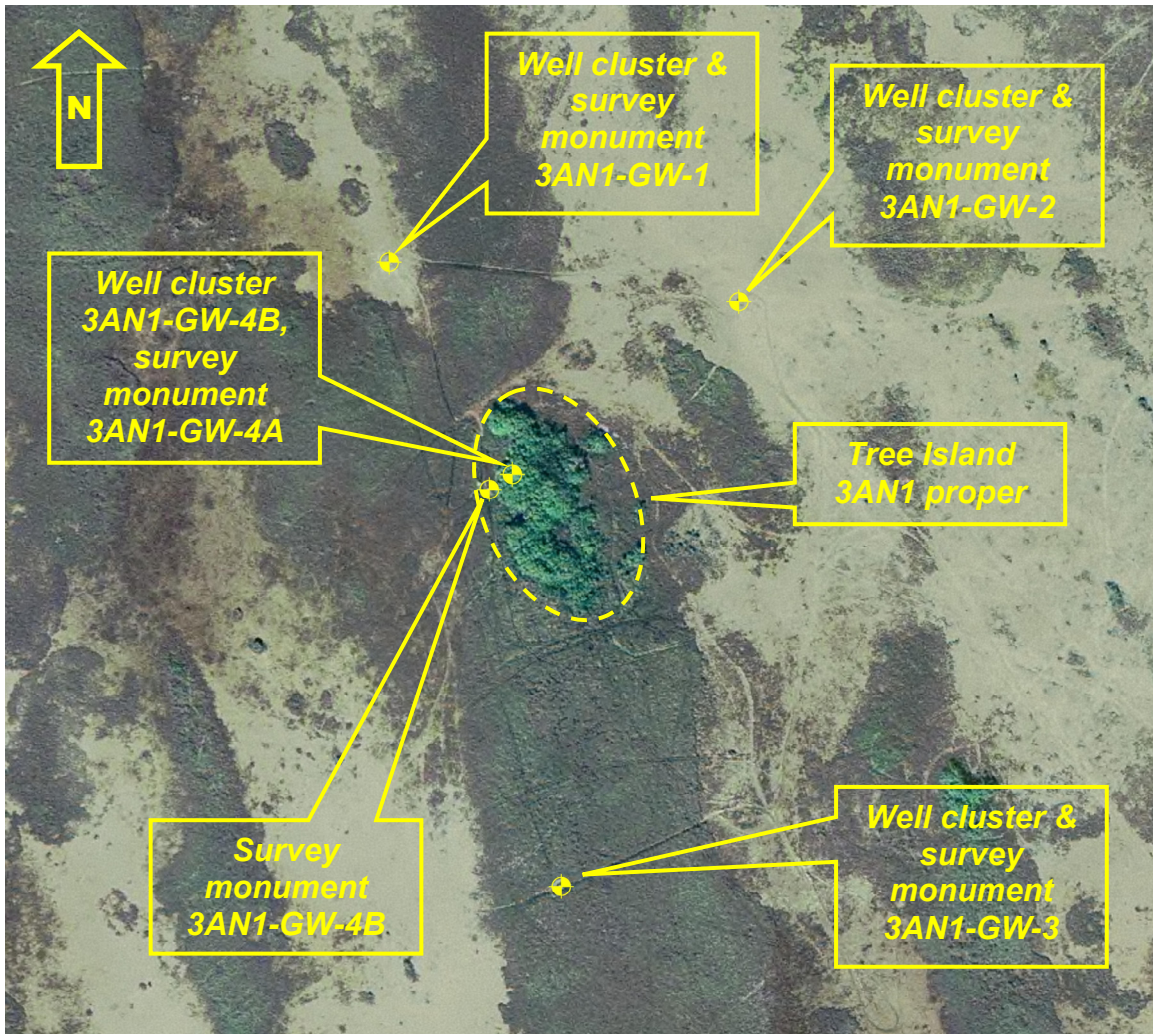


Figure 3: Key features at Tree Island 3AN1

This ground distance shown across the photograph from the left edge to the right edge is approximately 2,800 feet. Source of aerial photograph: LABINS World Wide Web site (<http://data.labins.org>); date of photograph reported to be 12/12/04.

ITEMS DELIVERED TO THE DISTRICT

In conjunction with this formal report, the following items are being delivered to SFWMD:

1. A three-sheet map of this specific purpose survey dated September 24, 2007, and entitled "MAP OF A SPECIFIC PURPOSE SURVEY OF TREE ISLAND 3AN1." That map and this document together constitute the formal report of this specific purpose survey.
2. This report in digital form (PDF format and Microsoft® Office Word format, created with Microsoft® Office Word 2003).
3. Electronic copies (PDF format) of all field notes.
4. Electronic copies of all computation sheets and related data files.
5. Autocad® 2004-format CAD files and a PDF format digital file of the three-sheet map (no. 1, above).
6. CORPSMET 95-generated metadata files.
7. Site photographs in digital format (some of which are reproduced in this report).

DATUMS FOR THE PROJECT

Elevations shown in this report are with respect to both the North American Vertical Datum of 1988 (NAVD 88) and the National Geodetic Vertical Datum of 1929 (NGVD 29). NAVD 88 elevations were determined by differential leveling (see **LEVELING METHODS**, below) from bench mark 3AN1-GW-1, a stainless steel bench mark at the well cluster to the northwest of the tree island. The elevation adopted for 3AN1-GW-1 is 13.615 feet above NAVD 88, and this value was obtained from the South Florida Water Management District (SFWMD) survey monument database, accessed through <http://data.labins.org> on September 21, 2007. (Note: A different elevation for 3AN1-GW-1 is set out in a SFWMD-provided data file named *SANI-GW-1HerrellKrupaRevised.xls*. The value published in that file is 4.155 meters, or 13.632 feet, above NAVD 88.)

No published NGVD 29 elevations are available for the bench marks at this site. For this survey, NGVD 29 elevations have been derived from NAVD 88 elevations by means of applying a datum shift, or offset value, of -0.442 meter (-1.450 feet). The sense of the algebraic sign of this value is NAVD 88 elevation minus NGVD 29 elevation. This value was obtained from the National Geodetic Survey (NGS) VERTCON model, computed using the NGS VERTCON Online web site (<http://www.ngs.noaa.gov/TOOLS/Vertcon/vertcon.html>, accessed August 2007, version 2.0). The geoid height value is that for the latitude and longitude of bench mark 3AN1-GW-1.

The horizontal datum used for this survey is the North American Datum of 1983 (NAD 83), and positions are alternatively expressed as geodetic latitude and longitude with respect to that datum or as Cartesian coordinates in the Florida State Plane Coordinate System, East zone (NAD 83), as defined by NGS. SFWMD provided positions with respect to NAD 83 for several control stations on site, namely 3AN1-GW-1 (the same

station noted above as the controlling bench mark), 3AN1-GW-2 (a stainless steel rod monument at the well cluster northeast of the island), 3AN1-GW-3 (a stainless steel rod monument at the well cluster to the south of the island), and 3AN1-GW-4B (a stainless steel rod monument at the west end of a wood boardwalk leading into the island on its west side). See the section **HORIZONTAL POSITIONS** below for details of the determination of horizontal position of features.

The conversion between meters and feet for this project was governed by the definition of the U.S. Survey Foot: 1200 meters = 3937 U.S. Survey Feet, exactly.¹

METHODS OF ELEVATION DETERMINATION

A closed 3-wire differential leveling loop using a Wild NA2 automatic optical level was performed in order to support the determination of elevations of the features at the site. The loop began and ended at the stainless steel rod bench mark 3AN1-GW-1, and included all four other stainless steel rod monuments: 3AN1-GW-2, 3AN1-GW-3, 3AN1-GW-4A (located at well cluster 3AN1-GW-4B in the interior of the island), and 3AN1-GW-4B.

The magnitude of the misclosure of this level loop, 0.0105 foot, fell within the allowable error of closure of 0.0280 foot. The allowable error of closure was specified by SFWMD and is computed as $\pm 0.03 \text{ feet } \sqrt{M}$, where M is the length of the loop in miles. The adjusted elevations from this level run were subsequently used in the determination of elevations of wells, other man-made features, and the ground surface. Additionally, this loop met the allowable misclosure specification for third order leveling as published by the National Geodetic Survey (NGS),² which is computed as $\pm 12 \text{ mm } \sqrt{K}$, where K is the length of the loop in kilometers. Equivalently, the NGS allowable misclosure can be expressed as $\pm 0.050 \text{ feet } \sqrt{M}$, where M is the length of the loop in miles.

Once the elevations of all stainless steel rod monuments were obtained, the elevations of the several features at each well cluster were computed from single-wire leveling observations performed with the NA2. At each well cluster are one or more PVC well pipes. The elevation of the top of each pipe was measured. Some clusters also have additional features such as a reference mark within the box at the top of the structure (typically a penciled or inked figure on the plywood "floor" of the box) or a staff gauge adjacent to the wells. At each well cluster, a pair of elevations of the ground was obtained next to the structure. See the section **GROUND ELEVATION DETERMINATION** below for further details about the measurement of ground elevations.

¹ An equivalent definition was promulgated into law by the Metric Act of 1866, and despite the adoption of the "International Foot" conversion since then for other purposes, the U.S. Survey Foot remains the convention used for much surveying practice in the United States. See, for example, Florida Statutes Chapter 177.091(19) for an equivalent definition (available online at http://www.leg.state.fl.us/statutes/index.cfm?App_mode=Display_Statute&URL=Ch0177/ch0177.htm).

² Federal Geodetic Control Committee, *Standards and Specifications for Geodetic Control Networks*, September 1984.

ACCURACY OF DERIVED DIFFERENCES IN ELEVATION AMONG WELLS

The elevations of the several wells in each of the four major well clusters (3AN1-GW-1, 3AN1-GW-2, 3AN1-GW-3, and 3AN1-GW-4B) are set out later in this report. From those elevations, one can compute the difference in elevation between any two wells taken from two clusters. Due to the measurement process, there is an inherent uncertainty to the value of such a computed difference in elevation. The estimated standard errors of the differences in elevation obtained from the elevations set out in this report are as follows:

- Elevation differences between wells at 3AN1-GW-1 and 3AN1-GW-2: 0.01 foot (1/8 inch).
- Elevation differences between wells at 3AN1-GW-1 and 3AN1-GW-3: 0.01 foot (1/8 inch).
- Elevation differences between wells at 3AN1-GW-1 and 3AN1-GW-4B: 0.01 foot (1/8 inch).
- Elevation differences between wells at 3AN1-GW-2 and 3AN1-GW-3: 0.01 foot (1/8 inch).
- Elevation differences between wells at 3AN1-GW-2 and 3AN1-GW-4B: 0.01 foot (1/8 inch).
- Elevation differences between wells at 3AN1-GW-3 and 3AN1-GW-4B: 0.01 foot (1/8 inch).

These estimated standard errors can be scaled by appropriate expansion factors to obtain uncertainties at other desired confidence intervals, in accordance with the principles of univariate probability and statistics. For example, multiply the standard errors by 1.96 to obtain the uncertainties at the 95% confidence interval. These values represent “plus-or-minus” uncertainties in the differences in elevation between pairs of features. For example, from Table 5 (below), the NAVD 88 elevations of wells 3AN1-GW-1 ¾" PVC and 3AN1-GW-3 ¾" PVC are 15.95 feet and 16.80 feet, respectively. This implies a difference in elevation between the two of 0.85 foot, with 3AN1-GW-3 being the higher of the two. The estimated standard error of this value is (per the list above) 0.01 foot, and the 95% confidence interval uncertainty would then be 0.02 foot. This means that at the 95% confidence interval, the difference in elevation between those two wells lies within the interval 0.83'–0.87', which is ± 0.02 foot ($\pm 1/4$ inch) on each side of the derived value of 0.85 foot.

Appendix C contains a brief description of the computational procedure used to obtain the estimated standard errors reported above.

GROUND ELEVATION DETERMINATION

At each well cluster and at 188 other predefined points (to be described later in this report), two ground elevations were measured. The first one is the elevation of the surface of the muck or organic material (referred to as the “soft” ground elevation from this point forward in this report). The second ground elevation is that of the top of the hard and more impermeable ground surface beneath the layer of organic material (the “hard” ground elevation). The hard ground elevation is measured at approximately the same horizontal position as the soft ground elevation.

The field crew obtained soft ground elevations by gently setting the shoe of a leveling staff or prism pole (the latter so named for the corner-cube prism target that it carries) onto the muck surface at a location thought to be undisturbed and at a “natural level,” as best as could be judged by visual means. The shoe of the leveling staff (Figure 4, below) has a rectangular cross section approximately 1.0 inch by 2.5 inches in size. This staff was used with the NA2 automatic level to measure the soft ground and hard ground elevations at the four well stations. When setting the leveling staff on the top of the muck, the bottom of the staff presented a “bearing surface” which helped to prevent the staff from sinking into the muck and corrupting the measurement of the soft ground elevation. The hard ground elevation was determined with the aid of a steel rod, on which the leveling staff was placed, and the procedure is described below.



Figure 4: Foot of leveling staff

At the 188 locations not adjacent to the well clusters, the soft and hard ground elevations were measured by means of Leica TC705 and TC805 electronic total stations measuring

to retro-reflector (corner-cube) prism targets. The distances and angles measured by the total station were stored in a TDS Ranger electronic data collector running TDS Survey Pro version 4.2 data collection software. The prism pole was placed on the muck surface for the measurement of the soft ground elevation. Figures 5 and 6 (below) show the shoe that would be attached to the bottom of the prism pole for this purpose. The bottom of that shoe is circular with a diameter of about 2.5 inches. The goal of using this shoe was to provide sufficient bearing surface to minimize the sinking of the target into the muck and obtain a more accurate elevation.



Figure 5: Side view of the prism pole shoe used for ground elevation measurement



Figure 6: Bottom view of prism pole shoe

All hard ground elevations were determined in one of two ways. One method was to drive a steel rod of known length into the muck until its downward motion was stopped by the hard ground surface. The elevation of the top of the rod, so driven, was measured using either the leveling staff and NA2 level or the prism pole and electronic total station. The known length of the rod was subtracted from that elevation in order to obtain the elevation of the hard ground surface. At the four well structures, the leveling staff (Figure 4) was placed on the top of the refusal rod. At all other locations where this method was used, the prism pole was placed atop the refusal rod.

The second method which was occasionally used with the prism pole was to replace the shoe shown in Figures 5 and 6 with a pointed-end shoe (not shown) and “driving” the pole to refusal by means of pushing down on the staff using body weight. This method was not suitable for deep muck, but for areas of shallow muck the hard ground surface could easily be identified when pushing the prism pole through the soft muck surface.

GROUND ELEVATIONS AT “GRID POINTS”

As noted above, hard and soft ground elevations were obtained at 188 points which are not associated with the well clusters. The locations of these points are based on an orthogonal grid pattern which was defined prior to commencing field work. The grid spacing varies. Over the island itself, the orthogonal distance between consecutive grid lines is 50 feet. Over the area of the surrounding swamp adjacent to the island, the spacing increases to 100 feet between grid lines. Figure 7 (below) illustrates the location of the 188 grid points at which elevations were measured. Table 6 (in the section **RESULTS: HORIZONTAL POSITIONS AND ELEVATIONS AT GRID POINTS**) sets out the

state plane coordinates of each grid point and the corresponding measured soft and hard ground elevations.

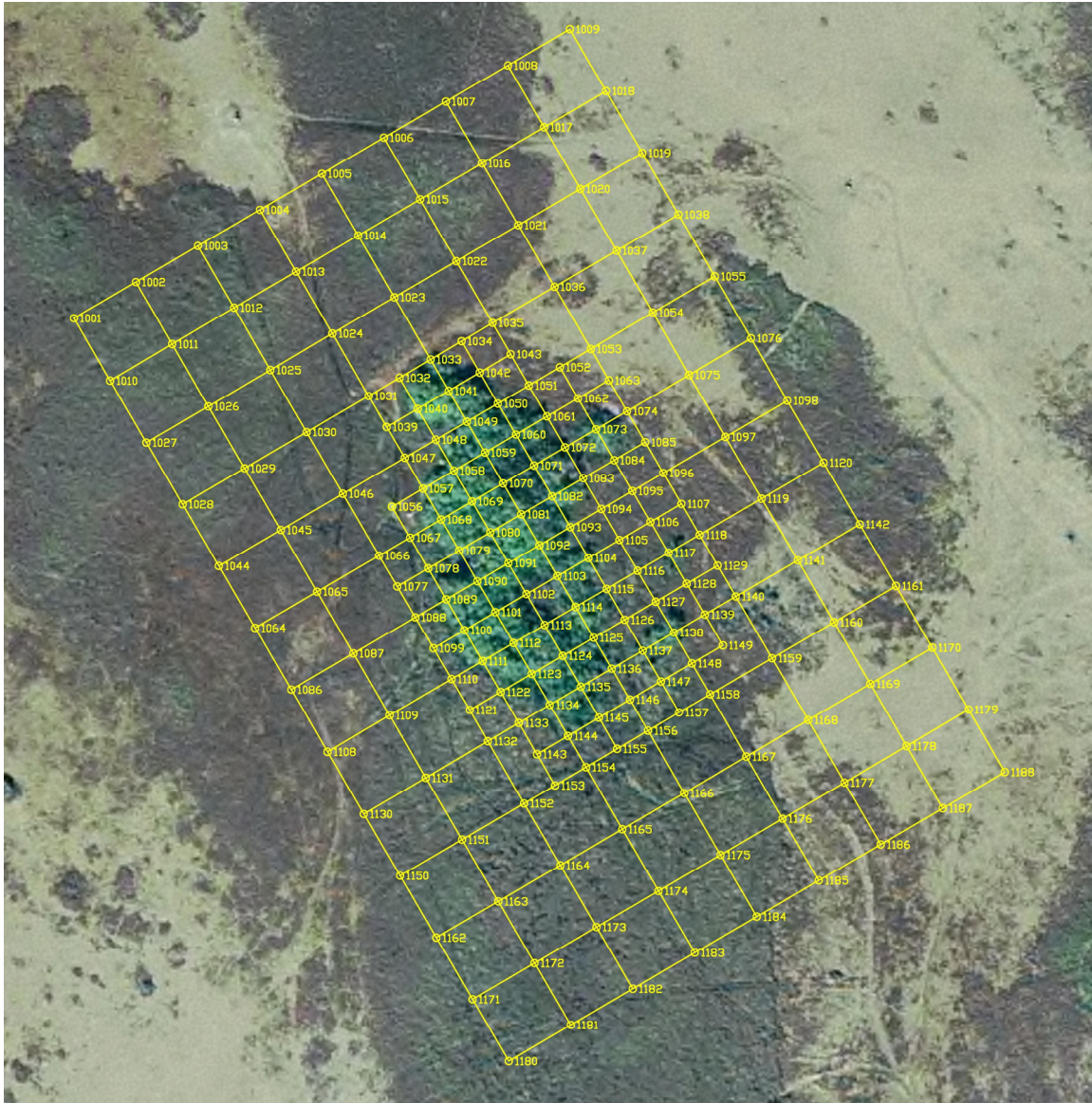


Figure 7: Configuration of grid at 3AN1 for ground elevation determination.

Source of aerial photograph: LABINS World Wide Web site (<http://data.labins.org>). The date of photograph is reported to be 12/12/04. The distance between consecutive grid points along each line is 50 feet on the island itself and 100 feet in the area surrounding the island.

As noted above, the locations of these 188 grid points were predefined. The instrumentation and data collection software used by the field crew allowed the person carrying the prism pole to navigate to each predefined position. The goal was to measure the ground elevations at a location which lies within a few tenths of a foot of the predefined location. Discretion was allowed in how closely the prism pole was placed to the predefined point before recording the measurements for elevation determination. Several conditions prevent placement exactly on the desired position, such as occasional

intervening obstacles which block the view of the target prism at the total station, vegetative debris lying on the ground at the grid point, and the requirement to measure the ground elevation in its natural state at an undisturbed location. The horizontal position of every soft ground measurement was computed from the observation data and subsequently compared to the corresponding predefined grid point position. The maximum deviation between the horizontal position of a grid point and the actual measured point is 0.6'.

Field notes of the determination of the ground elevations at the grid points are in field book 1243, pp. 31, 34–40, 42, and in the accompanying TDS electronic data files (named *3an1*.RAW*).

METHOD OF DETERMINING HORIZONTAL POSITIONS

As noted in the section on the project datums, SFWMD provided horizontal positions of four stainless steel rod monuments (3AN1-GW-1, 3AN1-GW-2, 3AN1-GW-3, and 3AN1-GW-4B) at the project site. A control traverse was performed (field book 1243, pp. 32–33) using a Leica TC705 electronic total station which included those four rod monuments plus the stainless steel rod monument 3AN1-GW-4A (located at well cluster 3AN1-GW-4B). The traverse was reduced and adjusted to compute the position of rod monument 3AN1-GW-4A.

As alluded to in the previous section of this report regarding the measurement of ground elevations at 188 regularly spaced grid points, horizontal positions of the prism pole were obtained concurrently with the elevation determination while using the electronic total station. The field operation consisted of the total station occupying one of the rod monuments and sighting the target pole occupying a grid point. The computation of the horizontal position of the prism target pole is based on the position of the rod monuments used (derived from the aforementioned control traverse) and from the measurements of angle and distance recorded by the electronic total station.

RESULTS: LEVELING ON WELL CLUSTERS 3AN1-GW-1, 3AN1-GW-2, 3AN1-GW-3, 3AN1-GW-4B

Tabulations of the elevations and other data obtained for the four principal well clusters follow. For each well group, differences between elevation values obtained by Keith and Schnars in 2007 (this survey) and previously obtained elevation values, provided by SFWMD in several Microsoft® Excel files, are tabulated. (Comparisons of the soft and hard ground elevations, between the measurements by this survey and the older supplied values, are omitted.)

WELL CLUSTER 3AN1-GW-1**Table 1: Revised elevation values, well cluster 3AN1-GW-1 (northwest of island)**

<i>Well name or other designation</i>	<i>Existing SFWMD elevation (NGVD 29)</i> (1)	<i>Existing SFWMD elevation (NAVD 88)</i> (2)	<i>K&S measured elevation (8/8/07) for this report (NGVD 29)</i> (3)	<i>K&S measured elevation (8/8/07) for this report (NAVD 88)</i> (4)	<i>Difference (K&S minus SFWMD, both datums)</i> (5)
3AN1-GW-1 (reference mark on plywood)	18.655	17.205	18.64	17.19	-0.02
3AN1-GW-1 (2" PVC pipe)	17.417	15.967	17.40	15.95	-0.02
3AN1-GW-1 (3/4" PVC pipe)	17.407	15.957	17.39	15.94	-0.02
Natural ground (top of muck/organic material)	N/A	N/A	10.2	8.7	N/A
Top of rock/impermeable ground	N/A	N/A	9.9	8.4	N/A
BM 3AN1-GW-1 (stainless steel rod)	15.082	13.632	15.065	13.615	-0.017
Staff gauge (Lag bolt at 13.70 foot graduation)	16.81	15.36	16.74	15.29	-0.07

All values shown in Table 1 are in units of U.S. Survey feet. The values in the five columns are derived as follows:

- (1) Column (1) values for the 2" and ¾" PVC pipes are taken from brass tags fastened to the plywood floor of the box on the well. The remaining values in column (1) are the respective column (2) values minus the datum offset of -1.450 feet.
- (2) For the 2" and ¾" PVC pipes, column (2) values are the respective column (1) values plus the datum offset of -1.450 feet. These values agree well with elevations in the SFWMD-supplied file *SANI-GW-2HerrellKrupaRevised.xls*. The remaining column (2) values are drawn directly from that file.
- (3) Column (3) values are the respective column (4) values minus the datum offset of -1.450 feet.
- (4) Column (4) values are derived from differential leveling observations conducted between August 6, 2007, through August 8, 2007, with this particular cluster being observed on August 8, 2007 (Keith and Schnars field book 1243, p. 25–26).
- (5) Column (5) values are obtained by subtracting column (1) values from the corresponding column (3) values; equivalently column (4) values minus column (2) values.

The last feature listed in Table 1 is a lag bolt on the staff at this well site. This bolt can be seen in the photograph in Figure 8 (below) at a “staff height” of 13.70 feet. Note that this means that the 13.70-foot graduation on the staff has a NAVD 88 elevation of 15.29 feet and a NGVD 29 elevation of 16.74 feet. This implies that the “zero” of the staff has a NAVD 88 elevation of 1.59 feet and a NGVD 29 elevation of 3.04 feet. This elevation of the staff zero is largely confirmed by information in SFWMD-supplied file *SANI-GW-IHerrellKrupaRevised.xls*, where the 15.00-foot staff graduation is reported to have a NAVD 88 elevation of 5.076 meters, or 16.654 feet, implying that the “zero” of the staff has a NAVD 88 elevation of 1.654 feet (within 0.07' of this K&S determination).



Figure 8: Photograph of the staff gauge at the northwest well cluster.

Note the lag bolt near the right edge of the staff at a gauge height of 13.70 feet, which is set out in Table 1.

WELL CLUSTER 3AN1-GW-2**Table 2: Revised elevation values, well cluster 3AN1-GW-2 (northeast of island)**

Well name or other designation	Existing SFWMD elevation (NGVD 29) (1)	Existing SFWMD elevation (NAVD 88) (2)	K&S measured elevation (8/8/07) for this report (NGVD 29) (3)	K&S measured elevation (8/8/07) for this report (NAVD 88) (4)	Difference (K&S minus SFWMD, both datums) (5)
3AN1-GW-2 (reference mark on plywood)	N/A	N/A	18.22	16.77	N/A
3AN1-GW-2 (2" PVC pipe)	18.291	16.841	18.28	16.83	-0.01
3AN1-GW-2 (3/4" PVC pipe)	18.281	16.831	18.27	16.82	-0.01
Natural ground (top of muck/organic material)	N/A	N/A	10.1	8.6	N/A
Top of rock/impermeable ground	N/A	N/A	9.4	7.9	N/A
BM 3AN1-GW-2 (stainless steel rod)	15.161	13.711	15.152	13.702	-0.009

All values shown in Table 2 are in units of U.S. Survey feet. The values in the five columns are derived as follows:

- (1) Column (1) values for the 2" and 3/4" PVC pipes are taken from brass tags fastened to the plywood floor of the box on the well. The remaining values in column (1) are the respective column (2) values minus the datum offset of -1.450 feet.
- (2) For the 2" and 3/4" PVC pipes, column (2) values are the respective column (1) values plus the datum offset of -1.450 feet. These values agree well with elevations in the SFWMD-supplied file *SAN1-GW-2HerrellKrupaRevised.xls*. The remaining column (2) values are drawn directly from that file.
- (3) Column (3) values are the respective column (4) values minus the datum offset of -1.450 feet.
- (4) Column (4) values are derived from differential leveling observations conducted between August 6, 2007, through August 8, 2007, with this particular cluster being observed on August 8, 2007 (Keith and Schnars field book 1243, p. 27).
- (5) Column (5) values are obtained by subtracting column (1) values from the corresponding column (3) values; equivalently column (4) values minus column (2) values.

WELL CLUSTER 3AN1-GW-3

Table 3: Revised elevation values, well cluster 3AN1-GW-3 (south of island)

<i>Well name or other designation</i>	<i>Existing SFWMD elevation (NGVD 29)</i> (1)	<i>Existing SFWMD elevation (NAVD 88)</i> (2)	<i>K&S measured elevation (8/8/07) for this report (NGVD 29)</i> (3)	<i>K&S measured elevation (8/8/07) for this report (NAVD 88)</i> (4)	<i>Difference (K&S minus SFWMD, both datums)</i> (5)
3AN1-GW-3 (plywood floor of box)	18.24	16.79	18.21	16.76	-0.03
3AN1-GW-3 (2" PVC pipe)	18.285	16.835	18.25	16.80	-0.04
3AN1-GW-3 (3/4" PVC pipe)	18.273	16.823	18.23	16.78	-0.04
Natural ground (top of muck/organic material)	N/A	N/A	10.5	9.0	N/A
Top of rock/impermeable ground	N/A	N/A	9.3	7.8	N/A
BM 3AN1-GW-3 (stainless steel rod)	15.056	13.606	15.016	13.566	-0.040

All values shown in Table 3 are in units of U.S. Survey feet. The values in the five columns are derived as follows:

- (1) Column (1) values for the 2" and ¾" PVC pipes are taken from brass tags fastened to the plywood floor of the box on the well. The remaining values in column (1) are the respective column (2) values minus the datum offset of -1.450 feet.
- (2) For the 2" and ¾" PVC pipes, column (2) values are the respective column (1) values plus the datum offset of -1.450 feet. These values agree well with elevations in the SFWMD-supplied file *SAN1-GW-31HerrellKrupaRevised.xls*. The remaining column (2) values are drawn directly from that file.
- (3) Column (3) values are the respective column (4) values minus the datum offset of -1.450 feet.
- (4) Column (4) values are derived from differential leveling observations conducted between August 6, 2007, through August 8, 2007, with this particular cluster being observed on August 8, 2007 (Keith and Schnars field book 1243, p. 28).
- (5) Column (5) values are obtained by subtracting column (1) values from the corresponding column (3) values; equivalently column (4) values minus column (2) values.

WELL CLUSTER 3AN1-GW-4B

Table 4: Revised elevation values, well cluster 3AN1-GW-4B (on island)

<i>Well name or other designation</i>	<i>Existing SFWMD elevation (NGVD 29)</i> (1)	<i>Existing SFWMD elevation (NAVD 88)</i> (2)	<i>K&S measured elevation (8/8/07) for this report (NGVD 29)</i> (3)	<i>K&S measured elevation (8/8/07) for this report (NAVD 88)</i> (4)	<i>Difference (K&S minus SFWMD, both datums)</i> (5)
3AN1-GW-4B (Top surface of plywood; no explicit reference mark)	N/A	N/A	16.07	14.62	N/A
3AN1-GW-4B (1" PVC)	16.212	14.762	16.19	14.74	-0.02
Natural ground (top of muck/organic material)	N/A	N/A	11.8	10.3	N/A
Top of rock/impermeable ground	N/A	N/A	10.8	9.3	N/A
BM 3AN1-GW-4A (stainless steel rod)	12.559	11.109	12.532	11.082	-0.027

All values shown in Table 4 are in units of U.S. Survey feet. The values in the five columns are derived as follows:

- (1) The column (1) value for the 1" PVC pipe is taken from the brass tag fastened to the plywood floor of the box on the well. The column (1) value for the rod monument is the corresponding column (2) value minus the datum offset of -1.450 feet.
- (2) For the 1" PVC pipe, the column (2) value is the corresponding column (1) value plus the datum offset of -1.450 feet. This value agrees well with the elevation in the SFWMD-supplied file *SANI-GW-41HerrellKrupaRevised.xls*. The column (2) value for the rod monument is taken directly from that file.
- (3) Column (3) values are the respective column (4) values minus the datum offset of -1.450 feet.
- (4) Column (4) values are derived from differential leveling observations conducted between August 6, 2007, through August 8, 2007, with this particular cluster being observed on August 8, 2007 (Keith and Schnars field book 1243, p. 29).
- (5) Column (5) values are obtained by subtracting column (1) values from the corresponding column (3) values; equivalently column (4) values minus column (2) values.

RESULTS: HORIZONTAL POSITIONS AND ELEVATIONS AT FOUR WELL CLUSTERS

In Table 5 below, the geodetic latitudes and longitudes listed are with respect to NAD 83; the northing and easting values are in units of U.S. Survey Feet and with respect to the Florida State Plane Coordinate System, East zone, NAD 83; and the elevation values are in units of feet above the datums noted in the column header.

As noted previously in this report, the horizontal positions of stainless steel rod monuments 3AN1-GW-1, 3AN1-GW-2, 3AN1-GW-3, and 3AN1-GW-4B were provided by SFWMD, and the values shown for those monuments in Table 5 are those provided positions. The tabulated position of the rod monument 3AN1-GW-4A is derived from the traverse measurements performed during this survey.

NAVD 88 elevations of stainless steel rod monuments 3AN1-GW-1, 3AN1-GW-2, 3AN1-GW-3, and 3AN1-GW-4B were provided by SFWMD. As noted in the section of this report **DATUMS FOR THE PROJECT**, the elevation of 3AN1-GW-1 was adopted as the controlling, fixed elevation which is the basis for all elevation determination in this survey. The NAVD 88 elevation for monument 3AN1-GW-1 shown in Table 5 is that value provided by SFWMD. All other NAVD 88 elevation values in the table are measured values derived from this survey’s differential leveling observations and the published elevation of 3AN1-GW-1.

All NGVD 29 elevations in Table 5 are computed by subtracting -1.450 feet (being the datum offset described in the section **DATUMS FOR THE PROJECT**) from the corresponding NAVD 88 elevation.

Table 5: Horizontal positions and elevations of wells

Designation	NAD 83 latitude (north)	NAD 83 longitude (west)	State plane coordinate (northing/Y, U.S. Survey Feet)	State plane coordinate (easting/X, U.S. Survey Feet)	Reference mark elevation (NGVD 29, feet)	Reference mark elevation (NAVD 88, feet)	Hard ground elevation (NGVD 29, feet)	Hard ground elevation (NAVD 88, feet)	Soft ground elevation (NGVD 29, feet)	Soft ground elevation (NAVD 88, feet)	Description
3AN1-GW-1	(Adjacent to stainless steel rod monument 3AN1-GW-1; monument position has been provided by SFWMD)				18.64	17.19	9.9	8.4	10.2	8.7	Surface water well/reference mark in box at top of well
3AN1-GW-1					17.40	15.95					2" PVC pipe
3AN1-GW-1					17.39	15.94					1" or 3/4" PVC pipe
3AN1-GW-1	26° 11' 16.35922"	80° 44' 25.25400"	674061.721	741313.379	15.065	13.615					Stainless steel rod monument
3AN1-GW-2	(Adjacent to stainless steel rod monument 3AN1-GW-2; monument position has been provided by SFWMD)				18.22	16.77	9.4	7.9	10.1	8.6	Reference mark in box at top of well
3AN1-GW-2					18.28	16.83					2" PVC pipe
3AN1-GW-2					18.27	16.82					1" or 3/4" PVC pipe
3AN1-GW-2	26° 11' 15.39099"	80° 44' 15.89528"	673965.679	742166.072	15.152	13.702					Stainless steel rod monument
3AN1-GW-3	(Adjacent to stainless steel rod monument 3AN1-GW-3; monument position has been provided by SFWMD)				18.21	16.76	9.3	7.8	10.5	9.0	Surface of plywood in box at top of well; no reference mark seen
3AN1-GW-3					18.25	16.80					2" PVC pipe
3AN1-GW-3					18.23	16.78					1" or 3/4" PVC pipe
3AN1-GW-3	26° 11' 01.32810"	80° 44' 20.68074"	672544.967	741733.012	15.016	13.566					Stainless steel rod monument
3AN1-GW-4B	(Adjacent to stainless steel rod monument 3AN1-GW-4A; monument position was measured by K&S as part of this survey)				16.07	14.62	10.8	9.3	11.8	10.3	Surface of plywood in box at top of well; no reference mark seen
3AN1-GW-4B					16.19	14.74					1" PVC pipe
3AN1-GW-4A	26° 11' 11.24745"	80° 44' 21.96698"	673546.221	741613.833	12.532	11.082					Stainless steel rod monument (at 3AN1-GW-4B well cluster)
3AN1-GW-4B	26° 11' 10.88488"	80° 44' 22.58417"	673509.501	741557.685	12.822	11.372	N/A	N/A	N/A	N/A	Stainless steel rod monument (at west end of dock at west side of the island)

RESULTS: HORIZONTAL POSITIONS AND ELEVATIONS AT GRID POINTS

In Table 6 below, the point numbers in the first column correspond to the numbers appearing next to the grid points depicted in Figure 7. The northing and easting values are in units of U.S. Survey Feet and with respect to the Florida State Plane Coordinate System, East zone, NAD 83. The soft and hard ground elevations are in units of feet above the datums noted.

Table 6: Soft and hard ground elevations at grid points

<i>Point number</i>	<i>Northing</i>	<i>Easting</i>	<i>"Soft" ground elevation (NAVD 88)</i>	<i>"Hard" ground elevation (NAVD 88)</i>	<i>"Soft" ground elevation (NGVD 29)</i>	<i>"Hard" ground elevation (NGVD 29)</i>
1001	673784.941	741087.740	8.7	5.8	10.1	7.2
1002	673835.436	741174.072	8.6	4.6	10.1	6.1
1003	673885.754	741260.340	8.4	5.4	9.9	6.8
1004	673936.394	741346.710	8.5	5.0	10.0	6.4
1005	673986.807	741433.060	8.5	8.1	10.0	9.5
1006	674037.285	741519.342	8.6	8.2	10.0	9.7
1007	674087.738	741605.678	8.5	8.3	10.0	9.7
1008	674138.226	741692.010	8.6	8.1	10.1	9.6
1009	674188.670	741778.338	8.7	8.3	10.2	9.7
1010	673698.606	741138.180	8.5	4.7	10.0	6.2
1011	673749.018	741224.514	8.7	4.4	10.1	5.8
1012	673799.606	741310.860	8.8	5.5	10.2	7.0
1013	673850.016	741397.184	8.7	6.2	10.2	7.7
1014	673900.487	741483.542	8.8	8.3	10.2	9.7
1015	673950.955	741569.846	8.6	8.5	10.1	9.9
1016	674001.426	741656.179	8.8	8.1	10.3	9.6
1017	674051.900	741742.467	8.6	7.7	10.1	9.2
1018	674102.357	741828.800	8.8	8.2	10.2	9.6
1019	674016.046	741879.153	8.5	7.5	10.0	9.0
1020	673965.532	741793.008	8.7	8.5	10.1	10.0
1021	673915.021	741706.835	8.8	8.2	10.3	9.6
1022	673864.781	741620.063	9.0	8.4	10.5	9.9
1023	673814.344	741533.820	8.9	8.0	10.3	9.5
1024	673764.112	741447.464	8.7	7.6	10.2	9.0
1025	673713.501	741361.287	8.4	6.1	9.9	7.5
1026	673663.153	741275.046	8.6	6.1	10.0	7.5
1027	673612.153	741188.635	8.5	5.5	10.0	7.0
1028	673526.434	741239.210	8.6	7.1	10.1	8.5
1029	673576.575	741325.441	8.7	6.7	10.1	8.2
1030	673626.776	741411.816	8.5	6.9	10.0	8.4
1031	673677.509	741498.046	8.8	8.5	10.3	9.9
1032	673702.482	741541.346	9.1	9.0	10.5	10.5
1033	673727.777	741584.484	9.1	8.9	10.6	10.4
1034	673753.241	741627.409	9.0	8.6	10.4	10.1

Point number	Northing	Easting	"Soft" ground elevation (NAVD 88)	"Hard" ground elevation (NAVD 88)	"Soft" ground elevation (NGVD 29)	"Hard" ground elevation (NGVD 29)
1035	673778.158	741670.980	8.8	8.2	10.2	9.7
1036	673828.828	741757.011	8.8	7.9	10.3	9.4
1037	673879.307	741843.237	8.7	8.2	10.1	9.6
1038	673929.704	741929.760	8.6	6.2	10.0	7.6
1039	673633.889	741523.356	9.0	8.5	10.5	9.9
1040	673659.586	741566.433	9.7	9.5	11.2	11.0
1041	673684.425	741609.735	10.0	9.8	11.5	11.3
1042	673709.823	741652.706	9.3	8.1	10.7	9.5
1043	673735.160	741696.437	8.8	7.9	10.2	9.3
1044	673439.647	741289.569	8.7	7.0	10.1	8.4
1045	673489.872	741375.982	8.7	6.9	10.1	8.3
1046	673540.346	741462.303	8.7	7.6	10.2	9.0
1047	673591.118	741548.539	9.1	8.6	10.6	10.0
1048	673616.223	741591.780	9.3	8.7	10.8	10.1
1049	673641.466	741634.942	9.9	9.7	11.4	11.1
1050	673666.718	741678.095	9.1	8.0	10.5	9.4
1051	673692.165	741721.511	9.1	8.1	10.6	9.5
1052	673717.097	741764.553	8.6	7.9	10.1	9.3
1053	673742.435	741807.609	8.5	7.9	10.0	9.3
1054	673792.841	741894.010	8.6	7.1	10.0	8.6
1055	673843.400	741980.188	8.8	6.6	10.2	8.0
1056	673522.491	741530.707	9.0	7.4	10.5	8.9
1057	673548.116	741573.683	9.0	8.2	10.5	9.7
1058	673573.280	741616.865	10.5	10.0	11.9	11.5
1059	673598.460	741659.858	9.5	8.2	11.0	9.7
1060	673623.365	741703.509	9.8	9.6	11.2	11.0
1061	673648.663	741746.642	8.9	8.2	10.4	9.7
1062	673674.245	741789.400	9.0	8.5	10.5	10.0
1063	673699.411	741832.598	8.8	8.4	10.2	9.8
1064	673353.191	741339.992	8.8	7.2	10.2	8.7
1065	673403.898	741426.343	8.7	7.3	10.2	8.8
1066	673454.168	741512.738	8.6	7.5	10.0	9.0
1067	673479.368	741555.949	8.7	6.9	10.2	8.3
1068	673504.566	741599.139	9.9	8.9	11.3	10.4
1069	673529.924	741642.239	9.7	8.8	11.1	10.2
1070	673555.495	741685.143	9.8	9.2	11.2	10.7
1071	673580.500	741728.665	9.4	8.6	10.9	10.1
1072	673605.610	741771.747	9.3	9.1	10.8	10.5
1073	673631.077	741814.643	10.6	10.1	12.0	11.5
1074	673656.246	741857.820	9.4	9.3	10.9	10.8
1075	673706.575	741944.676	8.6	8.4	10.0	9.8
1076	673756.801	742030.798	8.8	6.8	10.3	8.3
1077	673410.917	741538.001	8.3	7.7	9.8	9.1

Point number	Northing	Easting	"Soft" ground elevation (NAVD 88)	"Hard" ground elevation (NAVD 88)	"Soft" ground elevation (NGVD 29)	"Hard" ground elevation (NGVD 29)
1078	673436.603	741580.996	8.7	6.9	10.1	8.4
1079	673461.259	741624.451	9.6	8.9	11.0	10.4
1080	673486.988	741667.326	10.4	10.1	11.8	11.5
1081	673512.278	741710.415	10.3	10.1	11.7	11.6
1082	673537.271	741753.747	9.4	9.0	10.8	10.4
1083	673562.535	741796.888	9.4	7.9	10.8	9.3
1084	673587.936	741840.314	9.4	8.9	10.8	10.4
1085	673613.222	741883.527	9.4	9.4	10.9	10.8
1086	673267.114	741390.415	8.7	7.9	10.2	9.4
1087	673317.543	741476.813	8.9	7.5	10.4	9.0
1088	673367.660	741563.315	8.4	6.7	9.8	8.2
1089	673393.187	741606.341	9.5	7.9	11.0	9.3
1090	673418.126	741649.510	10.0	9.7	11.4	11.1
1091	673443.850	741692.545	9.6	8.4	11.1	9.9
1092	673468.563	741736.060	9.7	8.6	11.2	10.1
1093	673494.100	741779.013	9.2	8.6	10.6	10.0
1094	673519.289	741822.163	9.2	9.0	10.6	10.4
1095	673544.810	741865.044	8.8	8.3	10.2	9.8
1096	673569.830	741908.553	8.9	8.4	10.4	9.9
1097	673620.007	741994.733	9.0	8.7	10.4	10.1
1098	673670.412	742081.090	8.8	8.5	10.3	9.9
1099	673324.438	741588.472	9.1	6.7	10.5	8.1
1100	673349.988	741631.569	9.1	8.4	10.5	9.9
1101	673374.648	741674.790	10.0	9.7	11.4	11.2
1102	673400.700	741717.782	9.3	9.0	10.7	10.4
1103	673425.887	741761.057	9.6	8.9	11.0	10.3
1104	673451.049	741804.363	10.2	9.8	11.6	11.2
1105	673476.351	741847.539	9.3	8.9	10.7	10.4
1106	673501.368	741890.598	9.2	8.5	10.6	9.9
1107	673526.320	741933.610	8.9	8.4	10.3	9.9
1108	673180.898	741440.891	8.8	8.3	10.2	9.7
1109	673230.784	741527.357	8.8	6.8	10.2	8.2
1110	673281.200	741613.688	9.2	6.5	10.7	7.9
1111	673306.838	741656.760	9.6	8.5	11.0	9.9
1112	673332.199	741699.977	10.3	10.0	11.7	11.4
1113	673357.418	741743.153	9.6	9.5	11.1	10.9
1114	673382.364	741786.285	9.6	9.3	11.0	10.7
1115	673407.883	741829.607	9.4	9.1	10.8	10.6
1116	673433.065	741872.712	9.2	8.7	10.7	10.1
1117	673457.667	741915.567	10.0	9.7	11.5	11.1
1118	673483.462	741959.012	9.2	8.8	10.6	10.3
1119	673533.830	742045.282	9.1	8.8	10.5	10.2
1120	673584.576	742131.666	9.0	8.2	10.4	9.6

Point number	Northing	Easting	"Soft" ground elevation (NAVD 88)	"Hard" ground elevation (NAVD 88)	"Soft" ground elevation (NGVD 29)	"Hard" ground elevation (NGVD 29)
1121	673238.032	741638.920	8.6	7.7	10.0	9.2
1122	673263.334	741682.042	9.1	8.7	10.6	10.2
1123	673288.530	741725.187	9.6	8.8	11.1	10.3
1124	673314.157	741768.331	9.9	9.3	11.3	10.8
1125	673339.237	741811.511	9.6	9.1	11.1	10.6
1126	673364.559	741854.706	9.0	8.2	10.4	9.6
1127	673390.155	741898.045	9.2	8.6	10.7	10.1
1128	673414.571	741940.879	9.2	8.5	10.6	9.9
1129	673440.360	741984.272	8.9	7.7	10.4	9.1
1130	673094.190	741491.464	8.8	8.0	10.3	9.5
1131	673144.460	741577.832	8.8	7.7	10.3	9.2
1132	673195.094	741664.140	8.6	7.0	10.0	8.4
1133	673220.466	741707.257	9.3	6.9	10.7	8.4
1134	673245.809	741750.428	9.5	9.0	10.9	10.5
1135	673270.616	741793.555	9.6	9.1	11.1	10.5
1136	673296.282	741836.800	9.4	9.0	10.9	10.5
1137	673321.532	741880.033	9.7	9.7	11.2	11.1
1138	673346.814	741923.202	9.9	9.3	11.4	10.7
1139	673372.236	741966.397	9.3	8.8	10.7	10.3
1140	673397.319	742009.515	9.2	8.7	10.7	10.2
1141	673447.522	742095.738	9.2	8.9	10.7	10.3
1142	673498.514	742182.099	9.2	7.9	10.6	9.4
1143	673177.447	741732.520	9.3	7.5	10.8	9.0
1144	673202.108	741775.650	9.3	8.0	10.7	9.4
1145	673227.834	741818.840	9.3	8.0	10.8	9.4
1146	673252.669	741861.941	9.2	7.8	10.6	9.2
1147	673277.887	741905.122	9.3	8.0	10.8	9.4
1148	673303.550	741948.364	9.2	8.5	10.6	9.9
1149	673328.881	741991.570	9.0	8.1	10.5	9.6
1150	673007.764	741541.986	8.9	8.4	10.3	9.9
1151	673058.773	741628.177	8.9	7.4	10.3	8.9
1152	673108.696	741714.584	8.7	7.0	10.2	8.4
1153	673134.015	741757.725	9.2	5.9	10.7	7.4
1154	673159.301	741800.888	9.0	5.7	10.5	7.1
1155	673184.536	741844.065	9.0	5.4	10.4	6.9
1156	673209.505	741887.172	9.1	6.9	10.5	8.3
1157	673234.810	741930.317	9.0	6.9	10.5	8.4
1158	673260.133	741973.494	9.5	7.4	10.9	8.9
1159	673310.438	742059.784	9.0	8.0	10.5	9.5
1160	673361.180	742146.248	8.9	8.3	10.3	9.7
1161	673411.826	742232.713	8.9	8.7	10.4	10.1
1162	672921.701	741592.337	9.2	8.7	10.6	10.2
1163	672972.055	741678.704	8.9	6.7	10.3	8.2

Point number	Northing	Easting	"Soft" ground elevation (NAVD 88)	"Hard" ground elevation (NAVD 88)	"Soft" ground elevation (NGVD 29)	"Hard" ground elevation (NGVD 29)
1164	673022.469	741765.032	9.3	6.1	10.7	7.6
1165	673072.972	741851.358	8.9	4.6	10.4	6.0
1166	673123.525	741937.716	9.2	5.2	10.7	6.7
1167	673173.917	742024.023	8.8	6.2	10.3	7.6
1168	673224.366	742110.319	8.7	7.3	10.2	8.7
1169	673274.784	742196.638	8.9	8.5	10.4	9.9
1170	673325.450	742283.133	9.1	8.9	10.6	10.3
1171	672835.599	741642.728	9.2	7.0	10.6	8.4
1172	672886.000	741729.170	8.6	5.6	10.0	7.0
1173	672936.333	741815.544	8.9	3.7	10.4	5.2
1174	672986.592	741901.788	8.9	6.3	10.4	7.8
1175	673036.926	741988.062	8.9	4.2	10.4	5.7
1176	673087.763	742074.591	8.6	5.8	10.0	7.2
1177	673138.045	742160.832	8.6	6.7	10.1	8.2
1178	673188.449	742247.084	8.4	7.8	9.9	9.2
1179	673238.819	742333.325	8.5	7.4	10.0	8.8
1180	672748.850	741693.325	9.8	9.5	11.2	10.9
1181	672799.560	741779.655	8.6	6.8	10.1	8.2
1182	672849.808	741865.944	8.9	3.9	10.4	5.4
1183	672900.253	741952.234	9.1	3.6	10.5	5.0
1184	672950.907	742038.720	8.9	5.9	10.3	7.3
1185	673001.215	742124.902	8.6	6.6	10.0	8.1
1186	673051.947	742211.523	8.7	6.7	10.1	8.2
1187	673102.148	742297.518	8.7	6.9	10.2	8.4
1188	673152.680	742383.962	8.7	7.5	10.1	8.9

APPENDIX A: ABBREVIATIONS

BM: Bench mark

K&S: Keith and Schnars

L.B.: Licensed surveying and mapping business

N/A: Not applicable, or data not available

NAD 83: North American Datum of 1983

NAVD 88: North American Vertical Datum of 1988

NGS: National Geodetic Survey

NGVD 29: National Geodetic Vertical Datum of 1929

PVC: Polyvinyl chloride

SFWMD: South Florida Water Management District

TDS: Tripod Data Systems, manufacturer of data collection hardware and software

APPENDIX B: PHOTOGRAPHS

Below appears a subset of the photographs taken at the site during this survey.



Figure 9: Well cluster 3AN1-GW-1 (northwest of island; view looking north)



Figure 10: Well cluster 3AN1-GW-2 (northeast of island; view looking north)

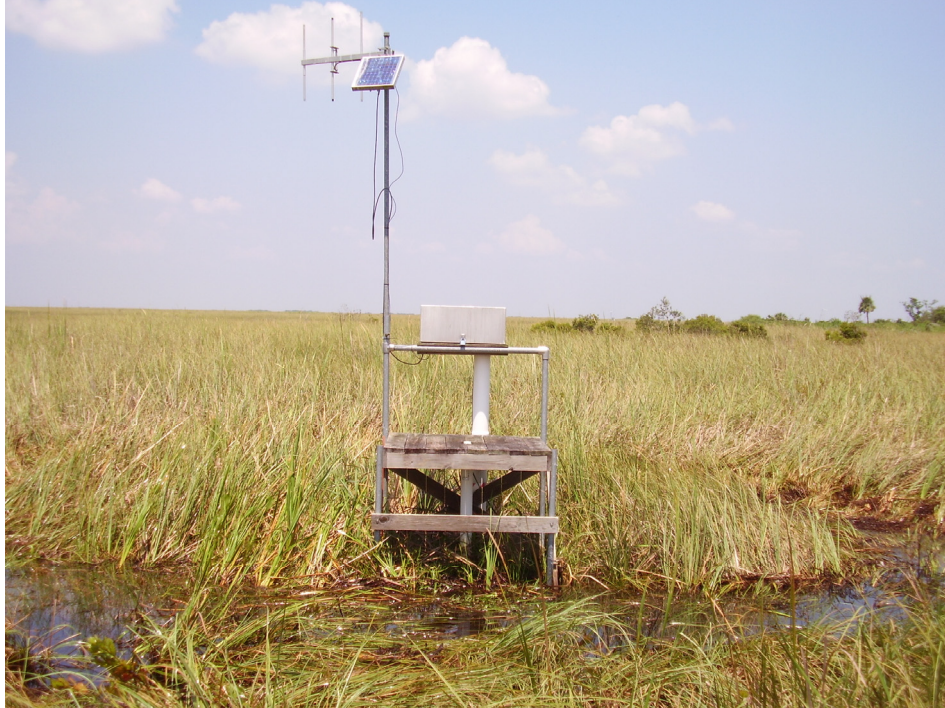


Figure 11: Well cluster 3AN1-GW-3 (south of island; view looking north)



Figure 12: Well cluster 3AN1-GW-4B (on island; view looking east)

APPENDIX C: DERIVATION OF UNCERTAINTIES IN COMPUTED DIFFERENCES IN ELEVATION

In this report, set out in the section **METHODS OF ELEVATION DETERMINATION**, are the estimated standard errors of the differences in elevation between the four major well clusters. These differences in elevation are obtained by subtraction of the elevations presented in Table 5. The standard errors were computed by means of the law of variance-covariance propagation³ (shortened to “covariance propagation” from this point on) and are based upon two assumptions about the measurement procedures used:

1. The three-wire differential leveling loop which tied together bench marks 3AN1-GW-1, 3AN1-GW-2, 3AN1-GW-3, and 3AN1-GW-4A are of “NGS third-order” quality; and
2. The measured differences in elevation between any given bench mark and each of the several adjacent wells (*e.g.*, 2" or 3/4" PVC pipes, etc.) have standard errors of 0.005 feet.

The NGS standards document noted in the section **METHODS OF ELEVATION DETERMINATION** states that a third-order elevation difference (*i.e.*, the difference between the elevations of two surveyed points) has a standard error of $2.0 \text{ mm} \sqrt{K}$, where K is the distance in kilometers between the two points in question, as measured along the path of the leveling operation. Equivalently, this standard error can be expressed $0.0083 \text{ feet} \sqrt{M}$, where M is the distance in miles. Given the sight lengths of the leveling operations (which is obtained from the reduction of the three-wire leveling notes), and assuming that the leveling meets the third order standard of accuracy, the standard error of the observed differences in elevation can be derived and subsequently used in covariance propagation computations.

For this project, the results of the least squares adjustment of the 3-wire leveling provided some of the information necessary perform the covariance propagation computation. A full presentation of the covariance propagation calculation is omitted from this report.

³ See, for example, *Linear Algebra, Geodesy, and GPS*, by Gilbert Strang and Kai Borre, p. 329.