THE FEASIBILITY OF USING DIGITALLY PROCESSED LANDSAT DATA TO DETERMINE COASTAL INUNDATION FREQUENCY

by

Robert W. Baumgardner, Jr.

Assisted by

Marcie D. Machenberg

Bureau of Economic Geology
The University of Texas at Austin
Austin, Texas 78712

Prepared for the
General Land Office of Texas
TDWR/TNRIS IAC No. (80-81)-1935

July 1981

Table of Contents

List of Figures

List of Tables

The Feasibility of Using Digitally Processed Landsat Data to Determine Coastal Inundation Frequency

I. Introduction

The purpose of this feasibility study was to determine if Landsat data could be used to determine the level and frequency of inundation of Texas' coastal areas. The presence of seawater is an important criterion in the legal definition of a coastal wetland. Seawater is defined by the Coastal Wetland Acquisition Act 33.231, Subchapter G, as water concentration of 1/20 of one percent or more by weight of total dissolved inorganic salts. To adequately define a coastal wetland, it is necessary to know what coastal areas are covered by seawater at times other than, and in addition to, during storms or hurricanes.

This preliminary research effort was limited to the use of Landsat computer compatible tapes (CCTs) on hand at the Texas Natural Resources Information System (TNRIS) for which Band 5 transparencies or prints were also available. Two study areas (fig. 1) were selected that had different land/water boundaries on Landsat images from different dates (figs. 2, 3).

The Detection and Mapping (DAM) computer program was used to extract the land/water boundary for each Landsat scene. The land/water boundaries for each study area were then overlain using a flatbed plotter and the computer graphics capabilities of the Geographic Information Subsystem (GIS) of TNRIS.

Water level data from tide gauges near the study areas were used to determine the elevation of the water surface at the time of the satellite overpass. The frequency of recurrence of that water level was calculated on the basis of tide gauge data for that calendar year (Section III).

No field work was conducted to determine the salinity of the water covering any part of the study area. Consequently, these data cannot be used to define any given area as a coastal wetland because such a definition is concerned specifically with inundation by seawater. However, these results do show that Landsat data can be used to delineate inundated areas repetitively. This is especially useful where the inundated areas are inaccessible.

II. Analysis of Landsat Data

Landsat data were analyzed with the Detection and Mapping (DAM) software package which detects surface water. The boundaries between water bodies and adjacent lands were then extracted. The accuracy of these boundaries is limited by two factors: (1) the resolution of the Landsat multispectral scanner, and (2) the accuracy of the control network generated for the Landsat scene being analyzed.

The resolution of the Landsat 2 and 3 satellites is determined by the size of the instantaneous field of view (IFOV) of the multispectral scanners. The IFOV of the scanners is 79 m x 79 m (259 ft x 259 ft). There is some sampling overlap in the cross-track direction, as the scanners collect data (U.S. Geological Survey, 1979), but for purposes of this study we will consider the maximum dimension of the nominal picture element (pixel) (79 m) to be the limit of Landsat data resolution.

To accurately locate a feature on a Landsat image requires a network of ground control points from the image. This network should meet the following criteria (National Aeronautics and Space Administration, 1973):

1. The control points must be distributed uniformly within the scene.
2. The features used for control must be stable over time.
3. The point used for control must be well-defined in the scanner data and on reliable maps.
4. Scanner-oriented coordinates of control points must be precisely measured.

5. Geographic coordinates of control points must be precisely measured on reliable maps.
6. The control network must be internally consistent, as demonstrated by a mathematical adjustment yielding minimal residual errors.

For the four Landsat scenes used in this study, a control network was generated using at least seven control points (table 1). The maximum acceptable root mean square (RMS) error, the average of individual residual errors for each control point, was defined as 125 m (410 ft) (R. Aanstoos, TNRIS, personal communication, June 10, 1981). Three of the four control networks used in this study have RMS errors substantially smaller than that (table 1).

The number of ground control points alone does not determine the accuracy of the control network. Quality of control points is also important, as indicated by criteria 3-5 (p. 2-3). A control network generated for a Landsat scene not used in this study had 12 control points of high quality and an RMS error of 29 m (95 ft) (R. Aanstoos, TNRIS, personal communication, June 10, 1981). The quality of a control point is, in practice, a function of the amount of time available to select points carefully. No data are available to indicate how many data points of what degree of accuracy are necessary to produce a network with a given RMS error.

Figures 2 and 3 show, at reduced scale, the water levels extracted from each image and overlaid on the same base map coordinates. These are two examples chosen from eight original maps (fig. 1). The original maps were generated at a scale of 1:24,000 to be overlaid on U.S. Geological Survey 7.5-minute topographic maps.

The difference in the area inundated on each date was measured on the original maps of figures 2 and 3 using a compensating polar planimeter. The area covered by water only on the low-water image was subtracted from the area covered by water only on the high-water image. On figure 2, the area inundated at high water exceeded the area covered at low water by 5.29 km^2 (2.04 mi^2). The trapezoidal area below the center of the map was not measured because it is a man-made pond. On figure 3 the difference in area inundated was 4.55 km^2 (1.78 mi^2). These values are somewhat inaccurate for reasons discussed below.

When the land/water boundary maps are overlaid on the topographic maps the misfit between them is as much as 4 mm (0.16 in). At a scale of 1:24,000 this is an error of 96 m (320 ft). Because the amount and direction of the error is not the same on all maps of each study area, it is not possible to correct it by shifting the land/water boundary map relative to the topographic base map. The error is a product of the inherently low (79 m) resolution of the Landsat data and the process of control network production. The flatbed plotter used to produce the maps has a resolution of 0.05 mm (0.002 in) (Mark Porter, Texas Dept. Water Resources, personal communication, July 8, 1981). An error in resolution of 0.05 mm (0.002 in) is only 1.25% of the maximum error detected, and therefore the plotter does not contribute significantly to the largest error detected.

III. Analysis of Tide Gauge Data

Water level data from the gauges in the study area (fig. 1) were used to determine (1) tide level at the time of satellite overpass, and (2) number of days during the year that the tide level at overpass time was equaled or exceeded. For example, at tide gauge no. 1 (fig. 1), the water level was 0.436 m (1.43 ft) above mean sea level on 8 May 1973 at the time of satellite overpass (10:26 am CST) (table 2). Gauge no. 1 has a total available record of 338 days for 1973. On 79% of those days, the water level rose as high or higher than 0.436 m (1.43 ft) above mean sea level (table 2).

The number of days of record for the years of the images ranges from 290 to 364 (table 2). These records are too short to use the percent figures (table 2) as accurate measures of frequency of inundation for any part of the study areas. However, for purposes of this study, the method has proven feasible. To compute an accurate frequency of inundation it will be necessary to examine tide gauge records for as long a period as possible.

An accurate delineation of the water level at a given inundation frequency will require more Landsat images with different water levels and data from all available tide gauges. Table 2 reveals that the same water level at different gauges may be exceeded by different amounts, as at gauges 4 and 5 for 1 October 1978. Such variation is commonly due to the position of a tide gauge in relation to bottom bathymetry, shorelines, occurrence of wind set-up and set-down, and other local factors.

IV. Conclusions

Landsat data can be useful for repetitive delineation of land/water boundaries. The accuracy of the water levels in figures 2 and 3 is limited by the resolution of the original Landsat data and the accuracy of the control networks for both images. When the original land/water boundary maps at a scale of 1:24,000 are overlaid on the U.S. Geological Survey topographic maps, it is apparent that as much as 4 mm (0.16 in), corresponding to a distance of 96 m (320 ft), of error exists in the land/water boundary maps. No data are available to determine how much more accurate these maps can be. The accuracy of the boundaries probably cannot be better than $\pm$ 79 m (259 ft), the limit of resolution of the Landsat data.

The percent of time the water level at overpass time is exceeded (table 2) is not a true inundation frequency. More water level data and Landsat images must be analyzed to calculate an accurate and statistically valid frequency of inundation. To be useful as a method of defining coastal wetlands the Landsat data must be supplemented by collection of water samples in the field to determine the salinity of the water in the study area.

REFERENCES

National Aeronautics and Space Administration, 1973, Procedures manual for detection and location of surface water using ERTS-1 multispectral scanner data, v. 3, control network establishment: Science and Applications Directorate, Lyndon B. Johnson Space Center, p. 1/1-3/26.

U. S. Department of Commerce, 1978, Local climatological data, Corpus Christi, Texas: Asheville, N. C., National Climatic Center.

U. S. Geological Survey, 1979, Landsat data users handbook, Section 4, Payload: p. 4/1-4/20.

FIGURE CAPTIONS

1. Location map of study areas. Tide gauge numbers refer to table 2. U.S. Geological Survey topographic maps identified as follows: (A) Kamey (B) Point Comfort (C) Port Lavaca West (D) Port Lavaca East (E) Odem (F) Taft (G) Annaville (H) Corpus Christi.

2. Land/water boundary map for Point Comfort 7.5-minute topographic map. The trapezoidal area below and to the right of center of map is a man-made pond, filled with water after May 8, 1973.

3. Land/water boundary map for Corpus Christi 7.5-minute topographic map.

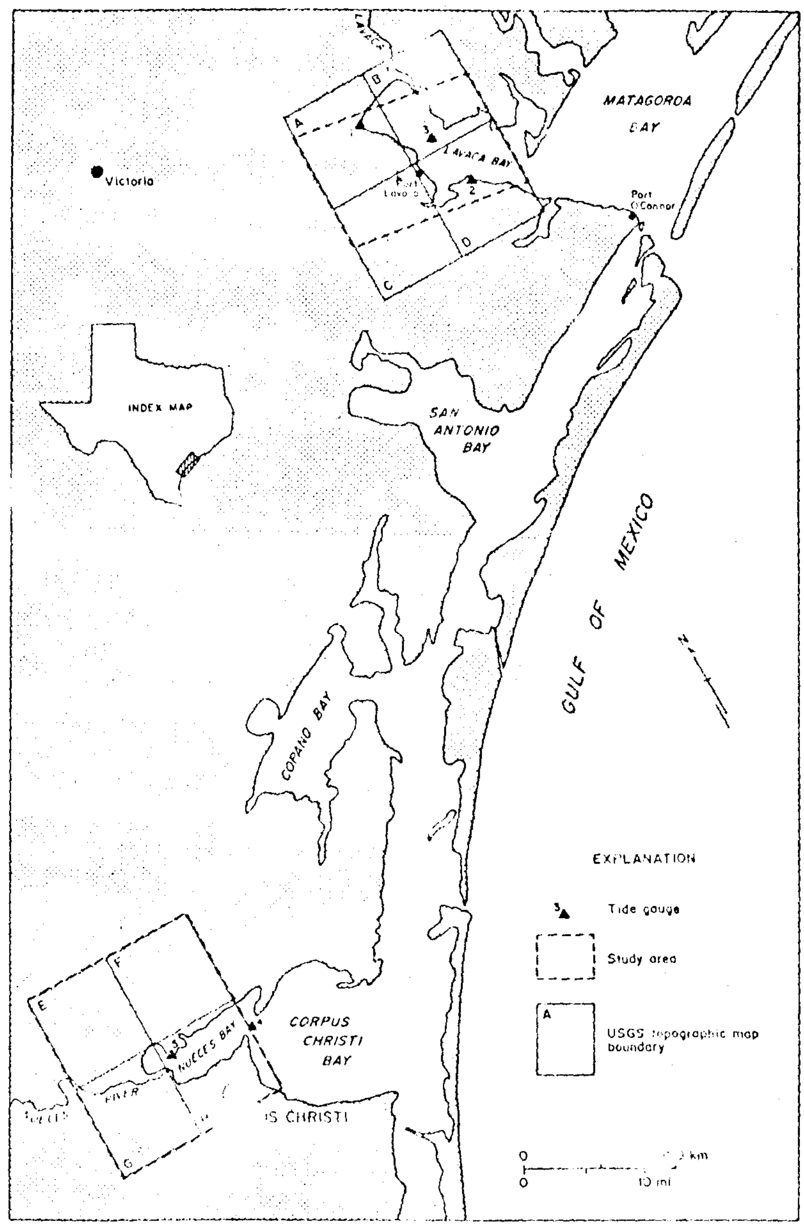
Table 1. Landsat scenes and control network specifications used in this study. Note that there is no correlation between the number of control points and the magnitude of the RMS error.

Landsat scene ID number	Scene date	Study area	Number of control points	RMS error (m)	Date control network produced
1289-16261	8 May 73	Lavaca Bay	8	111.0	19 Mar 81
2375-16112	1 Feb 76	Lavaca Bay	9	57.5	30 Dec 80
1146-16320	16 Dec 72	Nueces Bay	7	82.5	pre Nov 79
21348-16030	1 Oct 78	Nueces Bay	13	68.0	pre Nov 79

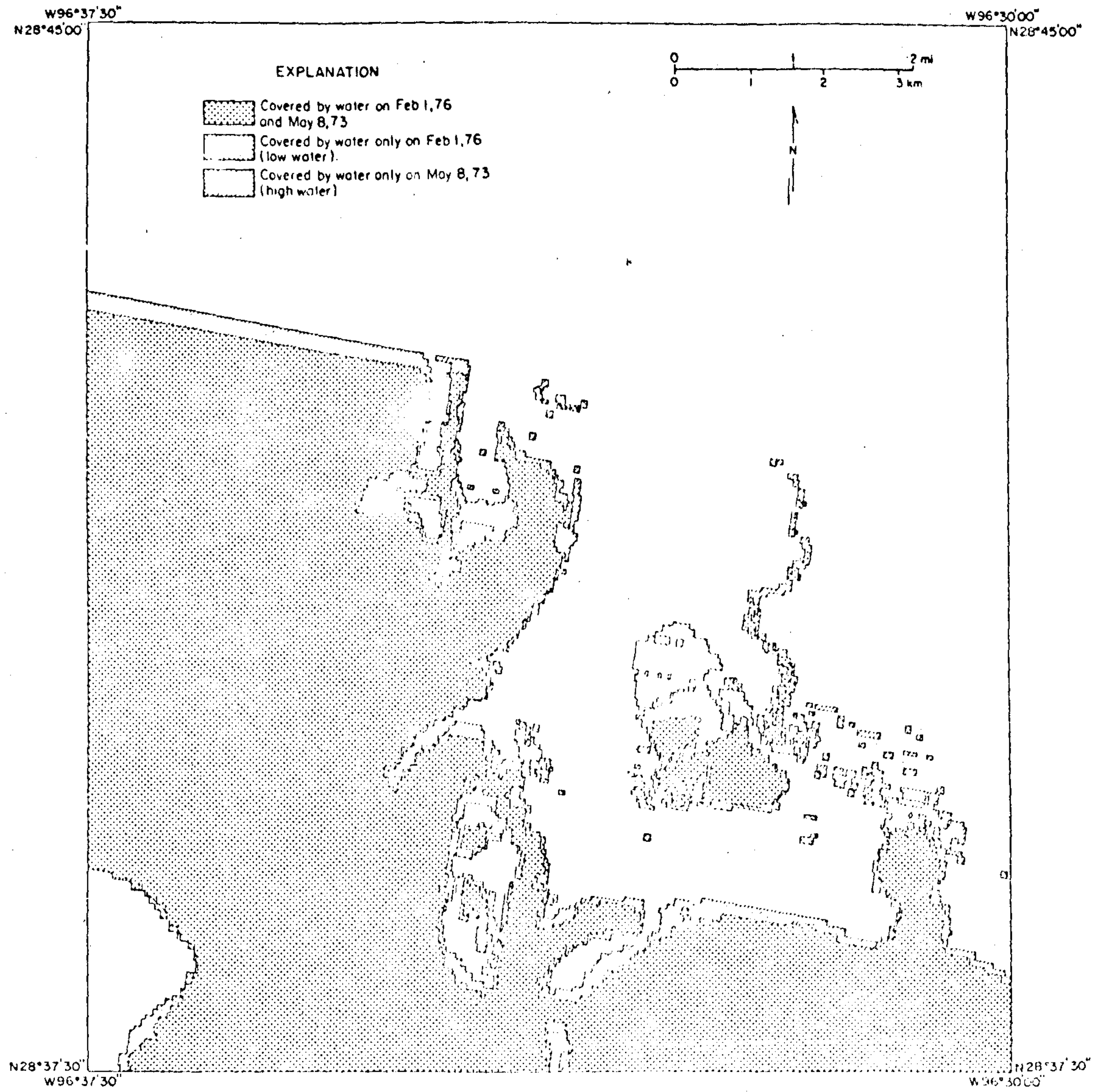
Table 2. Water level data from tide gauges in the study areas. Datum is mean sea level. Gauge numbers refer to figure 1. High water levels on 1 Oct 78 were not increased by wind action. Winds for the previous 32 hours were offshore, with velocities between 2.1 and 4.6 m/sec (4.7 and 10.3 mph) (U.S. Department of Commerce, 1978).

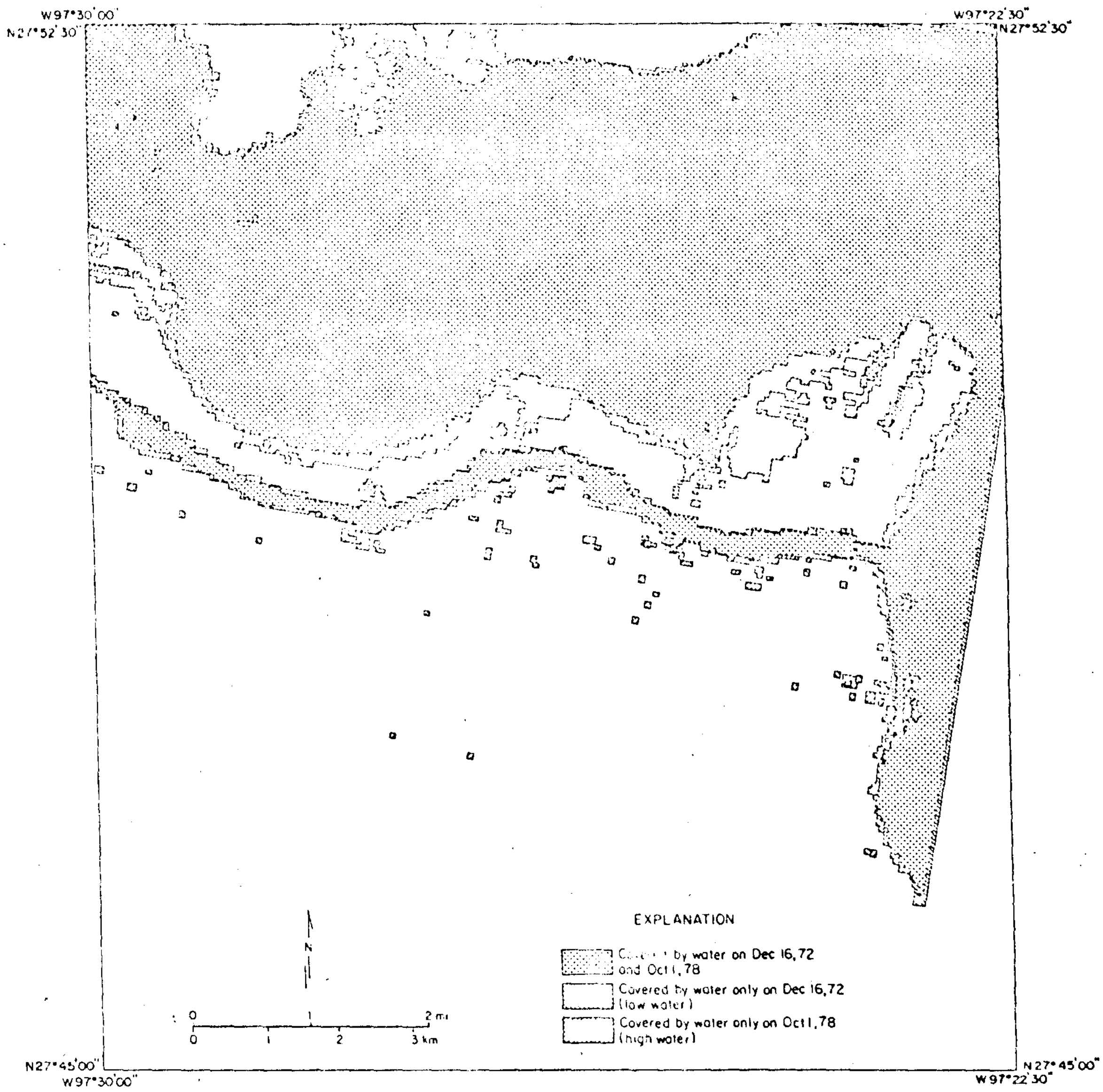
Study area	Date	Gauge name	Gauge no. this study	Water level at overpass (m)	Length of record (days)*	Percent of days water level equaled or exceeded
Lavaca Bay	8 May 73	6-mile-Rd. Co. Park	1	+0.436	338	79
	8 May 73	Magnolia Beach	2	+0.354	335	68
	1 Feb 76	6-mile-Rd. Co. Park	1	-0.229	364	100
	1 Feb 76	Highway 35 bridge	3	-0.223	351	100
Nueces Bay	16 Dec 72	Highway 181 bridge	4	+0.061	346	100
	1 Oct 78	Highway 181 bridge	4	+0.869	332	24
	1 Oct 78	Phillips well #5	5	+0.869	290	36

*In the same calendar year as Landsat overpass.



MATAGORDA
BAY
Victoria
LAVACA BAY
Port
O'Connor
INDEX MAP
SAN
ANTONIO
BAY
GULF OF MEXICO
COPANO BAY
EXPLANATION
Tide gauge
Study area
USGS topographic map boundary
CORPUS
CHRISTI
BAY
NUECES BAY
10 mi


W96°37'30"
N28°45'00"
W96°30'00"
N28°45'00"
EXPLANATION
Covered by water on Feb 1,76 and May 8,73
Covered by water only on Feb 1,76 (low water).
Covered by water only on May 8,73 (high water)
0 1 2 mi
0 1 2 3 km
N
N28°37'30"
W96°37'30"
N28°37'30"
W96°30'00"


W97°30'00"
N27°52'30"
W97°22'30"
N27°52'30"
N
0 1 2 mi
0 1 2 3 km
EXPLANATION
by water on Dec 16,72 and Oct 1,78
Covered by water only on Dec 16,72 (low water)
Covered by water only on Oct 1,78 (high water)
N27°45'00"
W97°30'00"
N27°45'00"
W97°22'30"