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Perimeter Survey by Photogrammetric Methods

Procedures for surveying the Mean High Water line, both photogrammetrically and by ground survey methods, are described and their accuracies are compared.

Abstract: *For years, the merits of surveying by photogrammetric methods versus surveying by ground methods have been a topic of debate by advocates of the two disciplines. Accuracies of both have been enhanced by recent technical improvements. In a departure from a mathematical dissertation, this paper presents, in a running dialogue, the full scope of a photogrammetric survey and its results compared with a high order detailed ground survey.*

Introduction

Recently a professional land surveyor was engaged to establish a meander line and to define the acreage the survey enclosed. Concurrently, the Florida State Topographic Office was instructed to meander and measure the same tract so that the acreages could be compared.

The ground survey method was basically a fixed procedure: A strong baseline followed by a perimeter traverse with sideshots and measurements to surveyor-selected directional changes in the meander. The photogrammetric approach involved several possible methods, all with varying degrees of accuracy. Three of these were

- To planimeter the area of a linedrawn map which delineated the boundary;
- To select meander points with a monocomparator and compute the area from the comparator coordinates; and
- To establish and record coordinates while viewing the subject in the third dimension with an instrument designed chiefly for contouring.

The results of the two approaches (ground/aerial) also could give their advocates the opportunity to compare accuracies and possibly costs.

In order to forestall private ownership of all beachfront properties and other valuable lands, the State of Florida is buying many of these properties for public use. A land developer offered to sell Honeymoon Island to the State. After months of negotiation, the participants agreed on a price of $62,000 per acre for the upland 410± acre island, totaling about 25 and one-half million dollars. It was to be purchased in seven parcel tracts, over a period of several years.

Honeymoon Island*

This island, now a point of land due to man-made filling on one end, is in the Gulf of Mexico off the town of Dunedin, a few miles north of Clearwater and St. Petersburg (Figure 1). The seaward side of the island contains a sandy beach-like material (white but not firm). The bayside is mostly mangrove, a very dense brush/tree plant whose roots must be washed by frequent saline tidal waters.

The shores of Florida contain many barri-

* Known originally as "Hog Island." It was visited frequently during the Twenties by honeymooning couples who stayed in a cluster of palm-thatched cottages, provided by the then-owner. He changed the name to more appropriately reflect its use.

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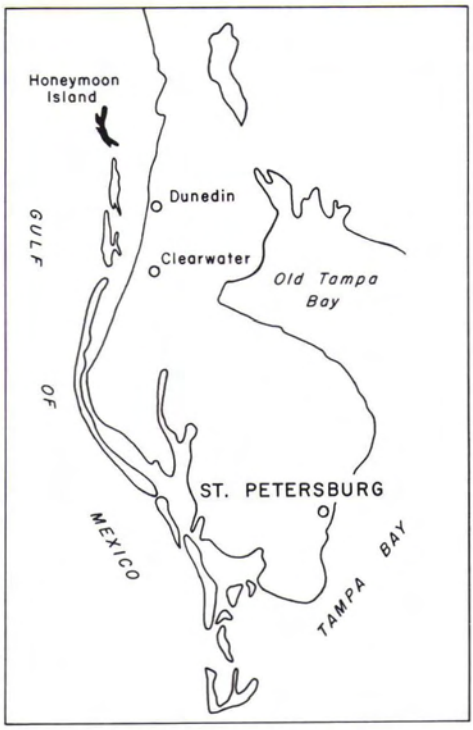

FIG. 1. Location map.

er islands of this type. The most notable are Palm Beach and Miami Beach. Barrier-lagoon coasts comprise 10 to 13 percent of the world's continental coastline.[1] Eons ago tidal action formed low bars offshore of certain types of coasts. These bars were generally parallel to the coastline. Storms and occasional strong tidal currents cut through the bars at irregular intervals. In time the bars grew and were exposed.

The exact stages through which an offshore island passes during its birth and early development are subjects of heated debate amongst geologists who specialize in coastal matters.[2] There are at least three hypotheses explaining the barrier island genesis: local derivation, shore drift, and ridge submergence.

Barrier islands such as Honeymoon Island have no natural soil. Flora is sustained by decomposed vegetation which previously grew on the island or was washed ashore.

Although the site of this project is now an island and is viable, its growth and shape are in no way stabilized. For example, Figure 2 illustrates the shape of the island in 1942. Born of the sea, the island continues to bow to the sea and change as it dictates. Spits and bars are formed by sustained littoral drift and frequently are partly or completely eroded by heavy seas. In other words, a barrier island is forever changing its shape and size. Occasionally one will retain its general size and shape as it migrates along the coast.

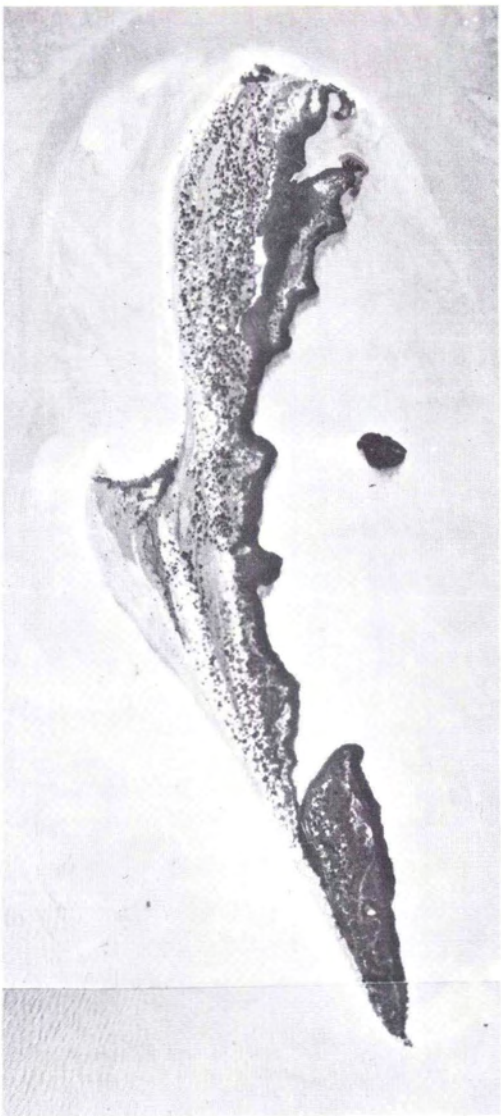

FIG. 2. Honeymoon Island in 1942.

The movement of the island did not concern the seller, but the size did. He was insistent that it be surveyed at its largest size. After months of discussions between lawyers and earth scientists on both sides, a new survey of the Island "as is" was agreed. It was further agreed that a precision survey would be made by a Registered Land Surveyor, delineating the exact acreage as measured on the meander line which separates the private upland from the seaward public lands.

The island is very low in elevation. The highest point is only about 5 ft above mean

sea level. A large area is inundated by Spring Tides* and other abnormal high waters. One segment of several acres is only one-quarter foot higher than the Mean High Water elevation. Although low marsh, this land meets the criteria of upland and is included in measurable acreage.

Mean High Water (MHW)

Probably due to the man-made causeway fill to the island, the rises and falls of the sea tides were altered from normal actions. This change became very important, because the Florida Law† clearly declares that the seaward limits of upland lands shall be at, and measured along, the meander of the Mean High Water line. This line (boundary) separates private ownership and state (public) ownership.

The MHW line is the average of all high tides§ over a complete epoch, a period of nearly 19 years. The tides' rise and fall are influenced by the moon, the sun, combinations of the two, the gyrations of the earth, storms at sea, the calms, and other factors, some of which may appear minor. (For example, a wind will pile water up or push it away, depending on the direction blown. A squall will lower the air pressure and raise the sea level. Sometimes weather phenomena will keep the seas high or low for days.)

Many tides normally rise and fall only a foot or so while others range up to 20 or more feet. Since 1830, the U.S. Coast and Geodetic Survey, now the National Ocean Survey (NOS) of the National Oceanic and Atmospheric Administration (NOAA), has closely monitored Atlantic, Pacific, and Gulf tidal actions and published predictions of high and low tides. These tide tables are readily available for nearly every port and cove in America. The basic historical data of tidal action are obtained by gauge readings in hours and minutes showing the exact level of water at the rise and fall of the sea.

The surveyor (now deceased) of Honeymoon Island who was originally employed by the seller, indicated on his property plat of the island that he had used a Mean High Water value of plus one foot* as obtained from a long-term tide gauge which was located on a dock in Dunedin. Due to the location and to the distance between the gauge and the island, some State people questioned the surveyor's decision to project the MHW elevation an appreciable distance.

These questions clouded the accuracy of the survey. Because the island is very low, a few tenths' vertical difference will vary the acreage considerably. At an appraised value of over $60,000 per acre, a tolerable survey error (accuracy) on a normal job could make a substantial dollar difference.[3]

The history of past events made it readily apparent that detailed tidal data were necessary before a confirmation survey could be made. After on-site review, the Chief, Bureau of Coastal and Land Boundaries, Florida Department of Natural Resources (DNR), decided that three short-range gauges should be installed on the Island to determine the exact elevation of the Mean High Water line. He selected a site on the Gulf side near the filled area, one near the northern tip of the island, and one on the bay side near the fill.

For 90 days these three gauges recorded every vertical movement of the tidal water. National Ocean Survey Tidal Scientists then correlated these readings with Primary Tidal Stations in Dunedin, Clearwater, and St. Petersburg. NOS next certified the elevations of Tidal Bench Marks (TBM) on the island. These TBM's were then connected to the National Geodetic Vertical Datum. This gave elevations of 1.29 ft on the bay side of the island, 1.27 ft near the northern tip, and 1.04 ft on the south. (Later an error of 0.14 ft was found which raised the south BM to read 1.18 ft.)

In September, 1975 the owner agreed to submit a second meander property survey by a professional land surveyor, based on the new MHW values. He further agreed to the State's making an independent survey, "...by other and different techniques...." This check was not intended to oversee the performance of a professional. Rather, in view of high land value and weeks of news publicity, State officials thought it a necessary safeguard of public monies involved.

State Topo Office (STO)

Over the past several years the State of Florida has been confronted with needs for factual information regarding physical land dimensions/quantities. The Administrative Branch and the Legislative Branch agreed

* Derived from "springing" or lively waters. These tides have the greatest variations, being associated with the full and new moons.

† The law defining the seaward boundary between the private and public domain dates back to British King Charles II. He directed his Lord Chief Justice, Sir Matthew Hale, to define such a boundary. His findings are now followed in many countries throughout the world.

§ Storm tides and similar spikes are discounted, as are extraordinary lows.

* NOS records show this MHW value as 1.17 ft.

to have the Department of Transportation's State Topographic Office perform those unique projects not readily adaptable to the private sector. And, for that work which can be conveniently performed by the latter, the STO advises the respective agencies and acts on their behalf in preparing specifications, etc.

STO was asked to photograph Honeymoon Island and to furnish the acreage of the island. The acreage was to be divided into seven tracts. Tracts two through six were to be as nearly 50 acres as possible. The total cost of the survey by STO was estimated to be about $6,500 and was to be completed in three months. This estimate was given in September, 1975. (The owner never disclosed his cost for the ground survey. He indicated it was considerably more.)

The STO's scheme was to place about 12 aerial targets on the island; to photograph* it at tide stage of MHW, and with an *XYZ* digitized stereoplotter to digitize the meander of the MHW line. (The stereoplotter was selected over the monocomparator because five such instruments were available if needed.) An electronic computer would convert the *XY* coordinates to a perimeter/acreage survey. The surveyor for the owner began his work in September. The agreement called for the survey and the acreage to be submitted for review and approval prior to Cabinet† concurrence at its regular meeting on December 23. The STO was instructed to follow the same schedule.

The first hint of problems for STO was the discovery that only two MHW tides were predicted during daylight photographic hours in the remaining weeks of 1975, at 12:20 P.M. on November 4 and 12:52 P.M. on November 5.

Photogrammetric Survey

The plan was to photograph the island as the sea rose toward high tide level at the instant it reached the Mean High Water elevation. NOS has done this many times on regular coastal mapping and achieved good results simply because the color infrared film readily separates the wet bottoms and the dry upland. The only problems awaiting on the Honeymoon project were the possibility of cloudy weather and/or rough seas. This would mean loss of conclusions within the time frame.

The original surveyor had established a baseline. STO aerial targets were placed over several of these markers and at additional locations for the photogrammetric survey. A field crew of the STO Geodetic Branch ran a high-order horizontal traverse connecting these targets with a monument previously established by the National Geodetic Survey.

Because on the bay side the limit of the MHW is within the cover of the mangroves, lines in the brush had to be cut inward from the bay in order to photograph the water at the proper stage. The surveyor was not confronted with preparing as wide a cut. However, both photogrammetrist and surveyor had to locate the exact Mean High Water line at many places throughout the mangroves.

This technique involves expanding the tidal datum throughout the entire vegetated areas by the use of interpolated water elevations. (Apparently the surveyor had to perform this task also on the beach areas.) An Interpolated Water Elevation (IWE) point is the MHW elevation determined by interpolation from established datums at two adjacent tide stations.[4]

Once the elevations of MHW were established at each of these many points, the line of MHW could be continuously established.*† Ground surveys were later meandered to these points. The photogrammetrists measured the distances to photo-identifiable points upland of the mangroves.

Several other techniques for determining the MHW line are acceptable and may have been used by the surveyor. Except for obtaining the coordinates of the base stations, there were no contacts by STO personnel with the surveyor in order to avoid accusations of collusion.

It was necessary to visit the island and set key targets. In addition to the survey, control targets were also set at MHW elevation along the water's edge. The photogrammetrist's attempts to observe and record on the ground the MHW in the mangroves during the first visit was an absolute failure. A storm at sea kept the tide-level completely

* With infrared film which readily delineates land from water.

† Florida has a form of State Government in which the Governor and six independently elected officials of prime State offices sit periodically to conduct state business.

* The IWE system is preferred because the tides do not rise and fall at the same instant. Also, the Mean High Water line is not a true contour. Its elevations differ from a few hundredths of feet upward.

† Post Script: Captain Jack E. Guth reported in early 1978 that another method for determining water elevations at isolated points between known elevations has been developed. This is known as Extrapolating Water Elevations (EWE). It and the IWE are currently being evaluated.

above the MHW elevation for several tidal cycles. Later the sea was more cooperative, yielding low tides, high tides, and MHW elevations.

The water on the Gulf side is absolutely clear. The bay side is slightly discolored. NOS photo experts recommended color infrared (CIR) film with a 520 nm filter. This should clearly image the wet areas, the yet unwashed dry beach sand, and cut lines in the mangroves.

Plans were for the Coastal Mapping Chief of the Florida Department of Natural Resources (DNR) to fly with the STO photo crew to Clearwater the morning of November 4. He was to place several targets on the water's edge at MHW elevation and to radio the photo crew exactly when the tide staff indicated the required Mean High Water position. This was predicted to be at 12:20 P.M.

Arriving on the island at about 11:00 A.M., he found the tide rising rapidly and nearing the desired elevation. Further compounding the problem, the sea was more active than anticipated. Luckily, the photo crew was already in the air near the site. The island was photographed at 11:32, MHW elevation. As a safeguard, the cameraman had loaded a second magazine with black-and-white infrared film. After the initial flight, he switched magazines and, using a 700 nm filter, rephotographed the island ten minutes later. The entire routine was repeated the following day at the exact time of MHW tide level, and with calmer seas.

Photography was made at 2 400 ft altitude with a 6 in. focal length Zeiss camera at 80 percent end lap. The color infrared was processed to film positives. On visual examination, it was virtually impossible to see the water's edge due to the extreme whiteness of the beach and transparency of the water. Detail in the cut lines was dark and equally vague. A call to NOS for advice resulted in a recommendation that the aerial film be sliced in order that we could see detail which had been recorded on the emulsion at wavelengths undetectable* by the human eye. Slicing in this instance involved making duplicate positive glass plates in black-and-white which better delineated the desired detail. Examples of the aerial photography are shown in Figure 3.

(As a failsafe, a level crew was sent to the island. If the water's edge could not be seen in the stereoplotters, a meander at known elevations could be run.)

New film positives, photographically sliced to reveal imagery not previously visible, were ready for the plotters on November 24. The delivery deadline was trimmed to December 19 so that Cabinet staff aides could review the surveys prior to action by the hierarchy.

The horizontal control was plotted on 1 in. = 80 ft manuscript sheets. Stereo operation began December 8. After experimenting with the film, the operators concluded that they could see better using one sliced diapositive and one CIR positive. (Alternate exposures at 60 percent forwardlap were used.)

Implementation called for absolute orientation of the stereo model, drawing a few of the more prominent trails, drawing the meander of the MHW shore outline of the mangrove both seaward and inward, and recording hundreds of readings at the water's edge. On the first model, one targeted control point was found to be 170 ft in error. Later, two others were also in error and unuseable. Fully two days' time were lost in clarifying the discrepancy. It was concluded that three targets were apparently moved by beachcombers or vandals. Additional targets and pass points allowed the work to proceed.

Every change in direction in the Mean High Water line along the shore was ticked and numbered. After numbering, all meander points were reconfirmed in the PG-2* plotters and their *XY* coordinates keypunched by the Dell Foster Quantizers. All work was reviewed in its entirety by a supervisor.

Due to the short deadline, several stereoplotters were assigned to the project. To simplify electronic coding and eliminate duplicate point numbering, each point was assigned a four digit numbering sequence.

When all stereo work was completed, the *XY* values were converted to calls, bearings, and distances, the acreage was determined, and a computer plot was made of Honeymoon Island. This was delivered on December 17. The surveyor delivered his work shortly afterwards. Portions of the surveyor's plat and the photogrammetric plot are shown in Figure 4.

Reliability of a ground survey is evaluated by a ratio of exactness to distance surveyed.†

* The human eye can detect reflected imagery between wavelengths of 0.4 and 0.7 nm of the electromagnetic energy spectrum. Infrared photographic film increases this recording of lightwave lengths to 1 nm (0.3 to 1.0).

* The Kern PG-2 was designed principally for precise contouring. We had previously evaluated it fully and were confident of its capabilities for accurate positioning.

† Geodetic survey results also include an elevation of the angle closure.

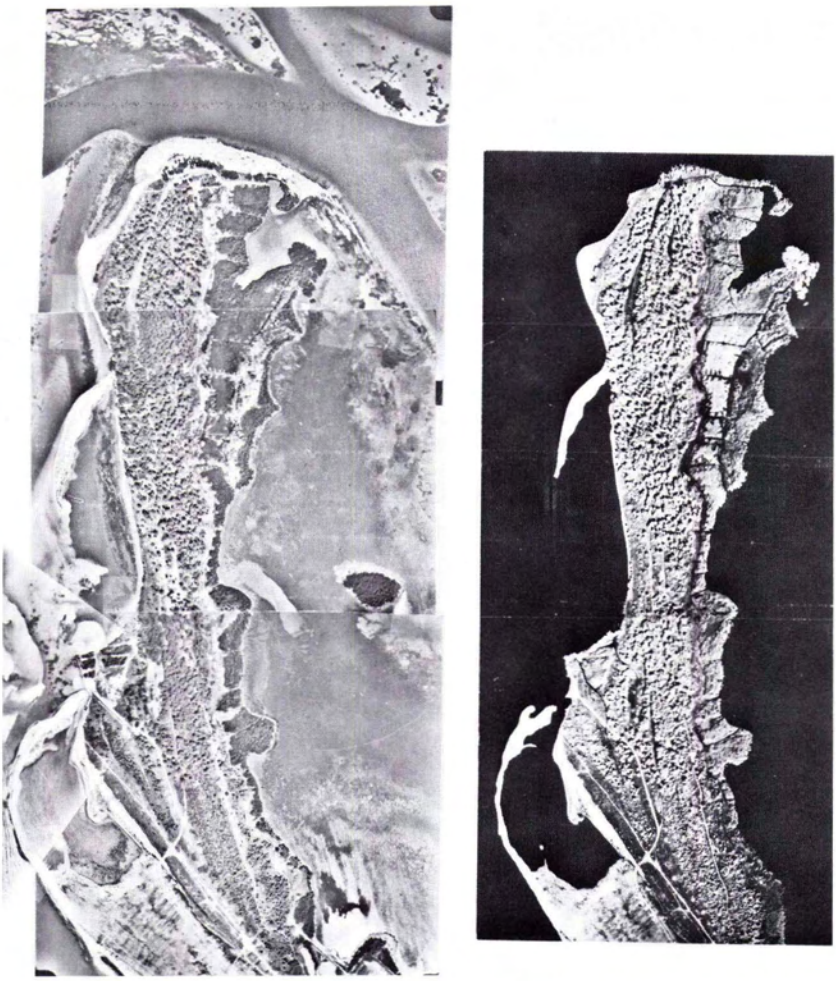

FIG. 3. The northern part of Honeymoon Island in 1975 as photographed with panchromatic film and black-and-white infrared film.

For example a survey closure of 1:10 000 simply means a 1 ft error in 10 000 feet measured. The greater the distance the larger the probable distance error. Distances and directions between nearby surveyed points are generally very accurate.

A completely different approach is necessary to evaluate the accuracy of positioning for points determined by photogrammetric methods. A position or floating error commonly referred to as RMS is always present.

Previous field research had given us the probability of this RMS of photography of several scales. In the Honeymoon project, we estimated that the accuracy of a point would float horizontally within a circle slightly larger than a saucer. But more importantly, the so-called error would oscillate throughout the entire saucer. It would not be confined to any specific area. Consequently, if enough meandered positions were taken, the points would counterbalance each other and the RMS would be reduced to nearly zero.

Our research had shown that, when several hundred points are to be measured, an accuracy gain was not noticeable at a lower flight height. For example, at 1 200 ft additional restraints would include: More turbulent air, more models, more flights, more control, plus a slower airspeed for the 80 percent cycling.

FINAL RESULTS

The acreages as determined by the STO and the private land surveyor were

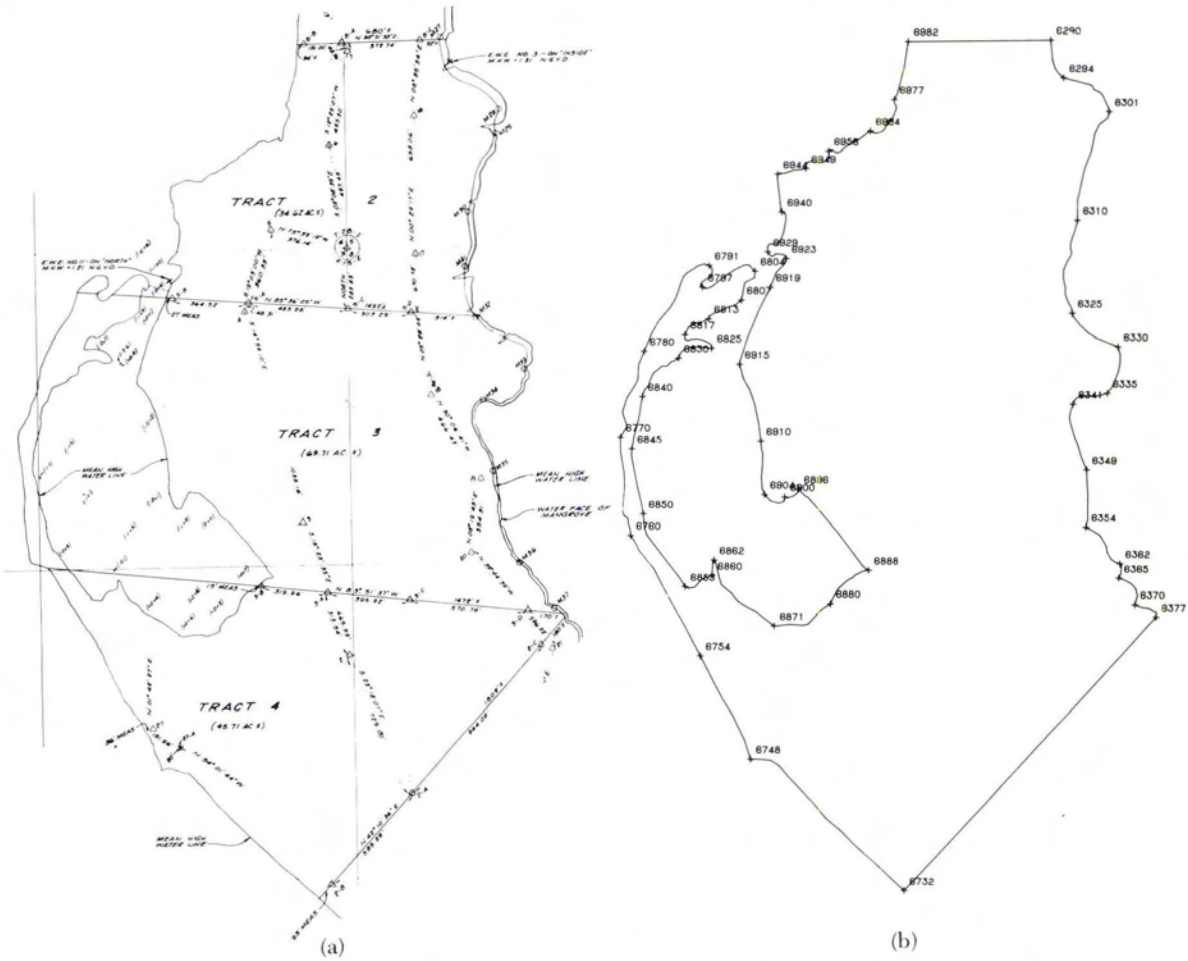

FIG. 4. A portion of the Land Surveyor's plat (a) and of the photogrammetric plot (b).

Tract	Photogrammetry	Surveyed	Difference
1	113.21	113.56	0.35
2	49.93	50.02	0.09
3	49.71	50.02	0.31
4	49.75	50.02	0.27
5	49.22	50.02	0.80
6	49.84	50.02	0.18
7	21.68	21.90	0.22
All*	383.34	385.56	2.22

The STO arbitrarily selected previously established meander points to obtain as nearly 50 acres as possible in tracts two through six. (New meander points could easily have been developed to give exactly 50 acres. A state official indicated probable suspicion of such exactness. Consequently, we chose approximations from prior selected meander points.) We do not know how the surveyor arrived at his exact quantity of 50.02.

* Does not include 20 acres of the island held back from the sale.

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