DEPTH MEASUREMENT AND BOTTOM CLASSIFICATION OF LAGUNA MADRE, TEXAS

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Prepared for

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1.0 INTRODUCTION

The US Army Corps of Engineers (USACE) has a requirement to map the water depth and bottom type in Laguna Madre, Texas, a coastal lagoon. Detailed bathymetric data are required to develop a hydrodynamic numerical model of Laguna Madre to aid in studying the environmental impact of dredging in this region Furthermore, delineation and identification of bottom type, including different types of sea grasses, in Laguna Madre are required to aid in studying the environmental impact of dredging in this region Figure 1 illustrates the location of Laguna Madre project area.

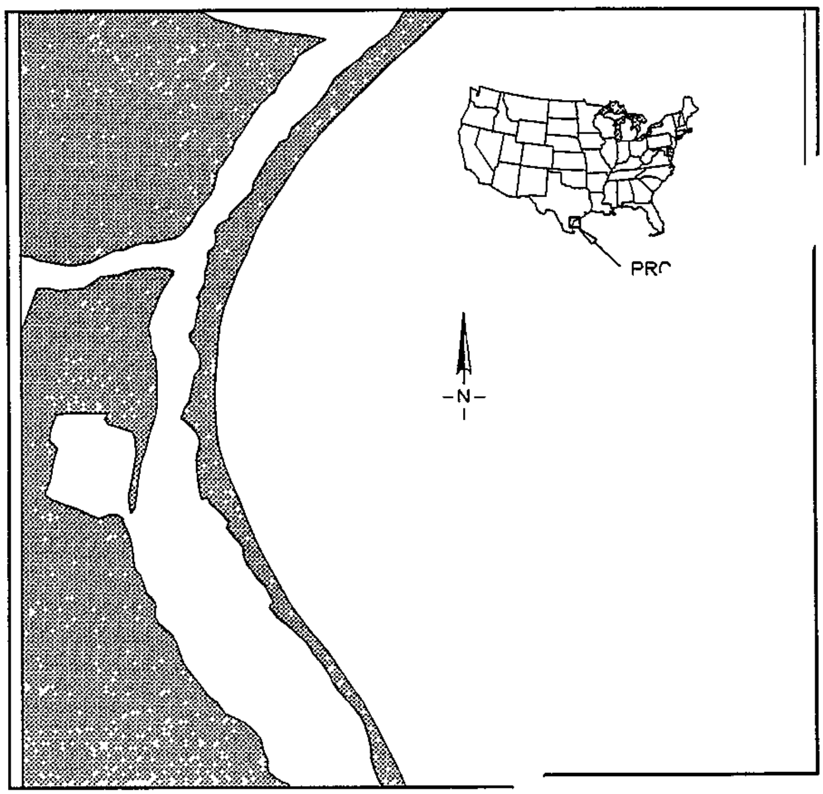


Figure 1. Location of the Laguna Madre project area

Included in this report is the results of the fusion of hyperspectral imagery with hydrographic survey data to produce accurate digital depths with positions and to identify and delineate different sea bottom types (sea grasses, sand, and mud) at Laguna Madre. During the investigation, two other useful products were identified and analyzed brown tide concentrations and land-water discrimination The brown tide is caused by a previously unknown micro algae with the proposed name of Aureoumbra lagunesis.

2.0 DATA COLLECTION

2.1 CASI Data

Hyperspectral data collection over Laguna Madre, Texas, began April 11, 1995. The hyperspectral imagery was collected by Borstad and Associates, Inc, using a system known as the Compact Airborne Spectrographic Imager (CASI) Hyperspectral imagery differs from earlier types of multispectral imagery in that it is comprised of a large number of spectral bands or spectral bands of small bandwidth, or both For imagery over Laguna Madre, the CASI used eleven bands, each of relatively small bandwidth, with which to collect environmental data Table 1 provides a list of the bands used for this study

The flight lines over Laguna Madre ranged in length from about 10-km to 15-km and about 2 km in width The CASI data were collected from an altitude of 3,350 m with a line spacing of about 1 km to allow a 50% overlap of the line-by-line imagery A total of 109 flight lines were flown covering a 1000 km^2 area

For ease of data collection and analysis, the project was subdivided into 11 areas, or blocks The block nomenclature and locations are illustrated in

Table 1 CASI band set used in Laguna Madre study

band #	wavelength (nm)
1	470 - 515
2	540 - 560
3	575 - 586
4	600 - 615
5	625 - 635
6	640 - 655
7	670 - 686
8	704 - 714
9	745 - 758
10	775 - 800
11	855 - 874

Figure 2 The blocks are sequentially labeled A through K moving southward from Corpus Christi Bay to Port Isabel

Global Positioning System (GPS) positioning was used to navigate the CASI imager. Differential GPS was utilized to improve positioning accuracy and yielded a horizontal accuracy of 5 m with respect to the aircraft position The aircraft velocity was approximately 100 knots, and with the nominal flight altitude of 3,350 m, the along-track pixel size was computed to be 4 03 m The cross-track pixel size was computed to 4 00 m. Since the platform altitude and velocity can vary somewhat during flight, the actual ground resolution may vary between 90% to 110% of these values. During geometric correction of the collected data, a resampling of the data occurs to a uniform 4 meter square pixel

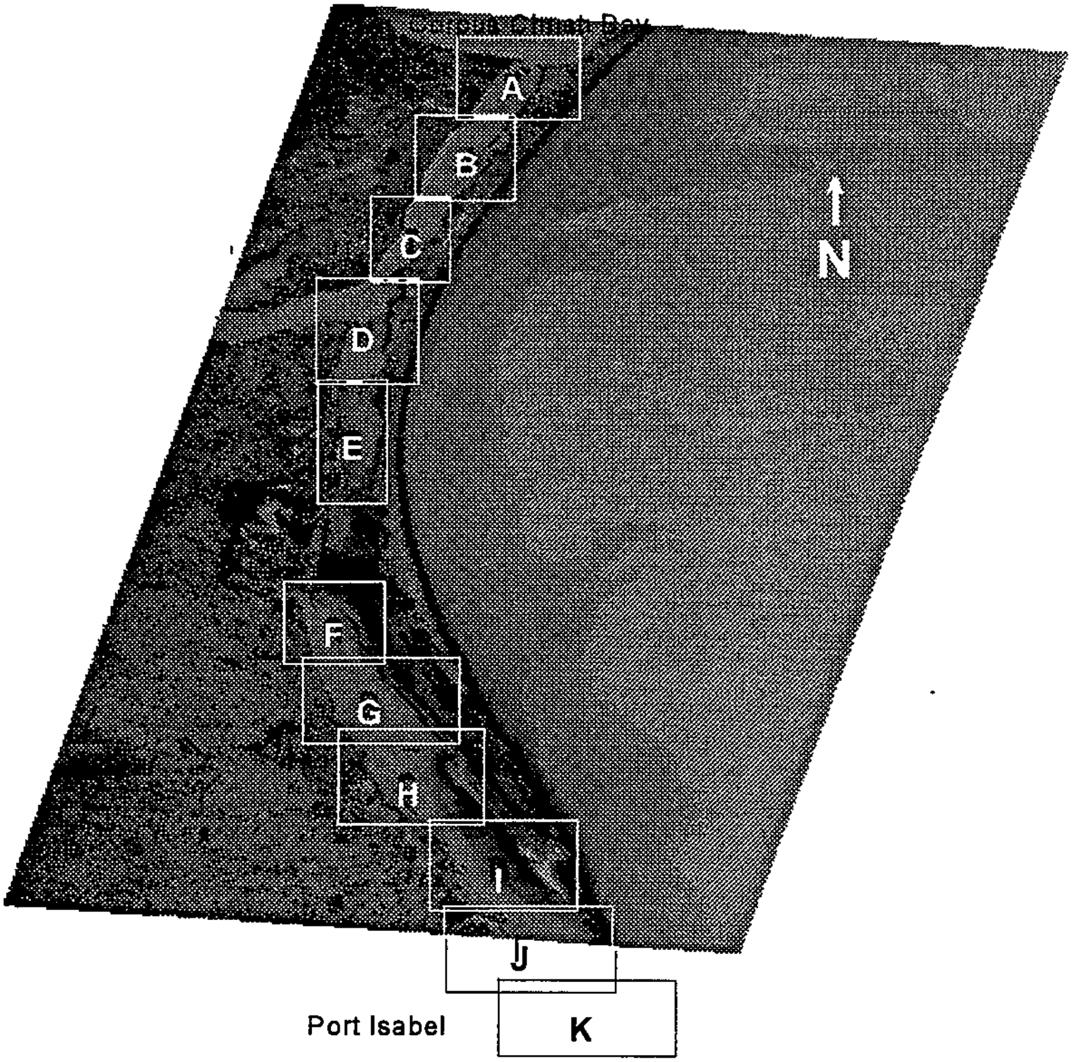


Figure 2 SPOT image of Laguna Madre showing the position of the CASI image blocks

Two primary environmental factors impacted the quality of the data received by the CASI over Laguna Madre. First, there was a persistent atmospheric haze layer that caused differential scattering and was dependent upon the angle and azimuth of the sun This scattering added additional position dependent light noise to the imagery of the water body itself and created difficulties in later processing and image interpretation

As seen in Figure 3, a photo taken from the cabin of the CASI aircraft, haze streamers and, at right, a tenuous haze blanket is evident Apparently, during this time of year, such atmospheric hazes are not uncommon along this area of the Texas coast

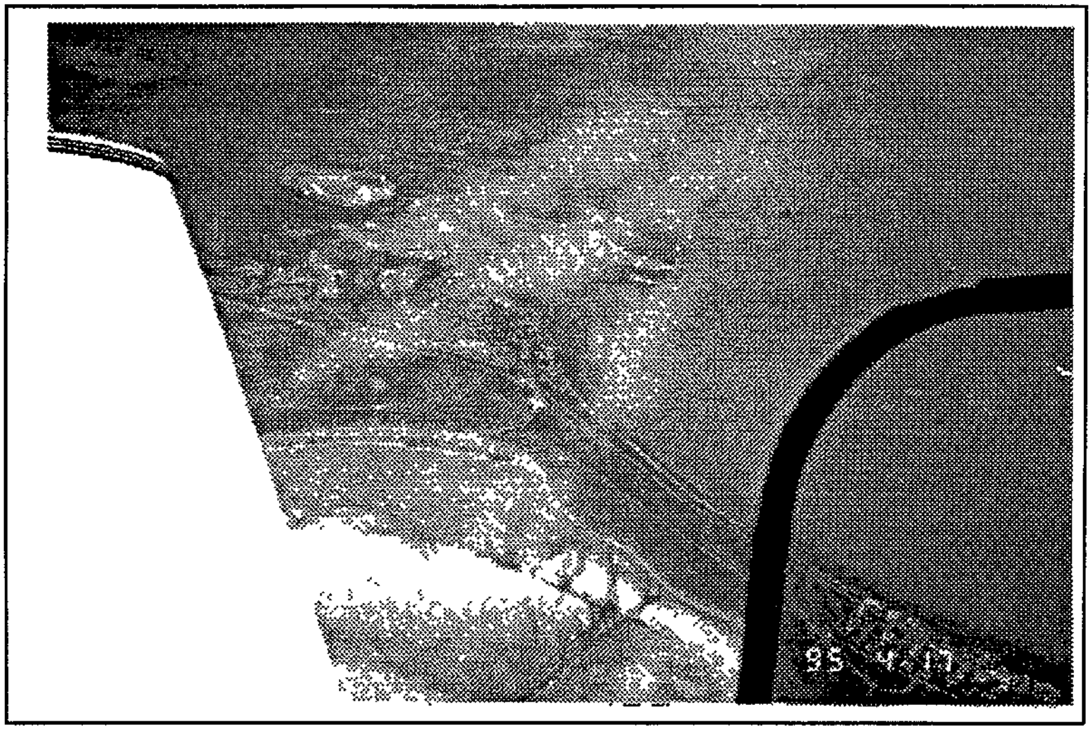


Figure 3 Atmospheric haze layers over Block K

Second, a resident brown tide bloom (Aureoumbra lagunesis) obscured the bottom in many places by adding increased attenuation to the water This obscuration often resulted in data loss which could not be compensated for during the post-processing procedures.

2.2 Calibration Data

Hydrographic survey data were acquired to calibrate the CASI imagery In particular, this depth information is necessary to allow further processing of the CASI imagery to extract bottom types for each pixel and to extract additional depth information. Hydrographic survey methods were employed to measure both deep and shallow water areas. Fathometer data were collected by John E Chance & Associates, Inc. using a single beam echosounder mounted on a survey boat. Shallow water areas were surveyed using an air boat with a sounding pole These data were collected on a 610 m grid minimum and corrected for local water level fluctuations Water level information collected during the survey operations were supplied by the Conrad Blucher Institute for correction of the data to Mean Lower Low Water (MLLW) Figure 4 illustrates collected bathymetry for Block I.

To Calibrate the CASI imagery for bottom classification in-situ, spectral measurements were made of different bottom types of interest (including several varieties of sea grass, sand, and mud) These measurements aided in establishing the spectral library needed to classify bottom type and optimum spectral bands

Additionally, the CASI data were adjusted to match SPOT (Systeme Probatoire pour l'Observation de la Terre) satellite imagery The SPOT imagery is a digital 'picture' of the earth's surface and is available at resolutions as fine as 10 m. These data were used to geo-correct the CASI imagery as necessary

Figure 4 Bathymetric data collected for Block I

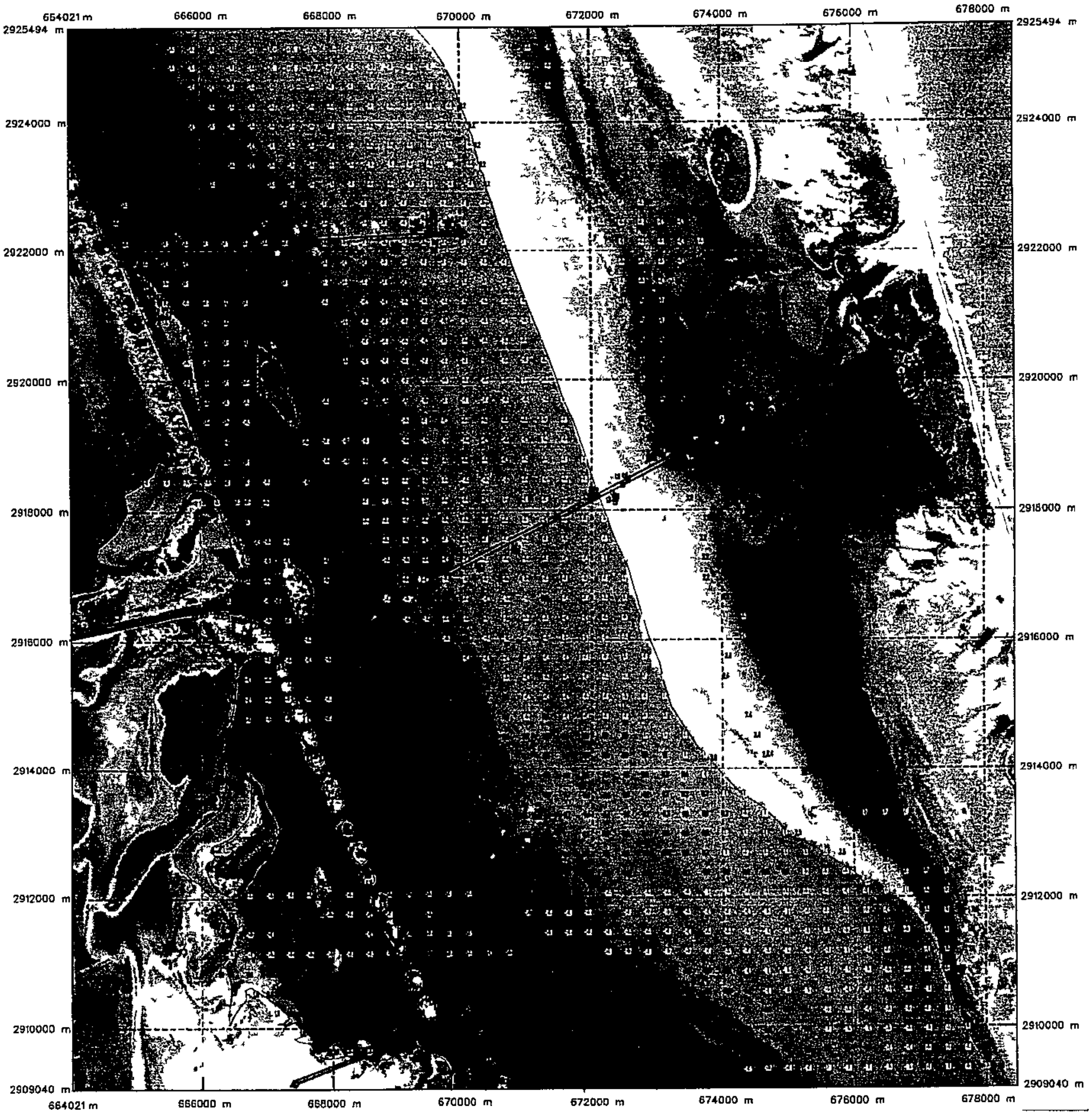


Figure 4. Collected bathymetry for Block I

3.0 ANALYSIS

Processing began with 16 bit individual flight lines that were calibrated to radiances for sensor altitude and then 'flattened' east to west Flattening was required to correct for the atmospheric scattering caused by the atmospheric haze layer present over Laguna Madre during data collection The scattering causes a cross-image brightness difference or 'tilt' that manifested itself in lines on the west of the image (most of the data flights were in the afternoon hours), being brighter than those on the east. Further, there was a north-south differential in lighting apparently caused by atmospheric scattering similar to that seen in the east-west differential. The fattening process acts to even out the brightness differences and without this step, the mosaic of a block of data would show strong 'seam' lines Such lines would make it almost impossible to draw meaningful conclusions concerning bottom type or water depth over the salient block.

The flattening step consisted of averaging the column radiances for a range of image lines which contained near-homogeneous spectral properties. An offset was computed for each column that provided flattening of the average radiance across the image, normalized to the radiance at solar nadir Further, for paired flight lines, a second order fit was made for series of pixel offsets across the image. After flattening, the CASI images were geo-corrected to SPOT imagery Normally, a second order geo-correction was required Since the SPOT scene did not cover the whole of the image area in the southern part of Laguna Madre, shoreline and road vectors were used to geo-correct the CASI imagery in that region.

Following the geo-correction process, color matching was implemented using a procedure specially devised for this project. The method involves defining the brightness difference between adjacent flight lines by subtracting the radiance values in one image from those in the overlap area of an adjacent flight line image. This was done on a pixel-by-pixel basis Using a polynomial fitting function, a fit was made based upon the along-track position Once the fit was determined, one flight line could be adjusted to match its pair This method, therefore, provides for real variations in illumination at the time of measurement Since it is important to match pixels correctly in the 50% overlap region, geo-correction must be done prior to this color matching technique. Following color matching, the flight lines were mosaiced together. In some block imagery, slight residual 'seams' in the final mosaic can still be seen Future cross-block normalization of some sort may eliminate these seams.

With the mosaics complete, brown tide and land-water discrimination block imagery products were first developed This allowed a land mask and brown tide mask to be applied to the block imagery that were used to compute bottom type and water depth In areas where the brown tide was most prominent, bottom information from the imagery was obscured due to the high attenuation water properties produced by the brown tide

With these masks completed, bottom type was determined using the field collected water depth information to normalize the imagery. Standard approaches, such as a maximum likelihood classifier yielded poor results when compared to bottom type field information over specific region within each image block Hence, a neural network approach with 'tracking' was developed. This method trains a neural network via back propagation to become a classifier and determine bottom type Tracking refers to comparing field bottom type regions to those same regions in the image wherein the bottom type has been computed Where there is a discrepancy with the field determined data, a statistical analysis of the local region where there was agreement and the local region where there was disagreement is performed. Using a threshold technique where there is sufficient agreement in the spectral summary statistics, the region where there is agreement with field data is increased to include those regions in disagreement with field data until the threshold value is exceeded. At this point, the area is not enlarged further.

Once the bottom type product was determined, a neural network was trained to compute the water depths form the CASI imagery. This was done using a three band input to the network. The bands were selected based on a knowledge of the spectral attenuation of the local marine waters.

4.0 DISCUSSION

Initially, the products desired were high resolution depth data (at 4-m by 4-m CASI ground resolution) and bottom type over Laguna Madre However, it became clear that two other products could be developed that were of significance in the study of the Laguna Madre environment. Brown tide concentrations could be determined using Fluorescent Line Height information via three bands of the CASI band set These concentrations, however, could only be given in a relative manner. Had field operations included sampling water borne chlorophyll concentrations in conjunction with the CASI overflight of a given block, absolute values could have been computed.

Land-water discrimination was another image product developed Since land boundary disputes arise, it is important to know where water ends and land begins. Using a CASI image band in the reflective infrared (IR), land-water discrimination imagery was generated. Band 11 that has a center wavelength of 864 nm, was used for this purpose

In both the brown tide and land-water discrimination imagery, it is important to remember, for each block, that this is a snapshot in time The brown tide distribution is subject to wind dispersal and coupled hydrodynamic regimes. The land-water discrimination is affected by shifts in water levels, runoff, and wind fields and is adjusted to MLLW Nonetheless, important information can be obtained from these products

Figures 5 and 6 illustrate the geo-positioned blocks over the SPOT imagery The high-resolution depth data, bottom classification, brown tide concentrations, and land-water discriminations are in Appendices A through K. Each appendix includes data corresponding to one image so that Block A is in Appendix A, Block B in Appendix B, and so on

5.0 ACCURACY

Comments on the accuracy of the data can be separated into error of computation of product and positional error associated with the product data. Section 2.0 on data collection addresses horizontal position accuracy of the CASI with respect to the aircraft position, about 5 m With errors in the mounting of the instrument on-board the airframe and misalignments of the camera and gyro system, the absolute error of the product data position could exhibit offsets of possibly 50 m to 100 m However, using the SPOT satellite imagery for Laguna Madre to re-map each CASI flightline, the absolute positioning error is reduced to about 5 m - 10 m

Error of computation of the product is dependent on the accuracy of the field depth measurements, as much reliance was placed in these field measurements. Custom algorithms were written to involve the bathymetric data in the determination of the water depth and bottom type imagery for each block. Each block was treated independently of the others in the analysis and in follow-on computation of relevant products

The accuracy of the relative concentration of brown-tide in Laguna Madre should be quite good The fluorescence line height is computed via a 3-band algorithm and has been used successfully in prior work (Gower and Borstad, 1990) This product, however, is only a snapshot in time of what the distribution of the brown tide was in a given block at the time of CASI data collection

The land-water discrimination product used band 11 (865 nm center

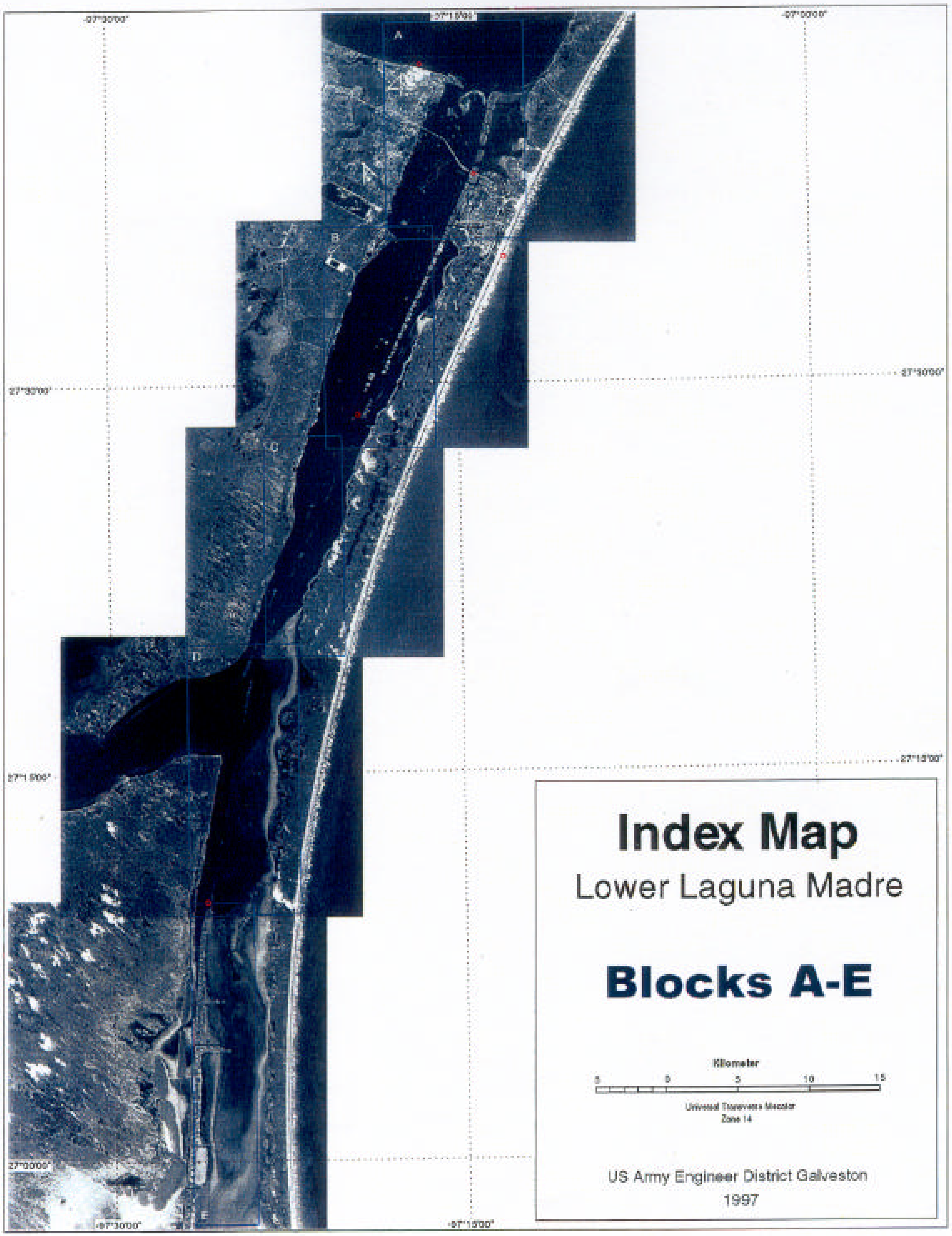


Figure 5. Geo-referenced block position for Blocks A through E

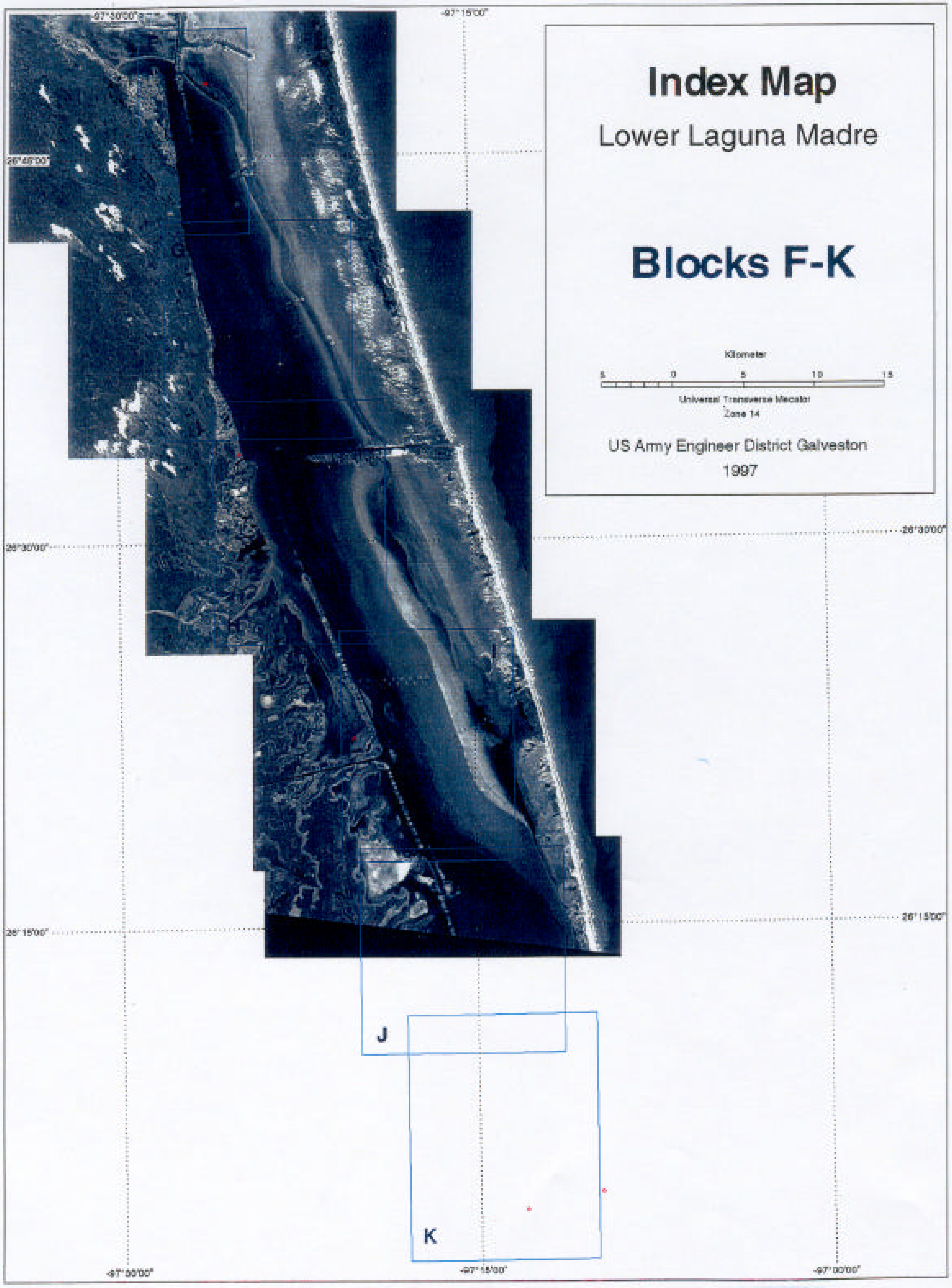


Figure 6. Geo-referenced block position for Blocks F through K

wavelength) to observe the reflective IR over each block Since near-IR is strongly absorbed by water and, in contrast, quite reflective off land, good boundaries are shown in these images. Thus, the accuracy relies primarily on the horizontal position accuracy as discussed previously Again, these boundaries are a snapshot in time For example, if a wet year occurs with a large amount of rainfall leading to drainage into pooling areas along the margins of Laguna Madre, then the land-water boundaries can shift.

Accuracy of these data may be verified through several techniques One possible, straight-forward approach would be to set up a sampling grid over some selected blocks. The blocks selected should be in both the north and south Laguna Madre The coarseness of the sampling grid will be determined by economics. At each intersection of the grid, a check of the accuracy of water depth and bottom type can be made

Furthermore, using the land-water boundary imagery, identifiable points (small islands or other landmarks) may be used to check the horizontal position accuracy of the product data since all products for a given block use the same geographic reference frame

Thus, a statistical database can be built upon for analysis of the two types of error mentioned above Eventually, a mean bias error can be computed over all blocks selected for each product. In this way, a valid statistical check may be made on the reliability of the product data and the accuracy of its positioning.

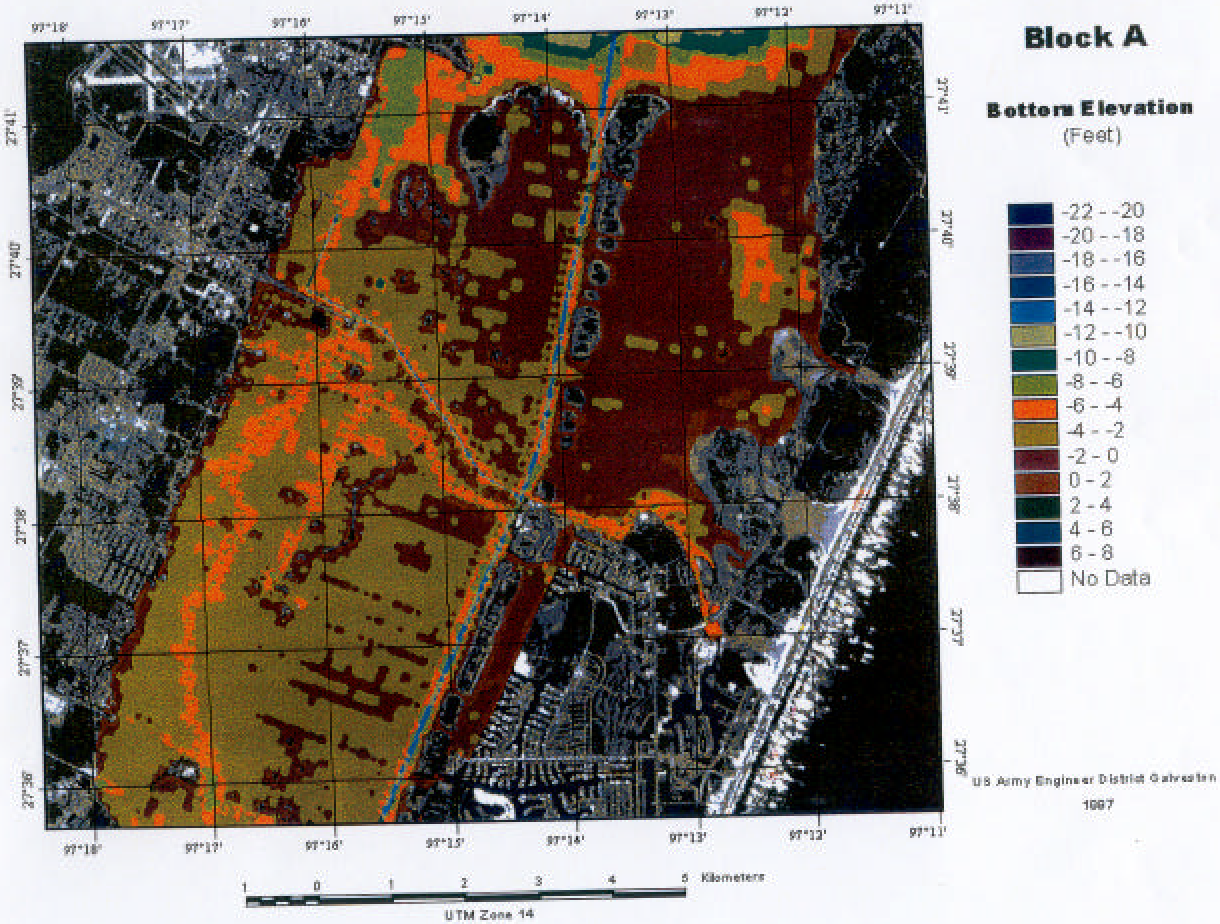
It should be noted that the CASI imagery and field surveys were collected at different times. Although, there was an overlap in time intervals of the collection of the two data sets, the CASI data were collected over a two month period from April through May of 1995 and the field survey operations were conducted over a three month period from May through July of the same year During the collection of both data sets, there were no meteorological events that would have caused significant bottom changes to the Laguna Madre Therefore, any error that may have been introduced during the correlation of the imagery and field surveys would be minimal

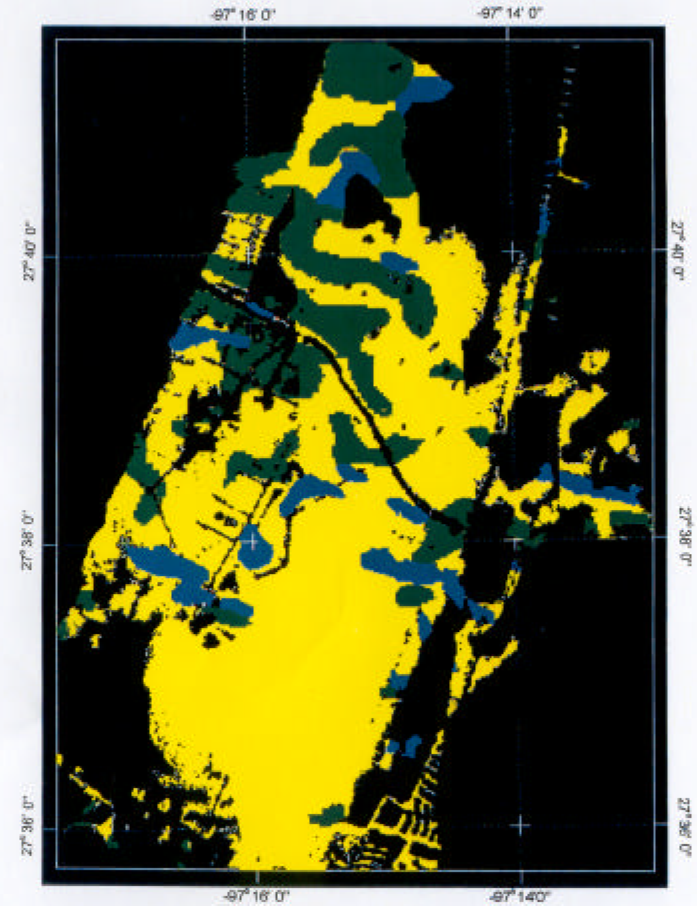
REFERENCES

Gower, J and G Borstad 1990 "Mapping of phytoplankton by solar-stimulated fluorescence using an imaging spectrometer," *Int. Journ. Rem. Sens.*, Vol 11, pp 313-320

APPENDIX A

Block A


Block A
Bottom Elevation
(Feet)
-22 - -20
-20 - -18
-18 - -16
-16 - -14
-14 - -12
-12 - -10
-10 - -8
-8 - -6
-6 - -4
-4 - -2
-2 - 0
0 - 2
2 - 4
4 - 6
6 - 8
No Data
US Army Engineer District Galveston
1997
Kilometers
UTM Zone 14



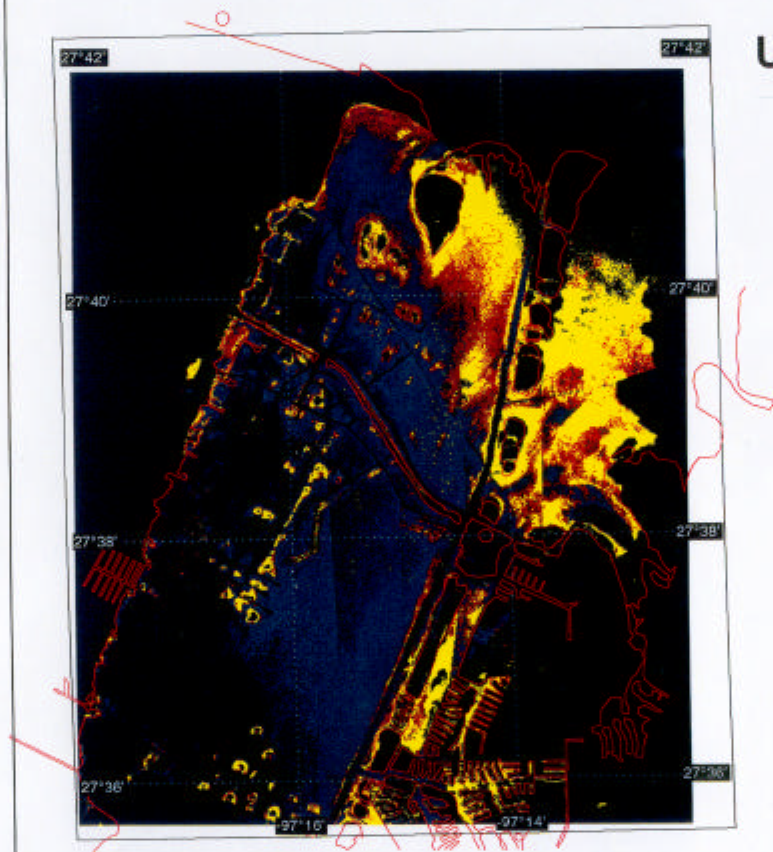
Upper Laguna Madre

Texas

Block A

Bottom Type

US Army Engineer District Galveston
1997



Upper Laguna Madre

Texas

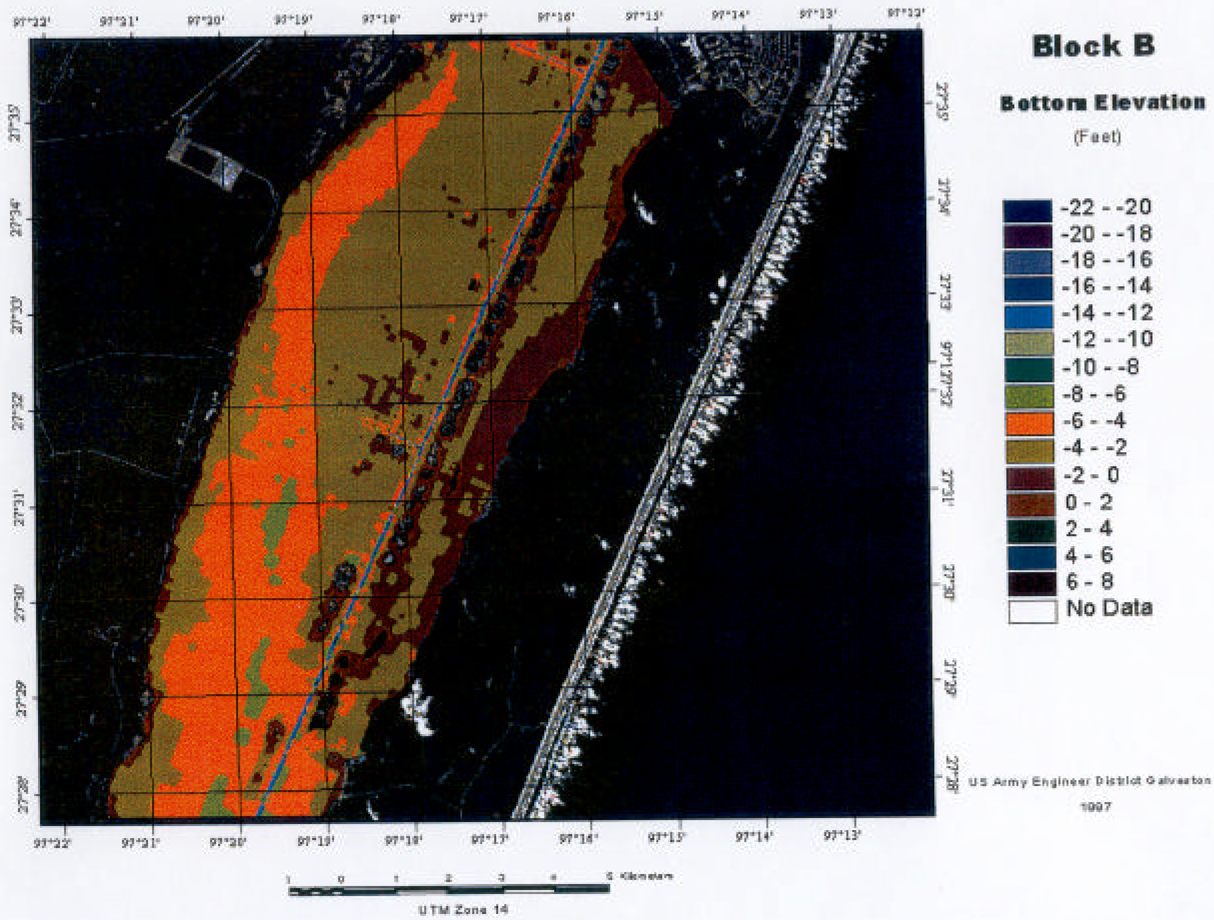
Block A

Brown Tide

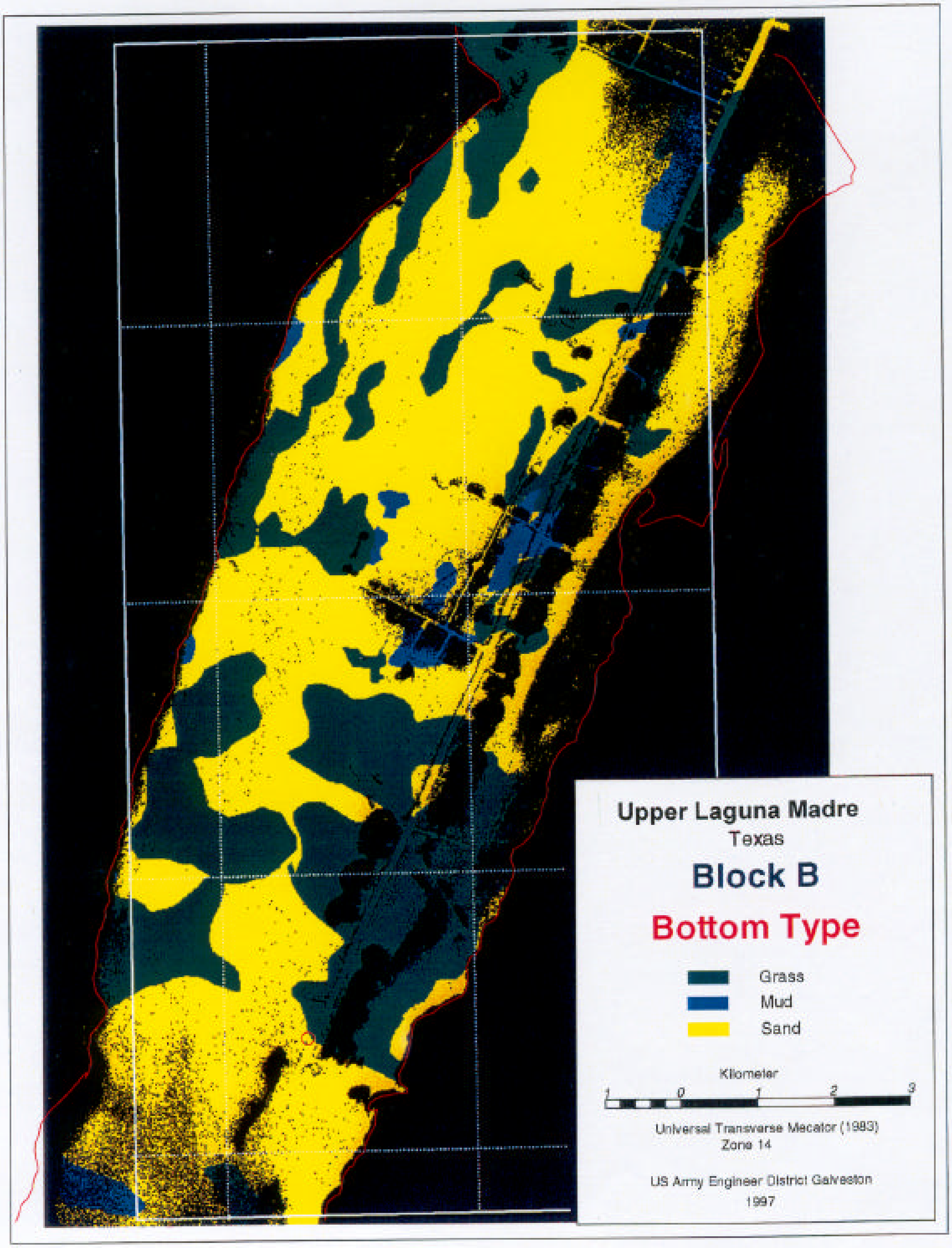
US Army Engineer District Galveston
1997

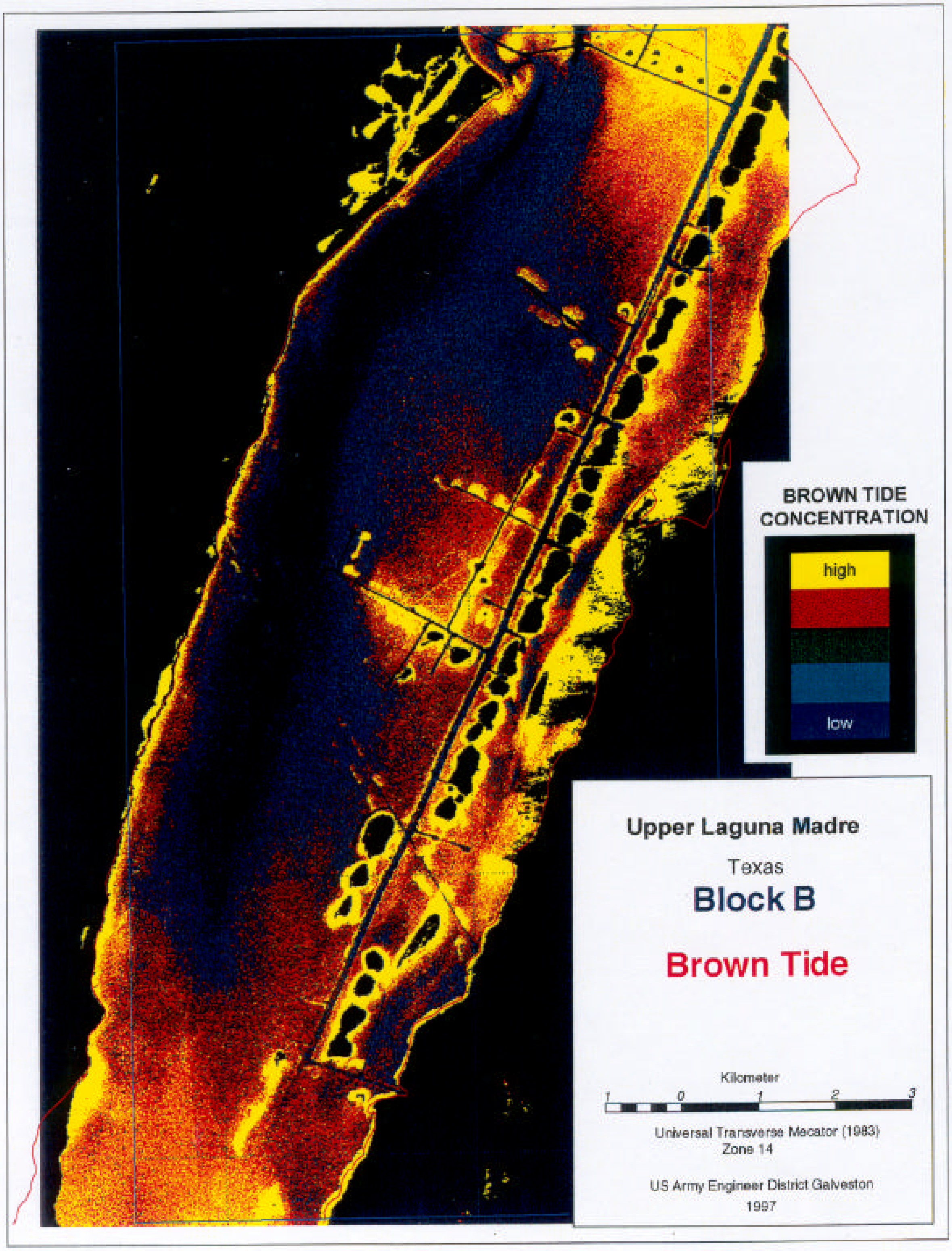
APPENDIX B

Block B



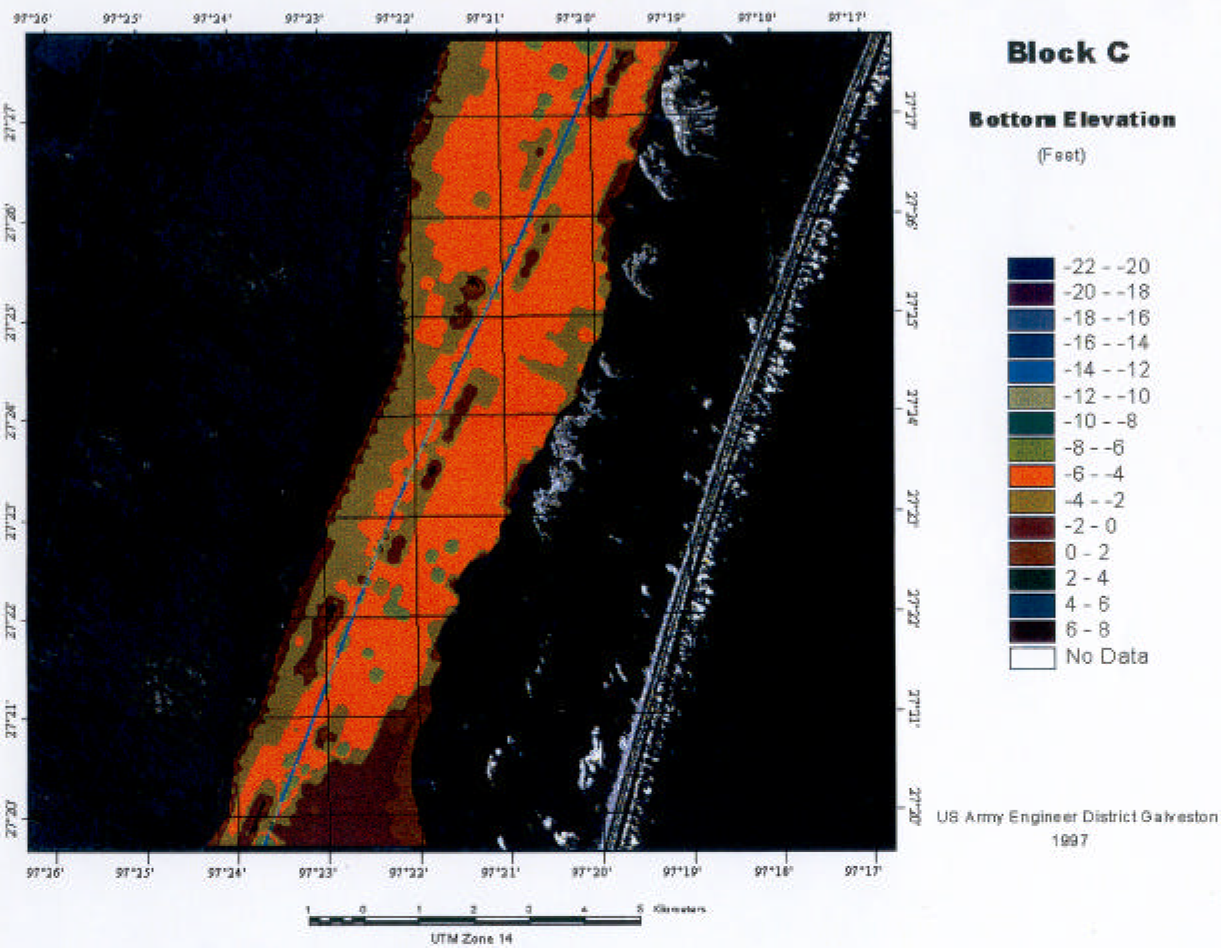
Block B
Bottom Elevation
(Feet)
-22 - -20
-20 - -18
-18 - -16
-16 - -14
-14 - -12
-12 - -10
-10 - -8
-8 - -6
-6 - -4
-4 - -2
-2 - 0
0 - 2
2 - 4
4 - 6
6 - 8
No Data
US Army Engineer District Galveston
1997
UTM Zone 14


Upper Laguna Madre
Texas
Block B
Bottom Type
Grass
Mud
Sand
Kilometer
1 0 1 2 3
Universal Transverse Mecator (1983)
Zone 14
US Army Engineer District Galveston
1997


BROWN TIDE
CONCENTRATION
high
low
Upper Laguna Madre
Texas
Block B
Brown Tide
Kilometer
1 0 1 2 3
Universal Transverse Mecator (1983)
Zone 14
US Army Engineer District Galveston
1997

APPENDIX C

Block C



Block C
Bottom Elevation
(Feet)
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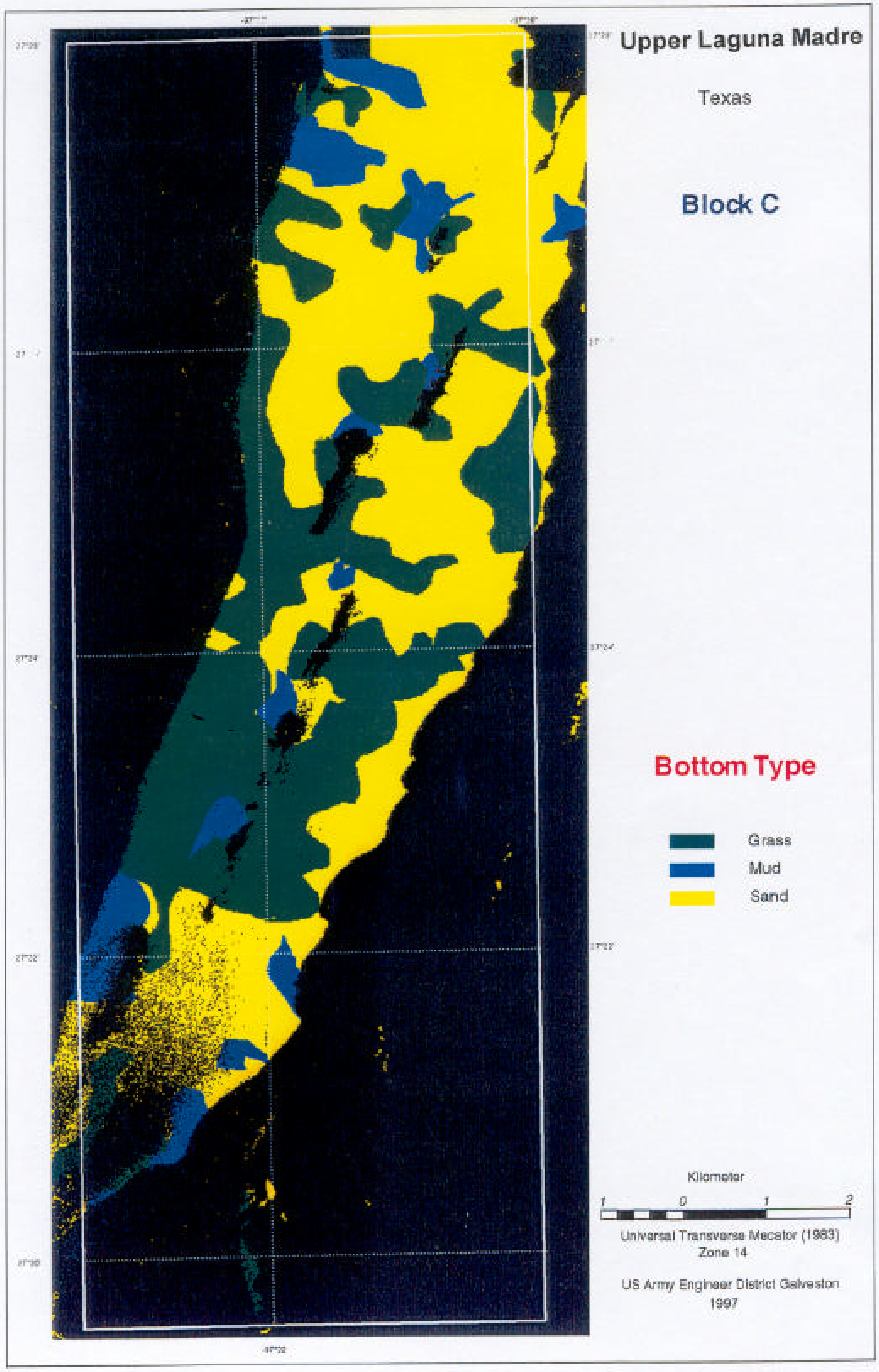
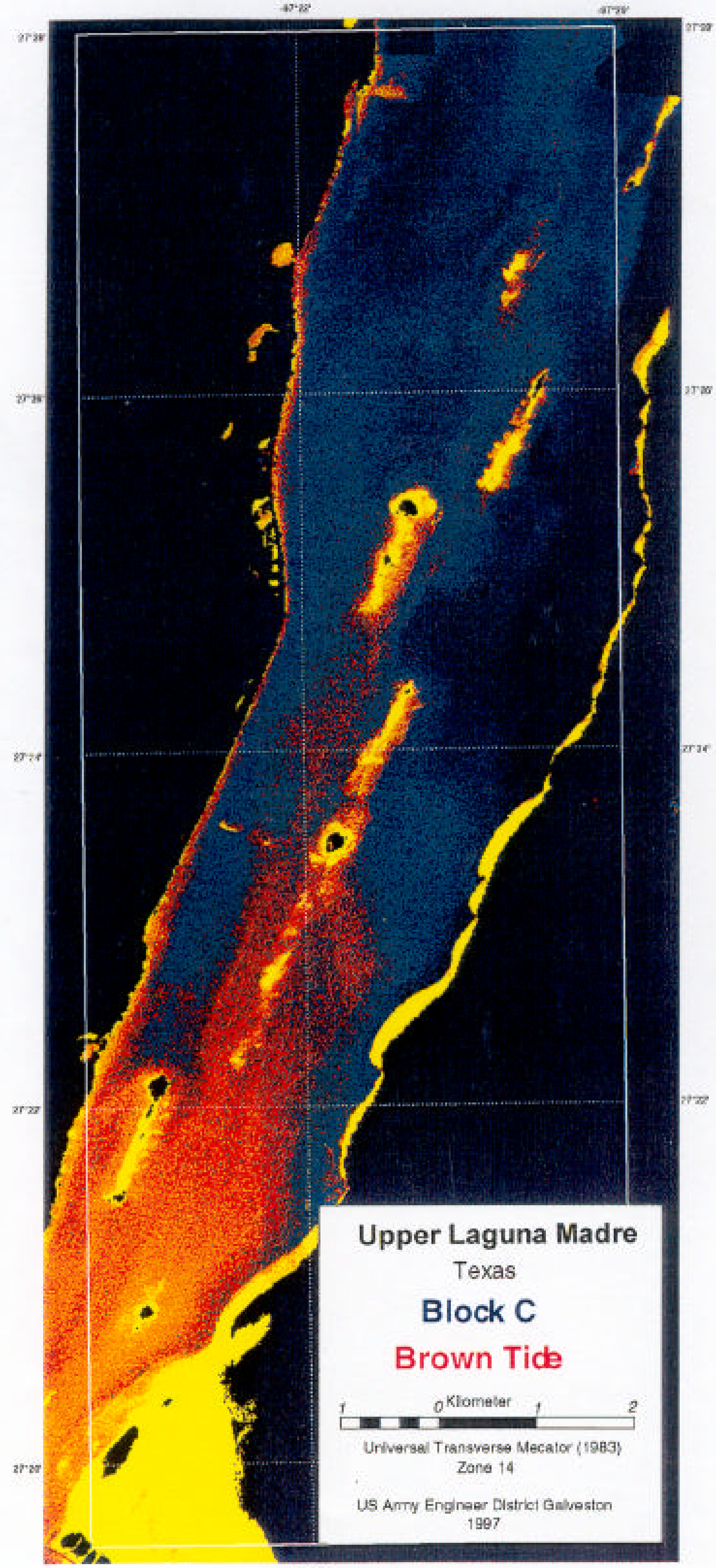
-20 - -18
-18 - -16
-16 - -14
-14 - -12
-12 - -10
-10 - -8
-8 - -6
-6 - -4
-4 - -2
-2 - 0
0 - 2
2 - 4
4 - 6
6 - 8
No Data
US Army Engineer District Galveston
1997
Kilometers
UTM Zone 14

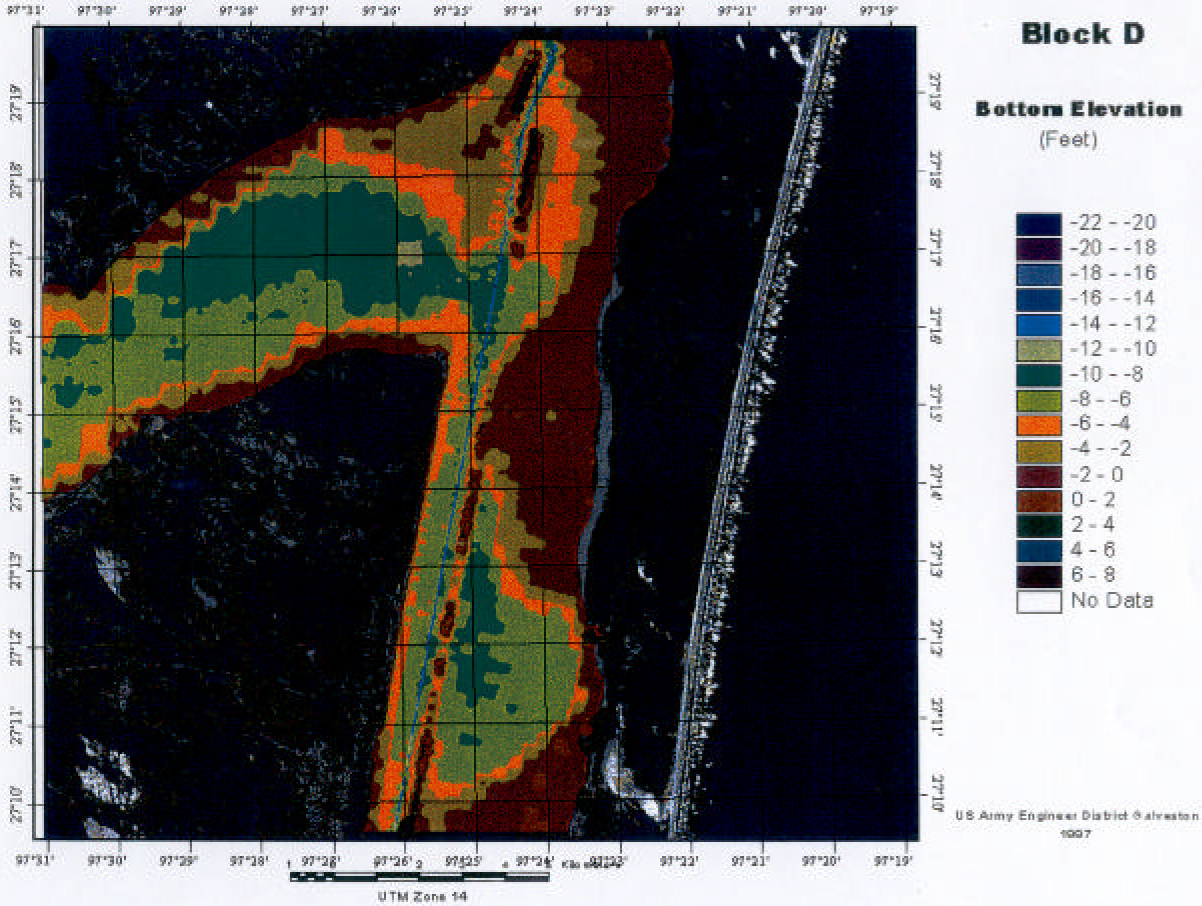

Upper Laguna Madre
Texas
Block C
Bottom Type
Grass
Mud
Sand
Kilometer
1 0 1 2
Universal Transverse Mecator (1983)
Zone 14
US Army Engineer District Galveston
1997

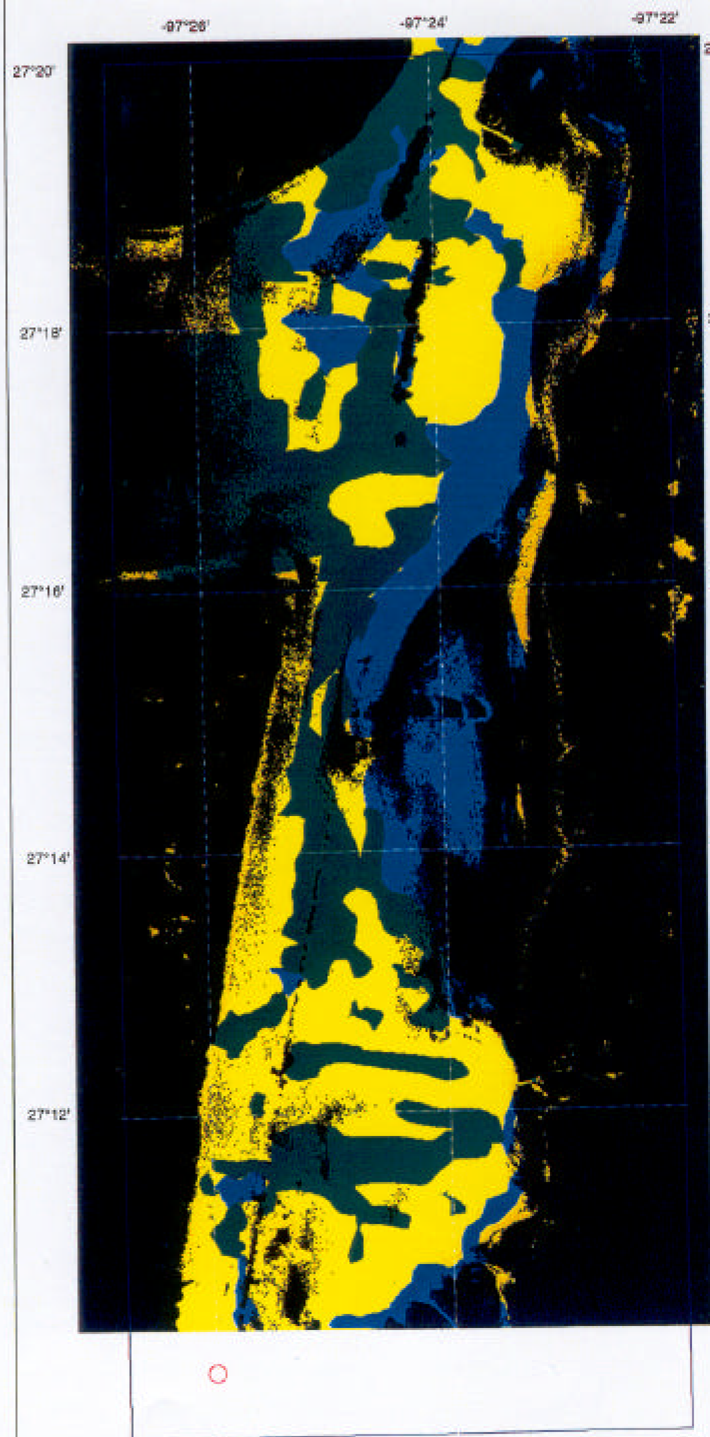

Upper Laguna Madre
Texas
Block C
Brown Tide
Kilometer
1 0 1 2
Universal Transverse Mecator (1983)
Zone 14
US Army Engineer District Galveston
1997


BROWN TIDE
CONCENTRATION
high
low

APPENDIX D

Block D


Block D
Bottom Elevation
(Feet)
-22 - -20
-20 - -18
-18 - -16
-16 - -14
-14 - -12
-12 - -10
-10 - -8
-8 - -6
-6 - -4
-4 - -2
-2 - 0
0 - 2
2 - 4
4 - 6
6 - 8
No Data
US Army Engineer District Galveston
1997
UTM Zone 14



Upper Laguna Madre

Texas

Block D

Bottom Type

- Grass
- Mud
- Sand

Kilometer

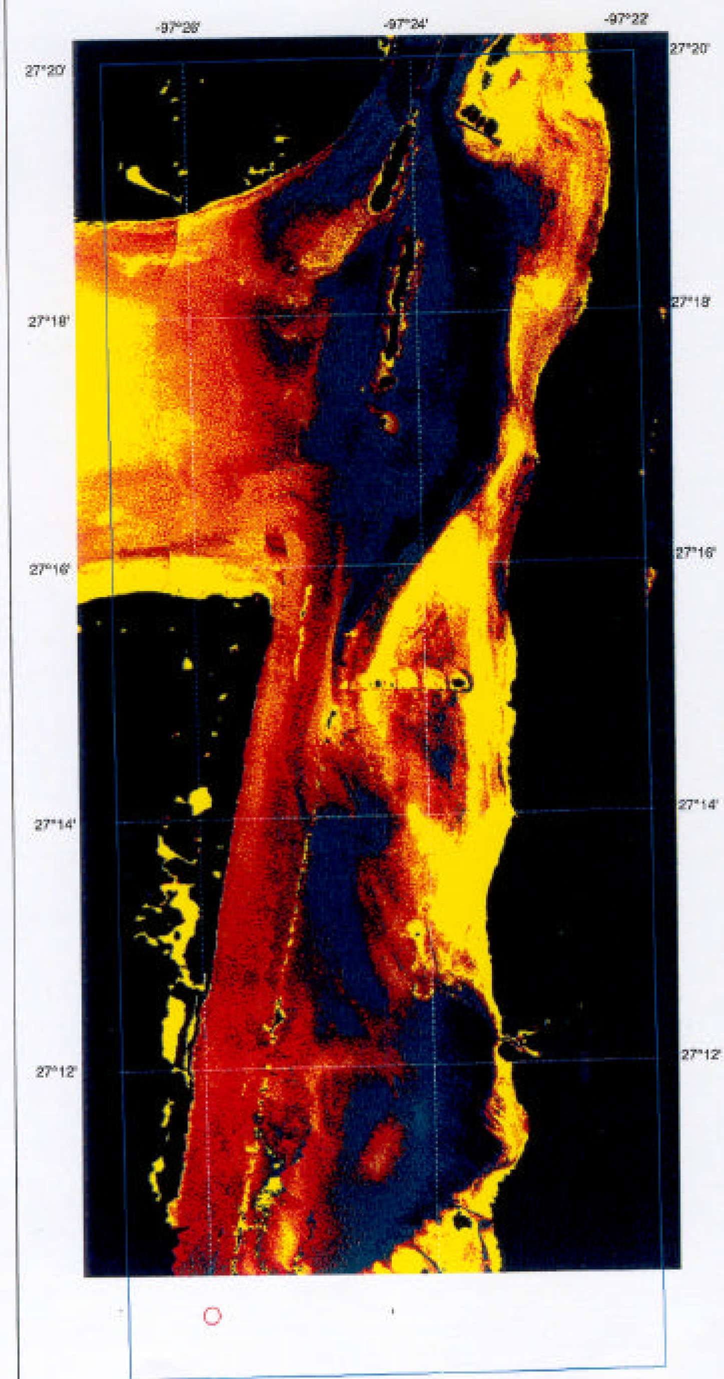
1 0 1 2 3

Universal Transverse Mecator (1983)

Zone 14

US Army Engineer District Galveston

1997



Upper Laguna Madre
Texas

Block D

Brown Tide

BROWN TIDE CONCENTRATION

Kilometer
1 0 1 2 3

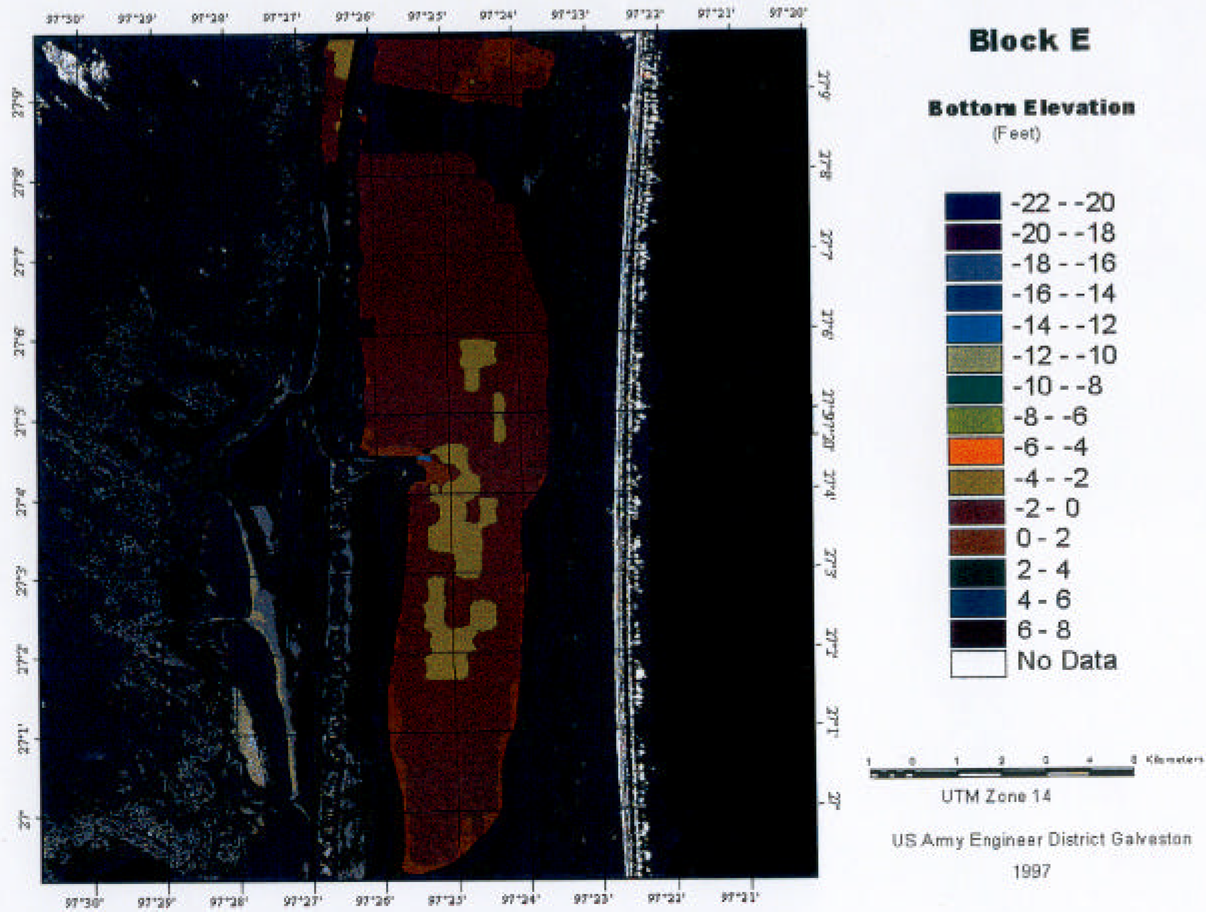
Universal Transverse Mecator (1983)
Zone 14

US Army Engineer District Galveston

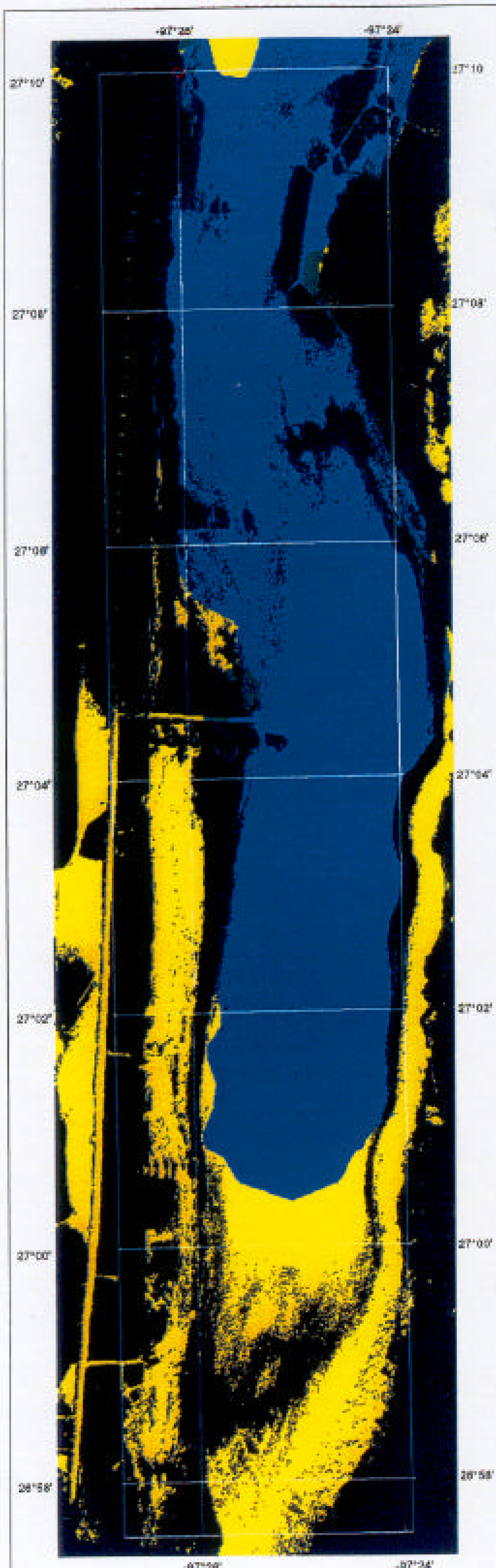
1997

APPENDIX E

Block E



Block E
Bottom Elevation
(Feet)
-22 - -20
-20 - -18
-18 - -16
-16 - -14
-14 - -12
-12 - -10
-10 - -8
-8 - -6
-6 - -4
-4 - -2
-2 - 0
0 - 2
2 - 4
4 - 6
6 - 8
No Data
UTM Zone 14
US Army Engineer District Galveston
1997



Upper Laguna Madre

Texas

Block E

Bottom Type

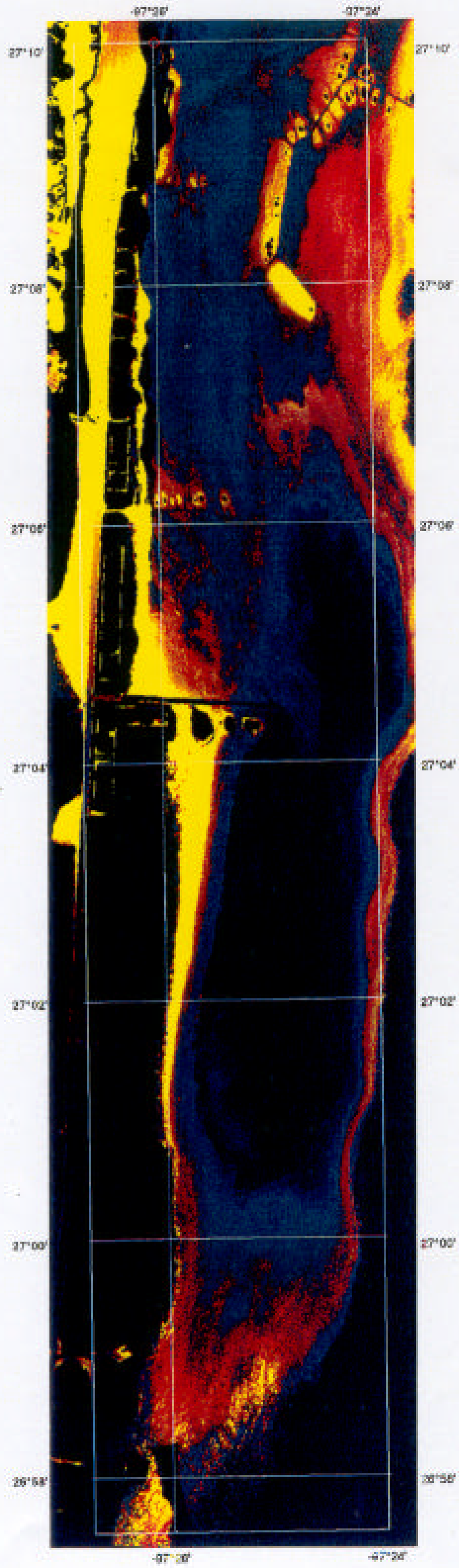
Grass
Mud
Sand

Kilometer
1 0 1 2 3

Universal Transverse Mecator (1983)
Zone 14

US Army Engineer District Galveston

1997



Upper Laguna Madre

Texas

Block E

Brown Tide

BROWN TIDE CONCENTRATION

Kilometer

1 0 1 2 3

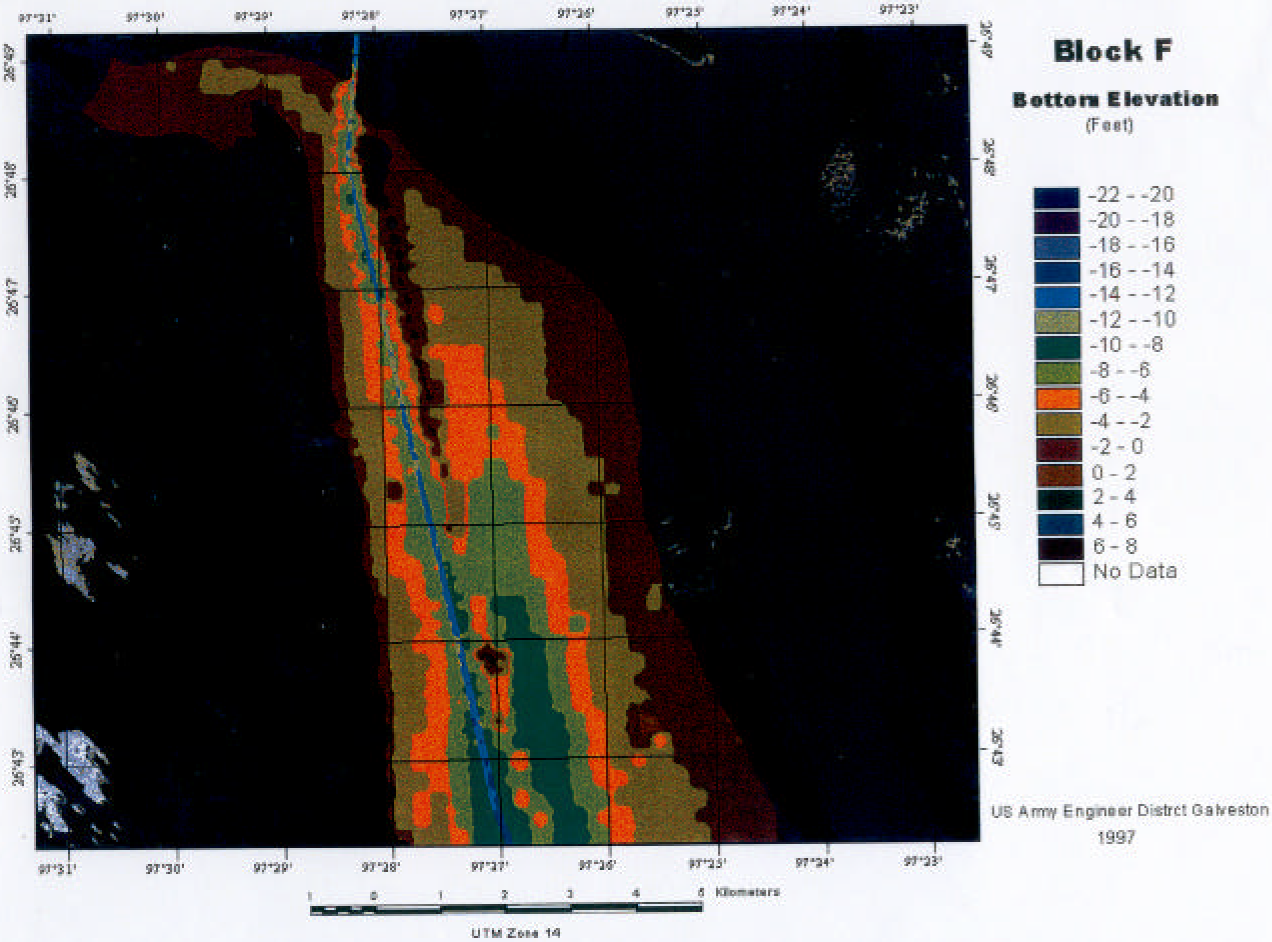
Universal Transverse Mecator (1983)
Zone 14

US Army Engineer District Galveston

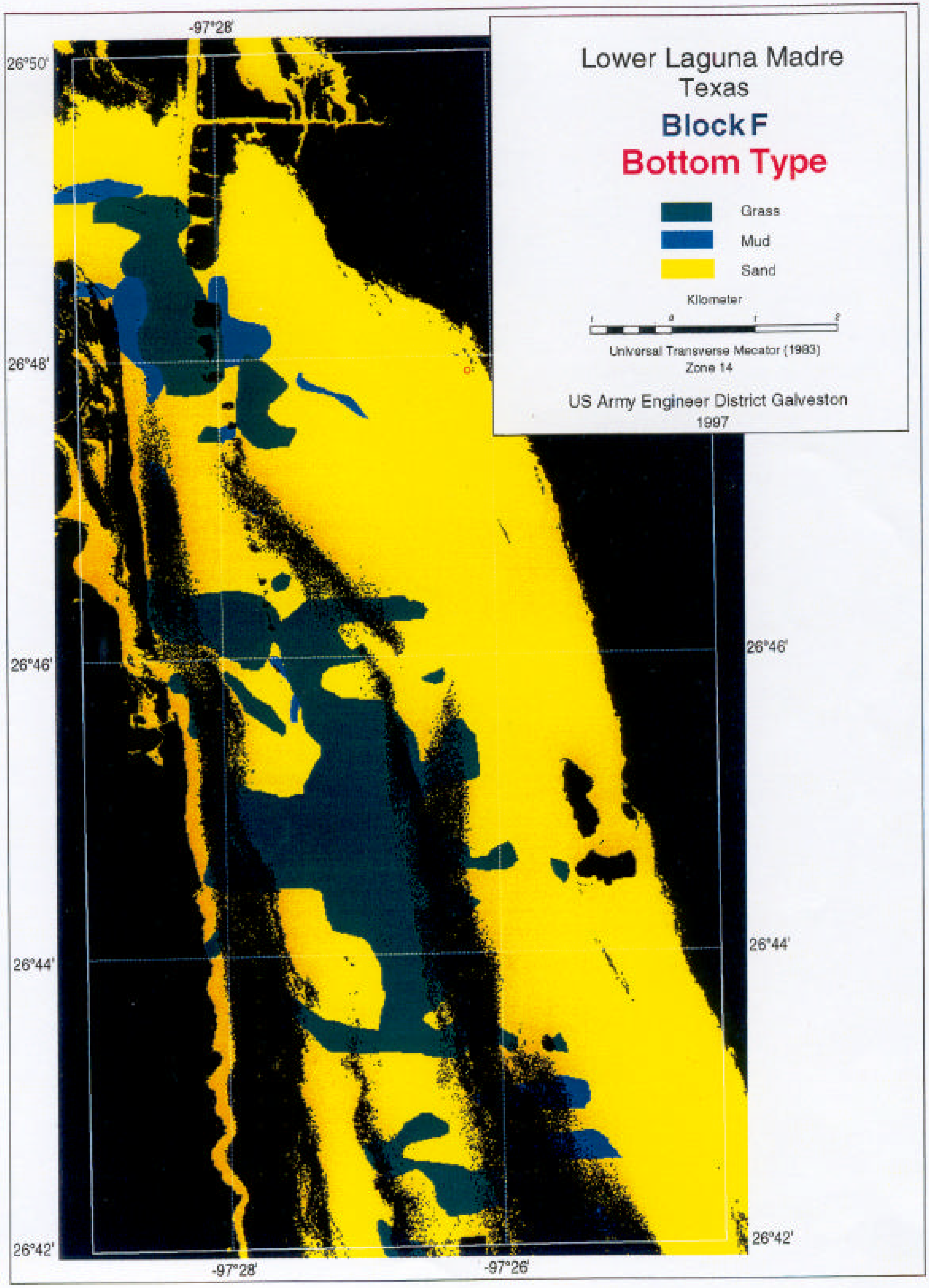
1997

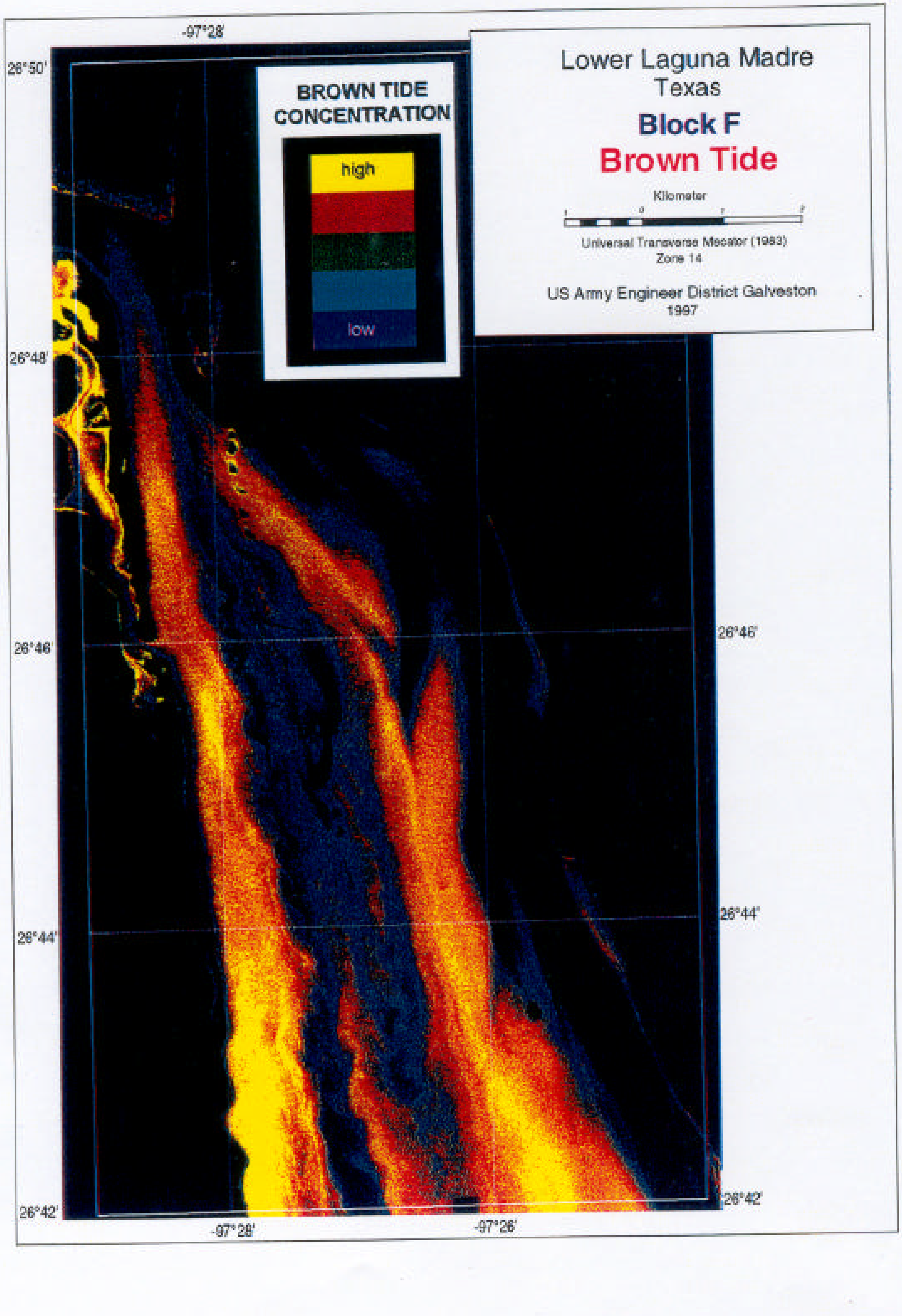
APPENDIX F

Block F



Block F
Bottom Elevation
(Feet)
-22 - -20
-20 - -18
-18 - -16
-16 - -14
-14 - -12
-12 - -10
-10 - -8
-8 - -6
-6 - -4
-4 - -2
-2 - 0
0 - 2
2 - 4
4 - 6
6 - 8
No Data
US Army Engineer District Galveston
1997
97°31'
97°30'
97°29'
97°28'
97°27'
97°26'
97°25'
97°24'
97°23'
26°49'
26°48'
26°47'
26°46'
26°45'
26°44'
26°43'
Kilometers
UTM Zone 14

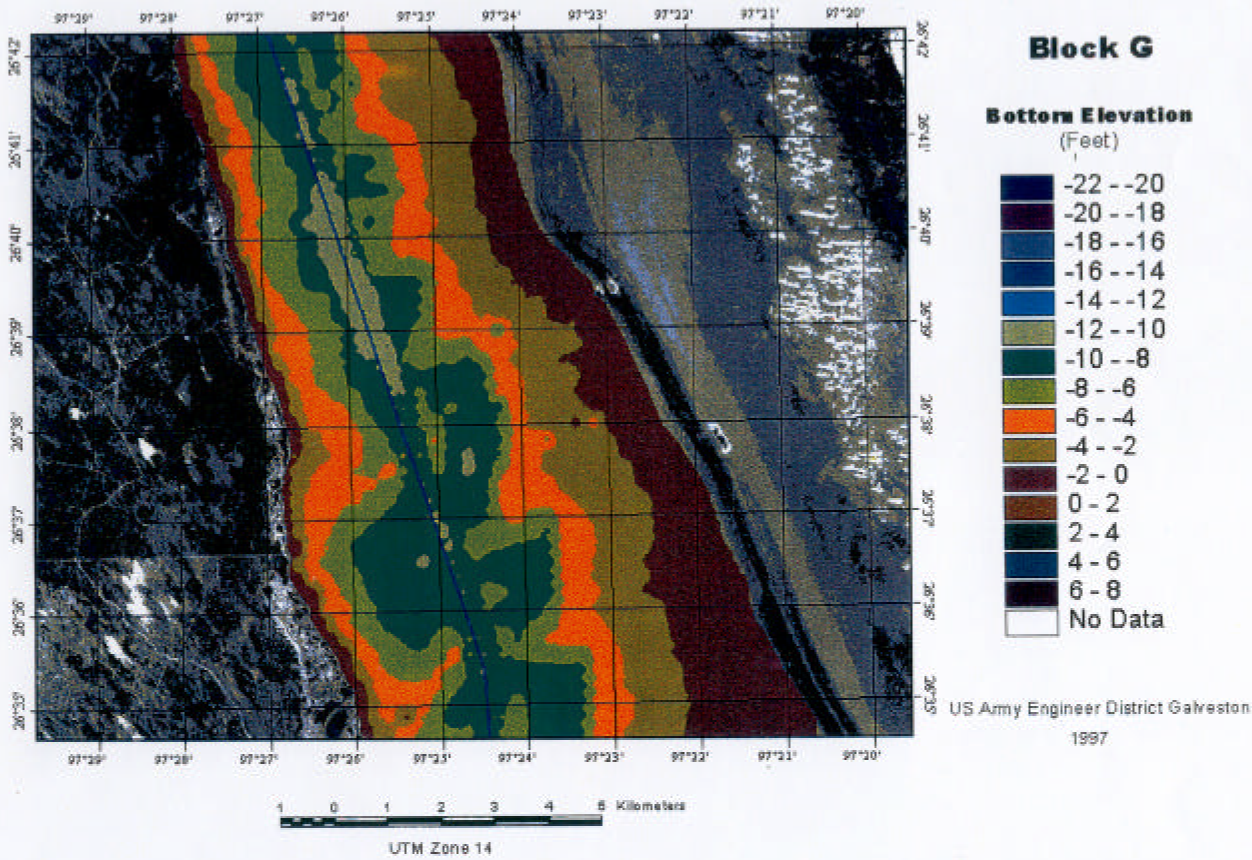

Lower Laguna Madre
Texas
Block F
Bottom Type
Grass
Mud
Sand
Kilometer
Universal Transverse Mecator (1983)
Zone 14
US Army Engineer District Galveston
1997
-97°28'
-97°26'
26°50'
26°48'
26°46'
26°44'
26°42'



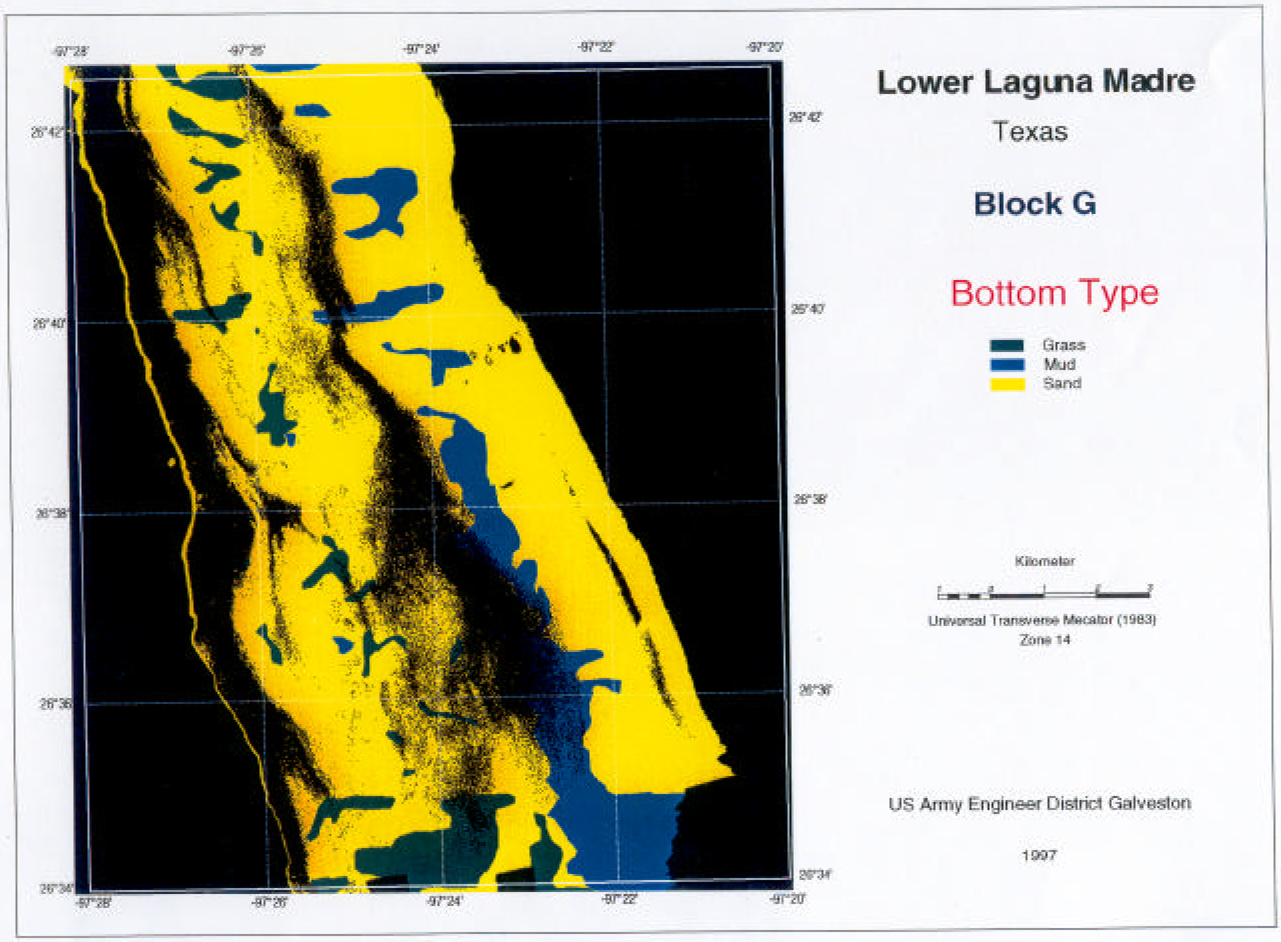
Lower Laguna Madre
Texas
Block F
Brown Tide
Kilometer
Universal Transverse Mecator (1983)
Zone 14
US Army Engineer District Galveston
1997
BROWN TIDE CONCENTRATION
high
low
-97°28'
-97°26'
26°50'
26°48'
26°46'
26°44'
26°42'

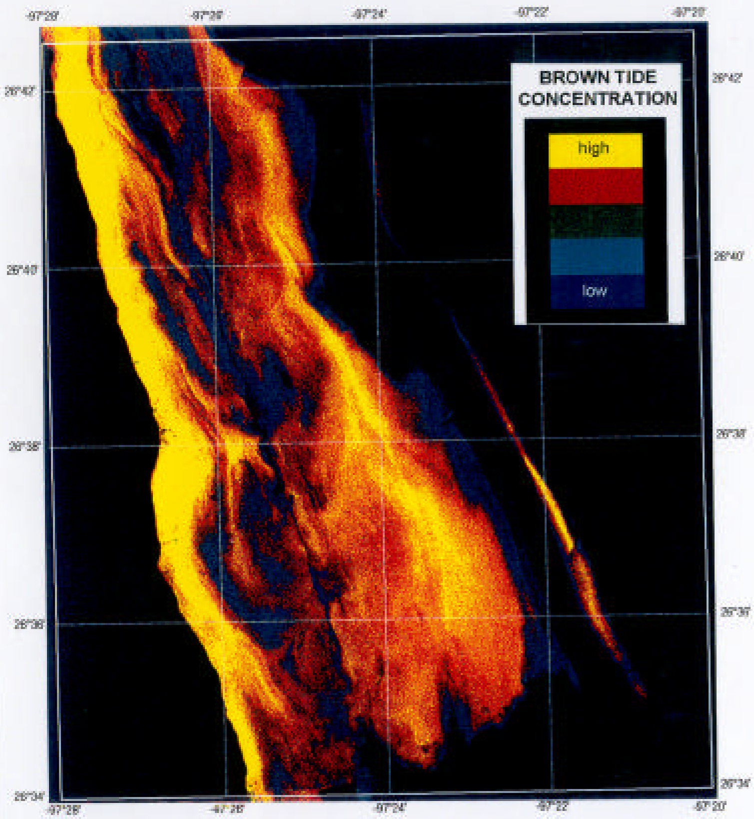
APPENDIX G

Block G



Block G
Bottom Elevation
(Feet)
-22 - -20
-20 - -18
-18 - -16
-16 - -14
-14 - -12
-12 - -10
-10 - -8
-8 - -6
-6 - -4
-4 - -2
-2 - 0
0 - 2
2 - 4
4 - 6
6 - 8
No Data
US Army Engineer District Galveston
1997
1 0 1 2 3 4 5 Kilometers
UTM Zone 14


-97°28'
-97°26'
-97°24'
-97°22'
-97°20'
26°42'
26°40'
26°38'
26°36'
26°34'
Lower Laguna Madre
Texas
Block G
Bottom Type
Grass
Mud
Sand
Kilometer
Universal Transverse Mecator (1983)
Zone 14
US Army Engineer District Galveston
1997



Lower Laguna Madre

Texas

Block G

Brown Tide

Kilometer

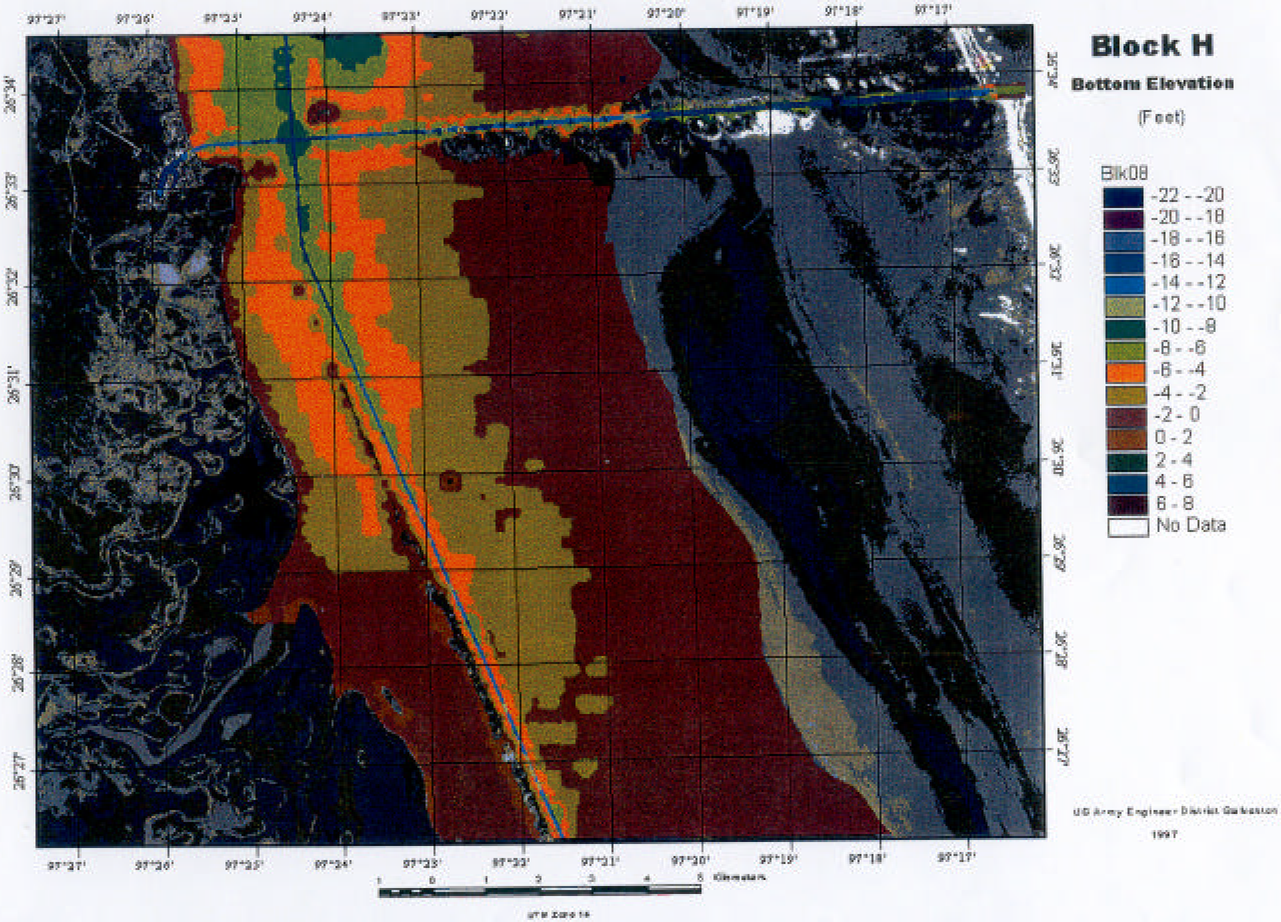
Universal Transverse Mecator (1983)
Zone 14

US Army Engineer District Galveston

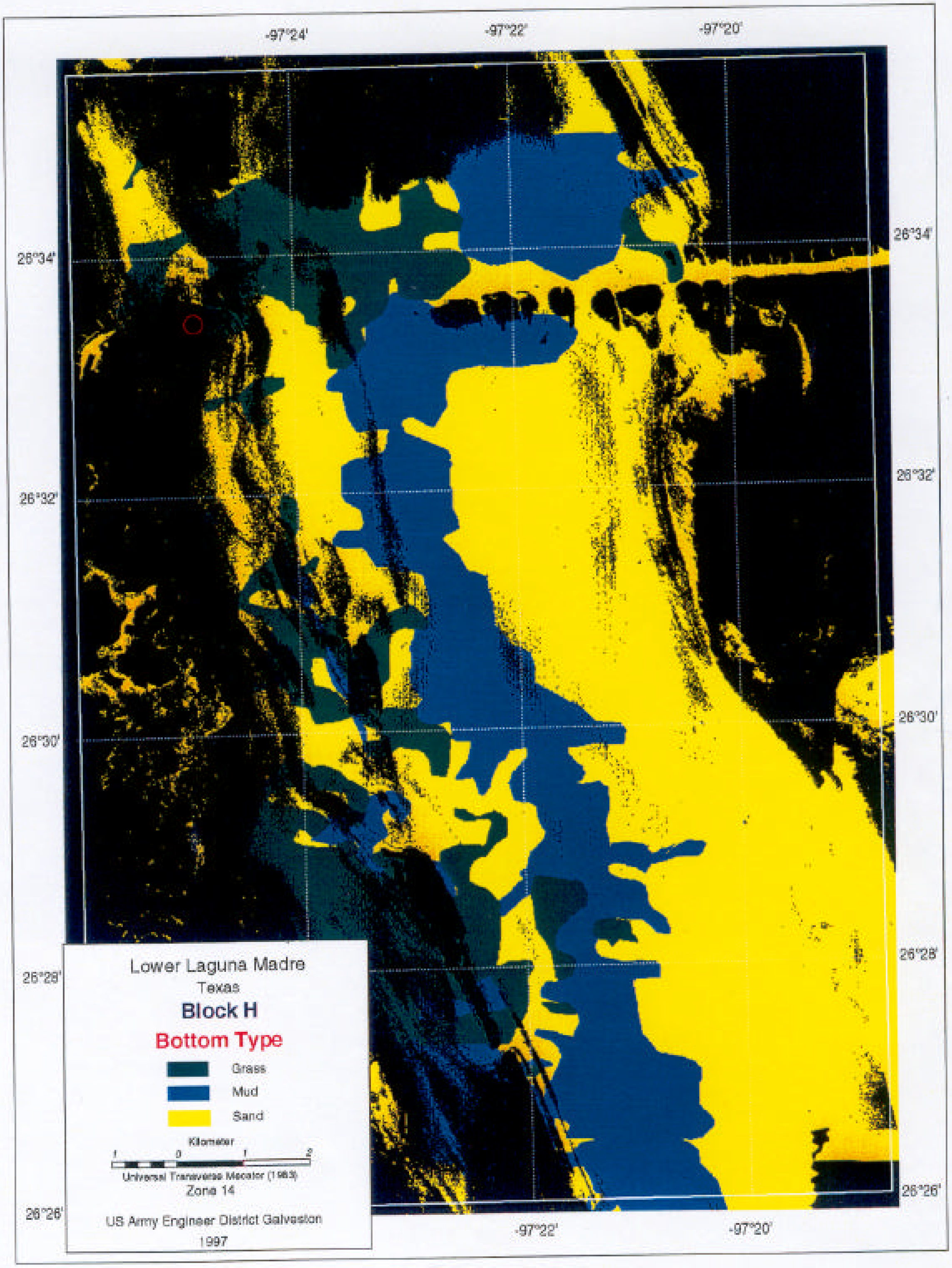
1997

APPENDIX H

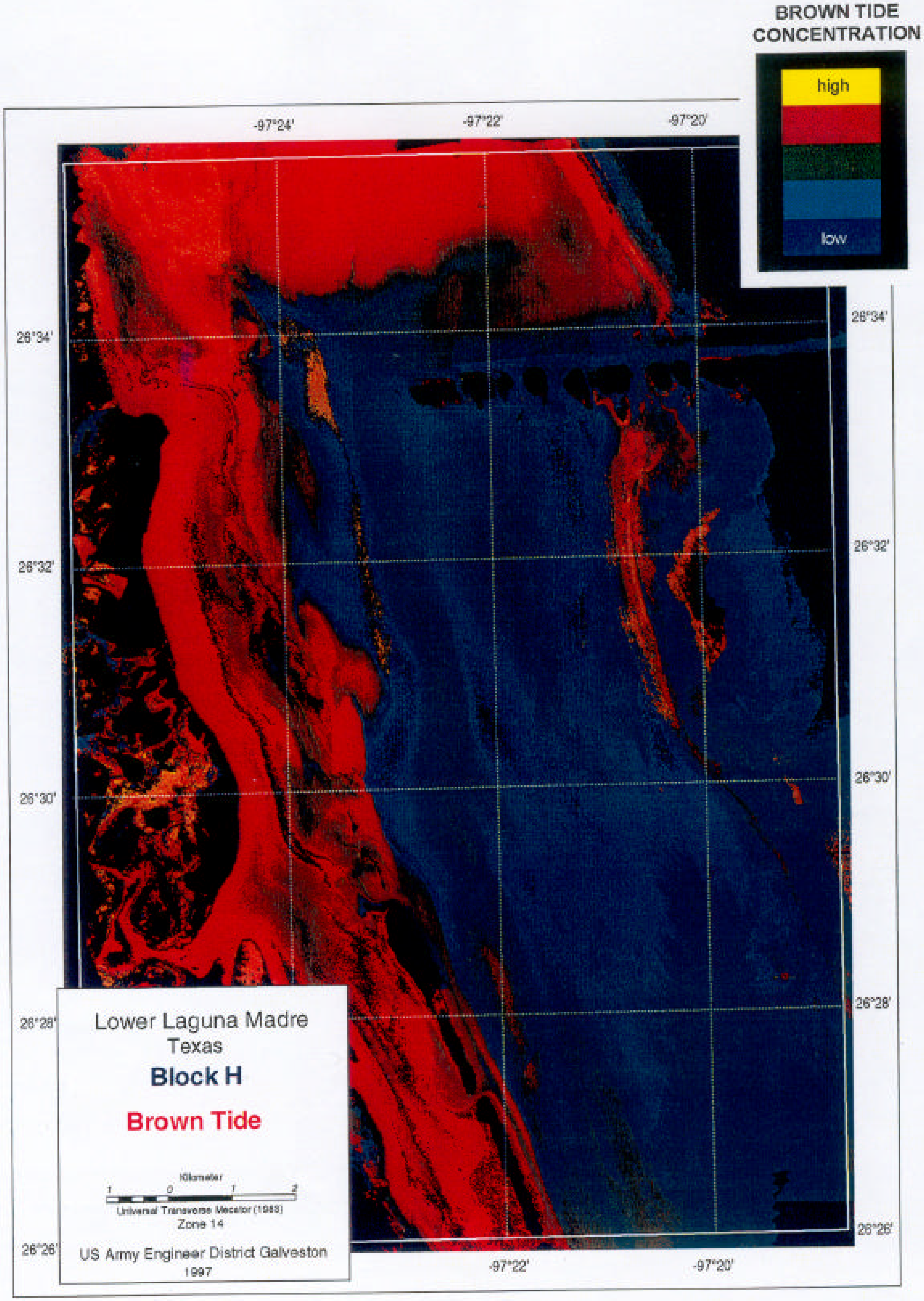
Block H



Block H
Bottom Elevation
(Feet)
Blk08
-22 - -20
-20 - -18
-18 - -16
-16 - -14
-14 - -12
-12 - -10
-10 - -8
-8 - -6
-6 - -4
-4 - -2
-2 - 0
0 - 2
2 - 4
4 - 6
6 - 8
No Data
97°27'
97°26'
97°25'
97°24'
97°23'
97°22'
97°21'
97°20'
97°19'
97°18'
97°17'
26°34'
26°33'
26°32'
26°31'
26°30'
26°29'
26°28'
26°27'
1
0
1
2
3
4
5
Kilometers

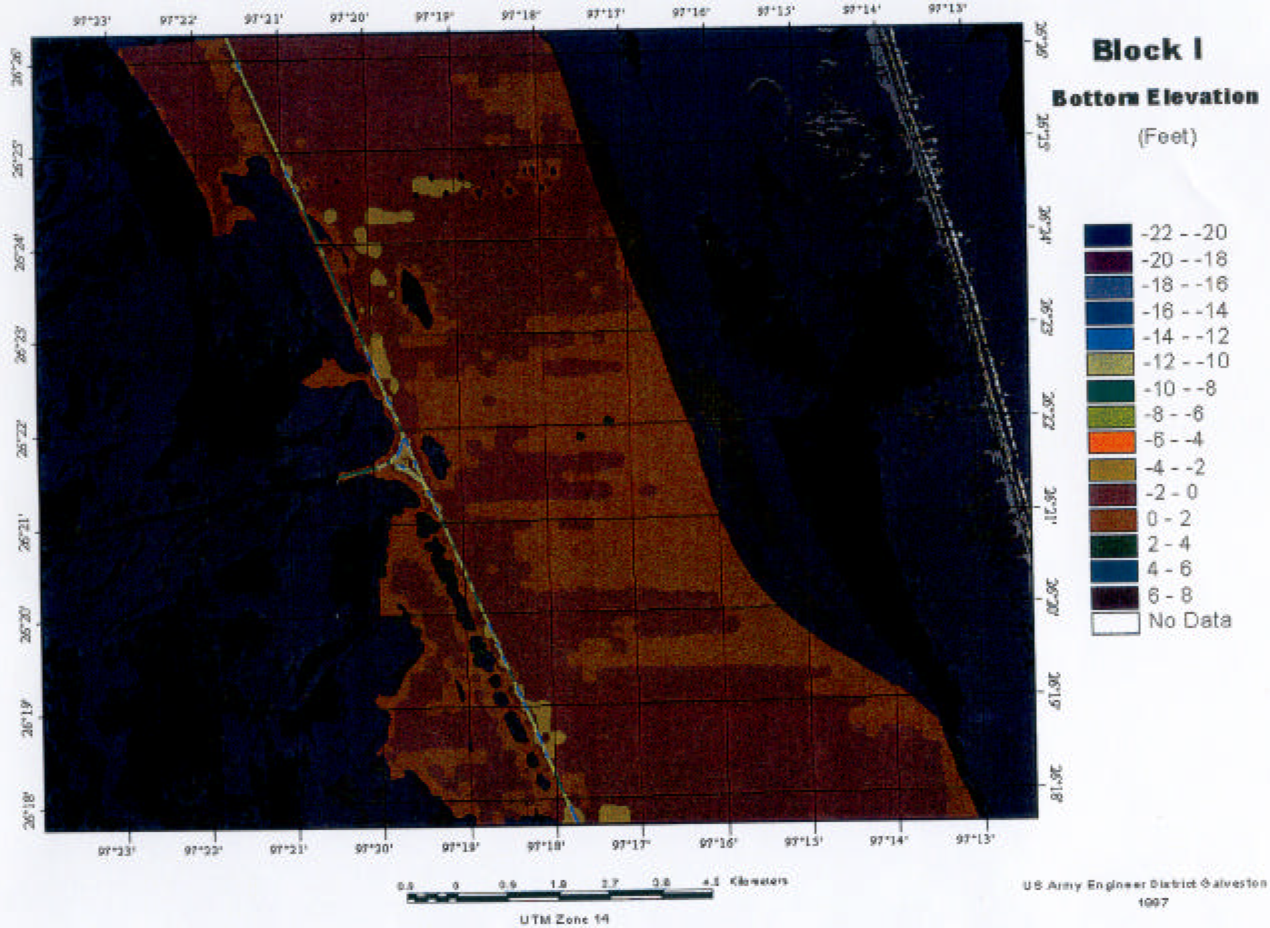


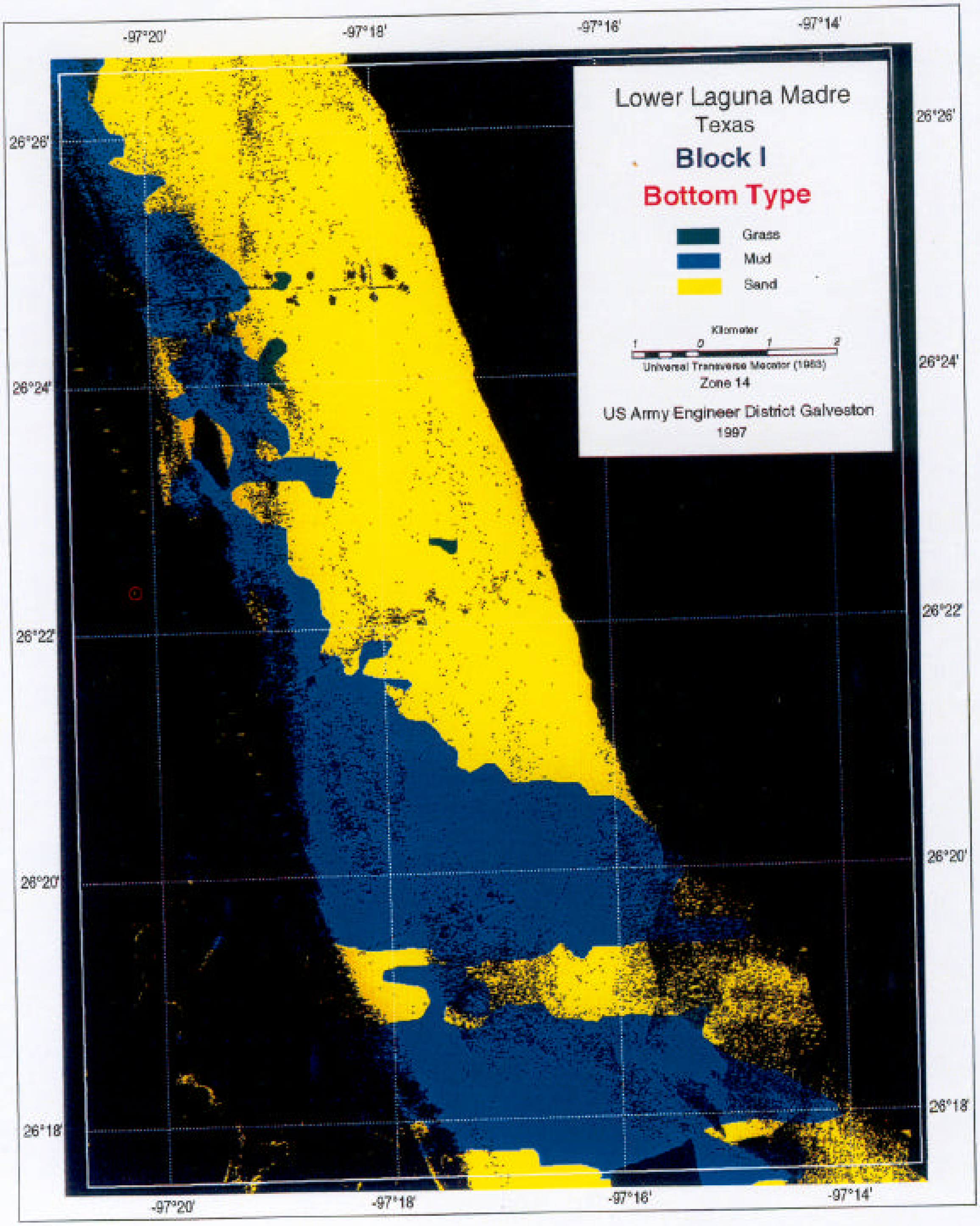
-97°24'
-97°22'
-97°20'
26°34'
26°32'
26°30'
26°28'
26°26'
Lower Laguna Madre
Texas
Block H
Bottom Type
Grass
Mud
Sand
Kilometer
Universal Transverse Mercator (1983)
Zone 14
US Army Engineer District Galveston
1997


BROWN TIDE
CONCENTRATION
high
low
-97°24'
-97°22'
-97°20'
26°34'
26°32'
26°30'
26°28'
26°26'
Lower Laguna Madre
Texas
Block H
Brown Tide
Kilometer
1 0 1 2
Universal Transverse Mercator (1983)
Zone 14
US Army Engineer District Galveston
1997

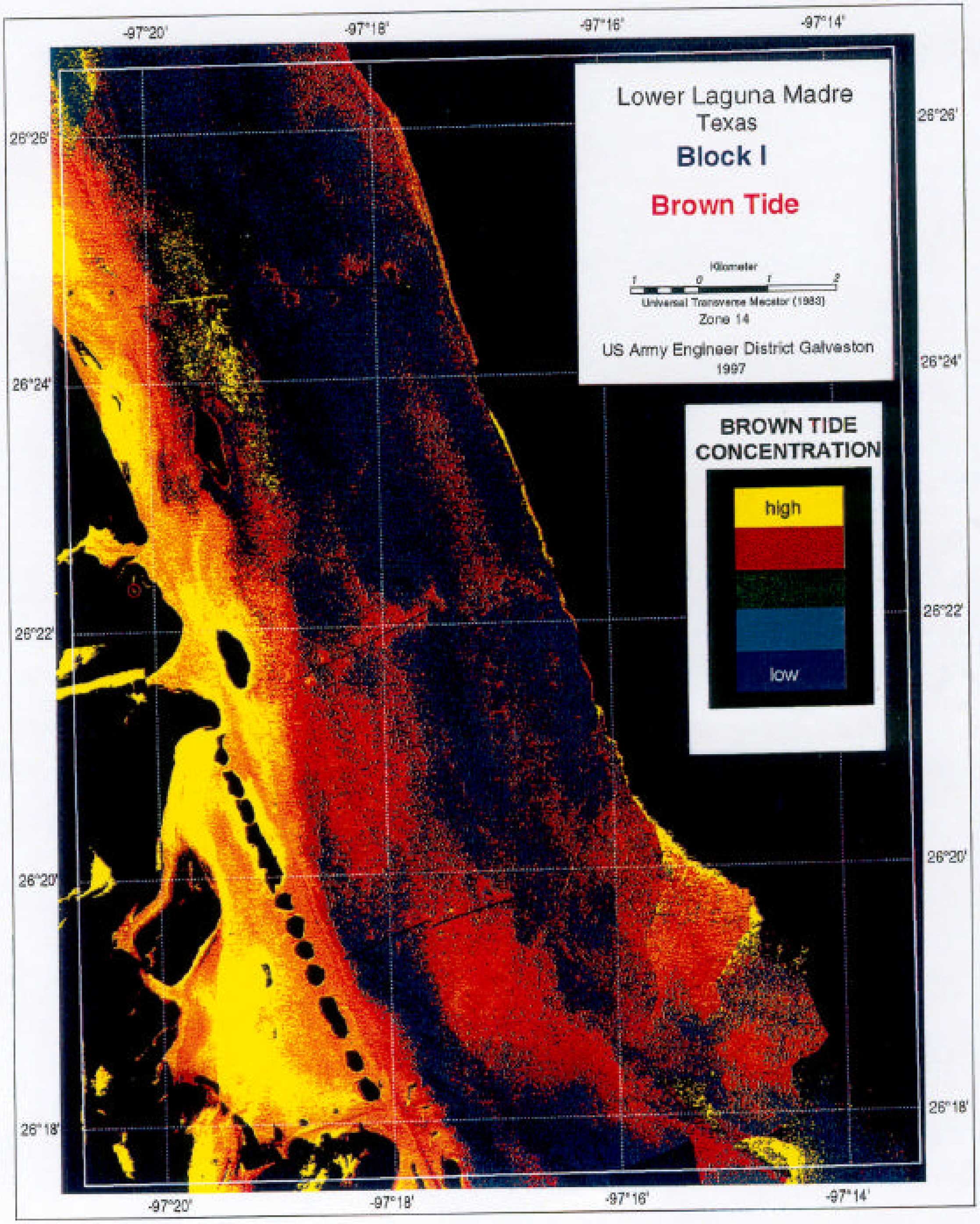
APPENDIX I

Block I


Block I
Bottom Elevation
(Feet)
-22 - -20
-20 - -18
-18 - -16
-16 - -14
-14 - -12
-12 - -10
-10 - -8
-8 - -6
-6 - -4
-4 - -2
-2 - 0
0 - 2
2 - 4
4 - 6
6 - 8
No Data
Kilometers
UTM Zone 14
US Army Engineer District Galveston
1997



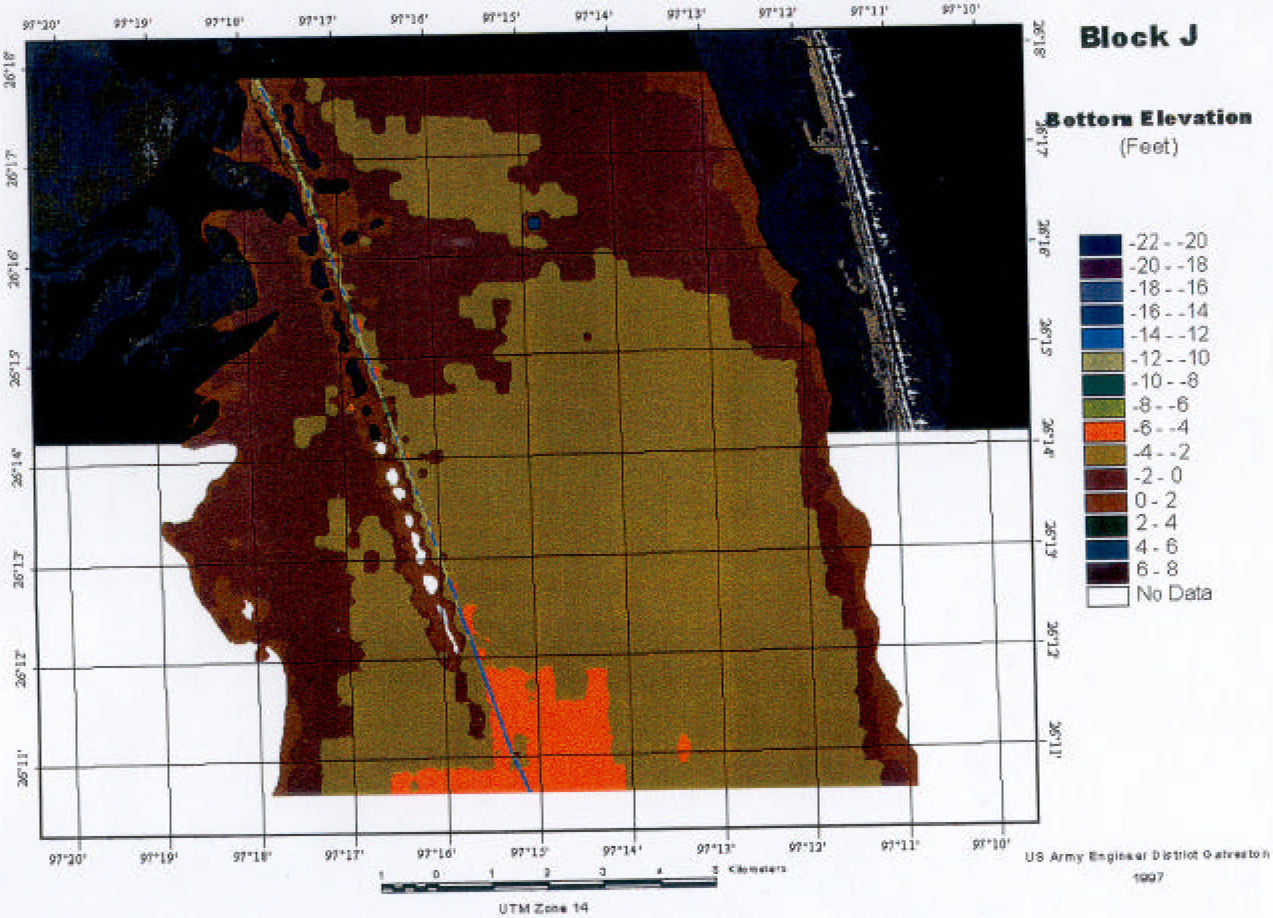
Lower Laguna Madre
Texas
Block I
Bottom Type
Grass
Mud
Sand
Kilometer
1 0 1 2
Universal Transverse Mecator (1983)
Zone 14
US Army Engineer District Galveston
1997
-97°20'
-97°18'
-97°16'
-97°14'
26°26'
26°24'
26°22'
26°20'
26°18'



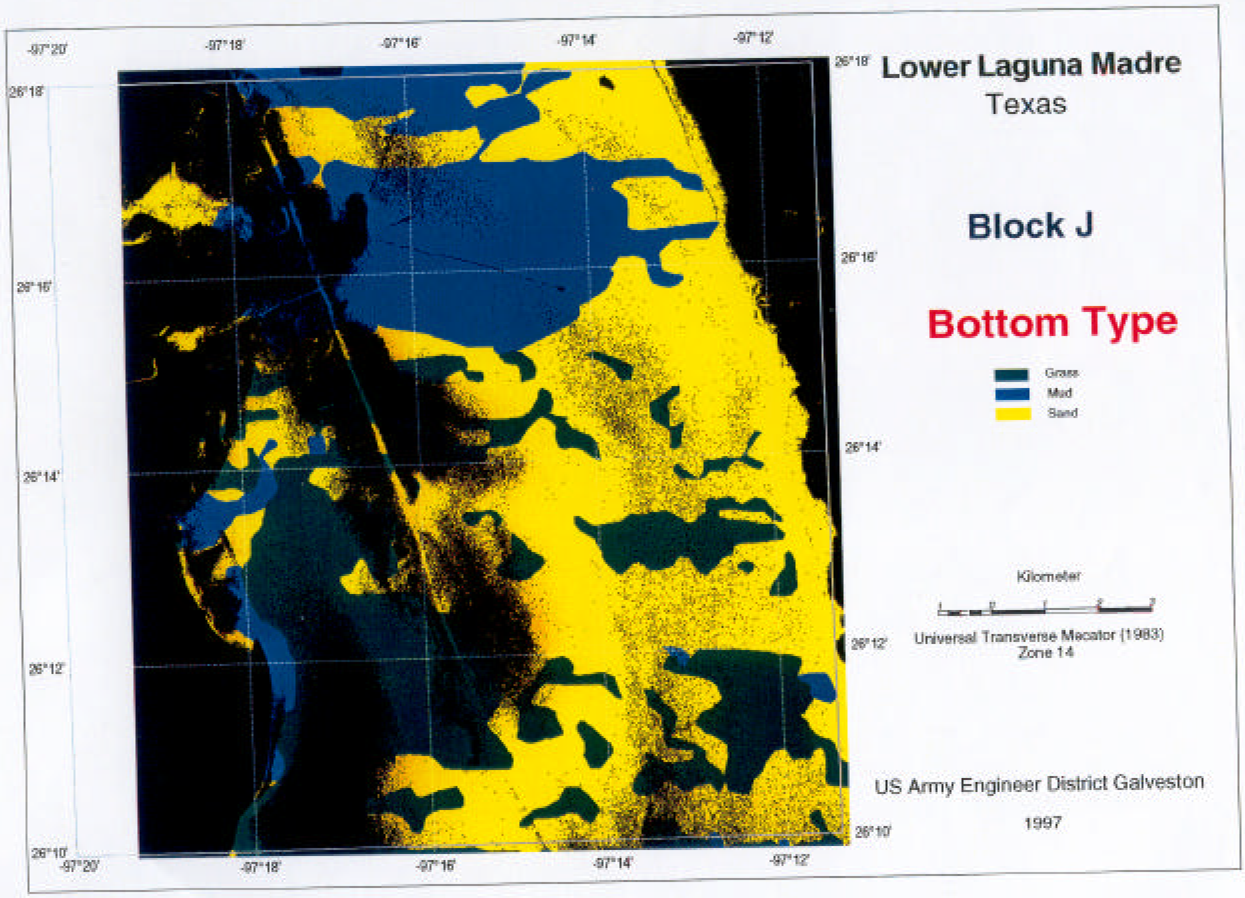
-97°20'
-97°18'
-97°16'
-97°14'
26°26'
26°24'
26°22'
26°20'
26°18'
Lower Laguna Madre
Texas
Block I
Brown Tide
Kilometer
1 0 1 2
Universal Transverse Mecator (1983)
Zone 14
US Army Engineer District Galveston
1997
BROWN TIDE
CONCENTRATION
high
low

APPENDIX J

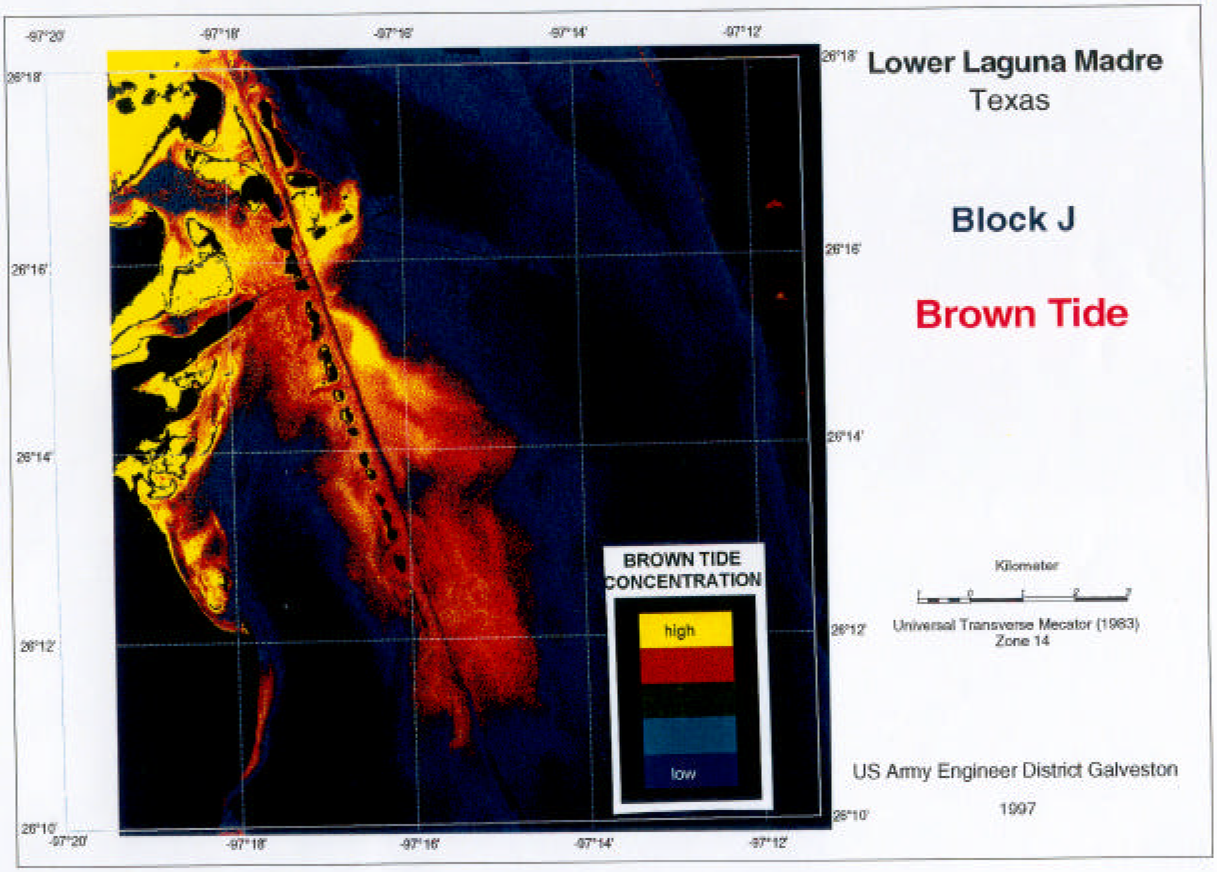
Block J



Block J
Bottom Elevation
(Feet)
-22 - -20
-20 - -18
-18 - -16
-16 - -14
-14 - -12
-12 - -10
-10 - -8
-8 - -6
-6 - -4
-4 - -2
-2 - 0
0 - 2
2 - 4
4 - 6
6 - 8
No Data
97°20'
97°19'
97°18'
97°17'
97°16'
97°15'
97°14'
97°13'
97°12'
97°11'
97°10'
26°18'
26°17'
26°16'
26°15'
26°14'
26°13'
26°12'
26°11'
Kilometers
UTM Zone 14
US Army Engineer District Galveston
1997

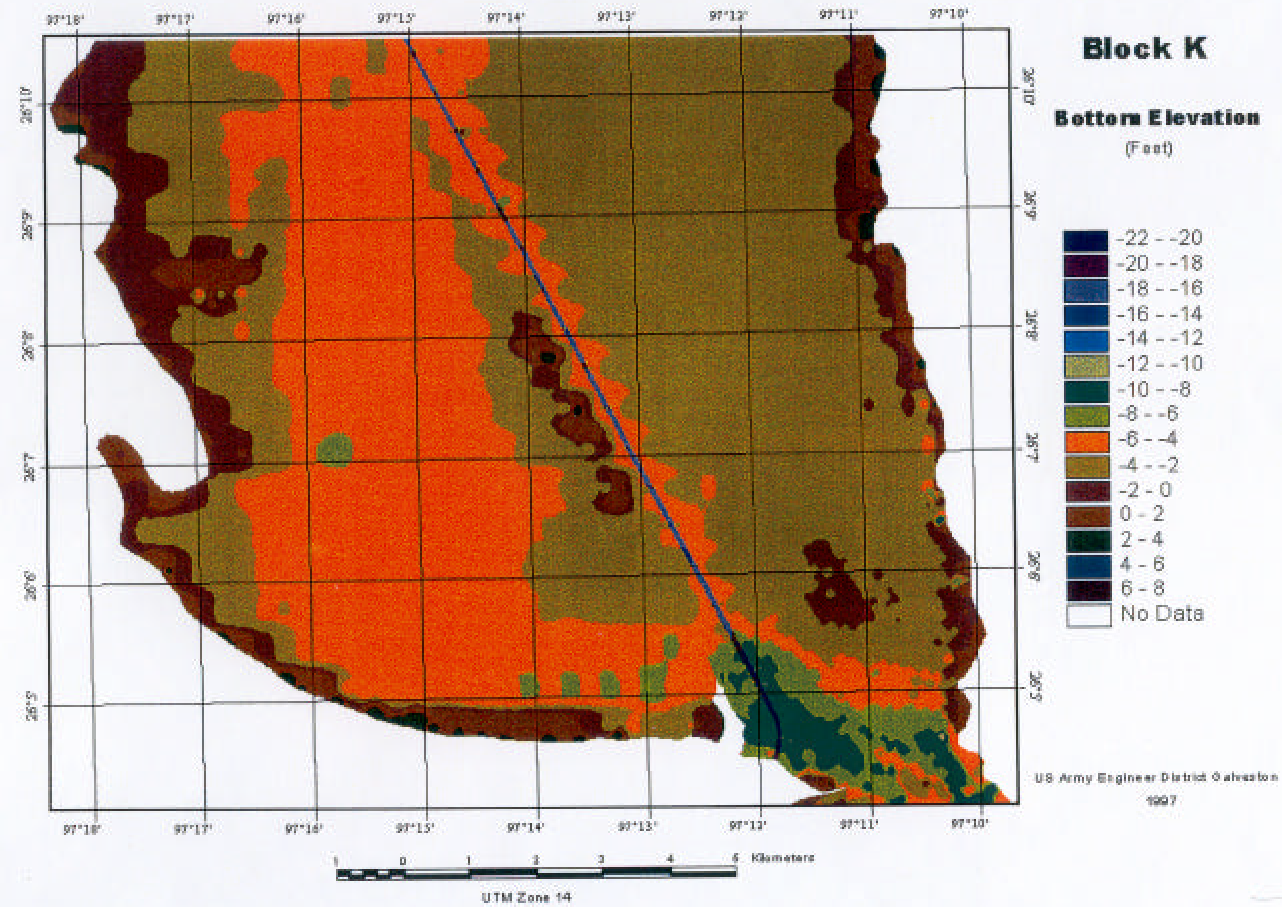


Lower Laguna Madre
Texas
Block J
Bottom Type
Grass
Mud
Sand
Kilometer
Universal Transverse Macator (1983)
Zone 14
US Army Engineer District Galveston
1997
-97°20'
-97°18'
-97°16'
-97°14'
-97°12'
26°18'
26°16'
26°14'
26°12'
26°10'

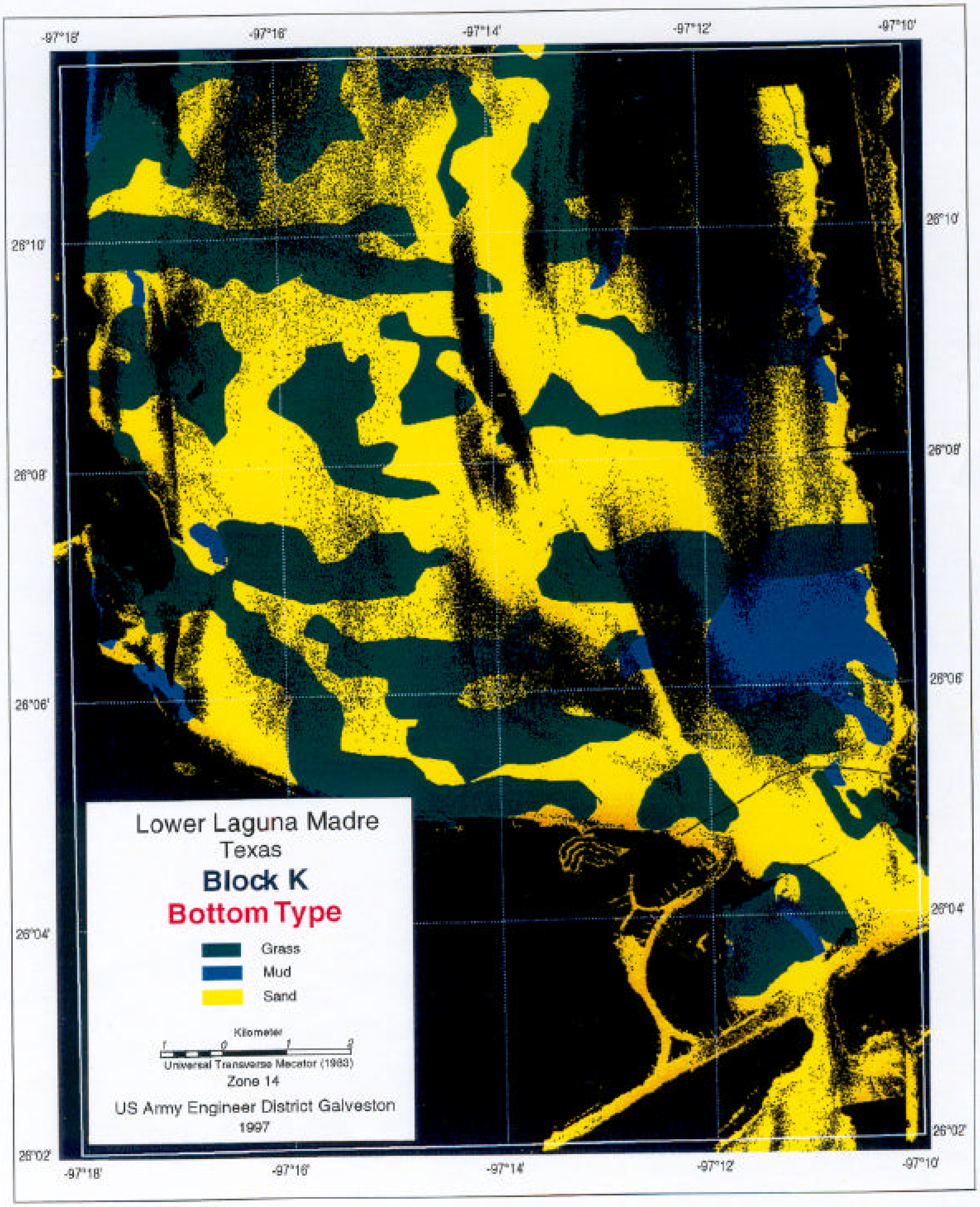

Lower Laguna Madre
Texas
Block J
Brown Tide
BROWN TIDE CONCENTRATION
high
low
Kilometer
Universal Transverse Mecator (1983)
Zone 14
US Army Engineer District Galveston
1997
-97°20'
-97°18'
-97°16'
-97°14'
-97°12'
26°18'
26°16'
26°14'
26°12'
26°10'

APPENDIX K

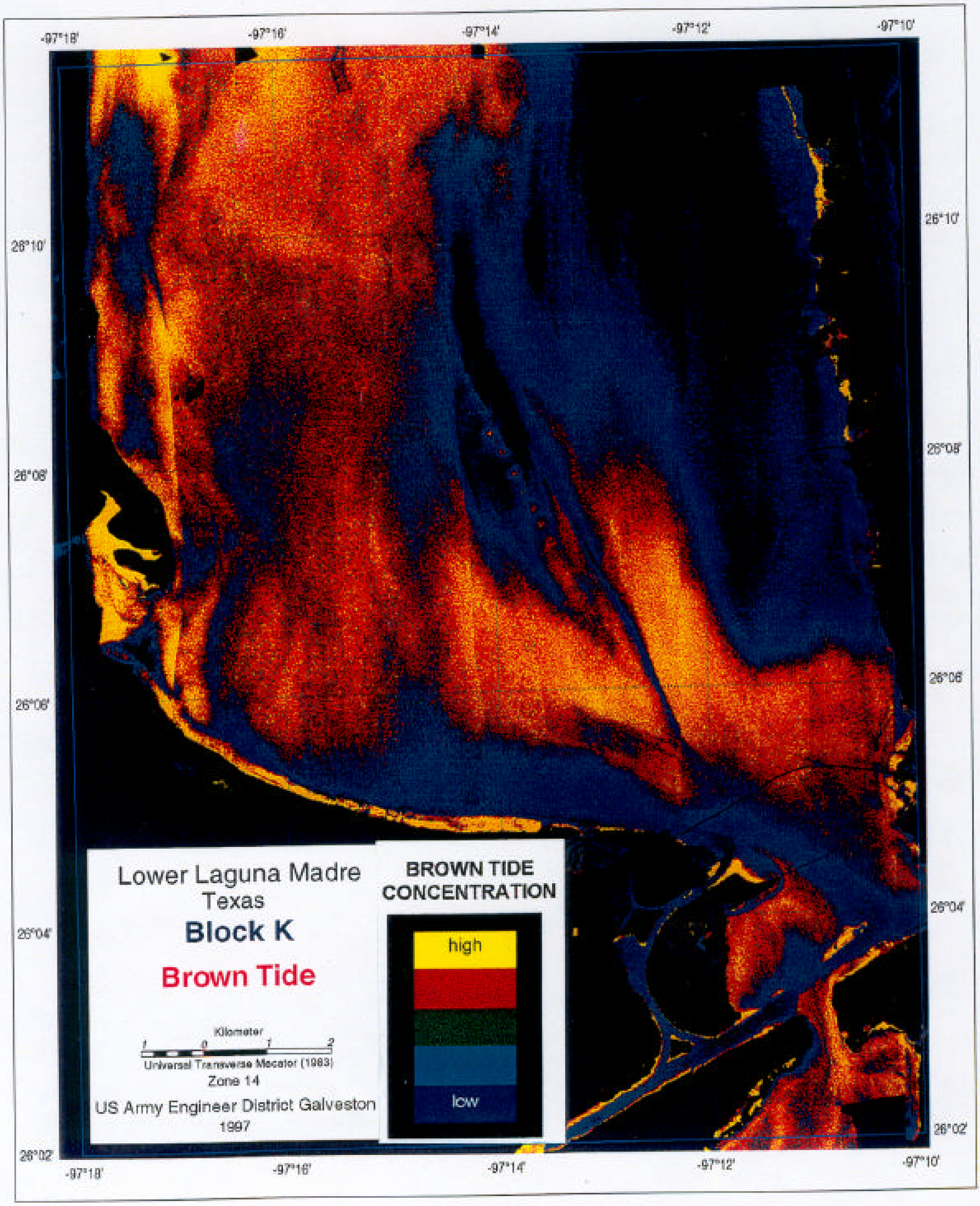
Block K



Block K
Bottom Elevation
(Feet)
-22 - -20
-20 - -18
-18 - -16
-16 - -14
-14 - -12
-12 - -10
-10 - -8
-8 - -6
-6 - -4
-4 - -2
-2 - 0
0 - 2
2 - 4
4 - 6
6 - 8
No Data
US Army Engineer District Galveston
1997
Kilometers
UTM Zone 14



-97°18'
-97°16'
-97°14'
-97°12'
-97°10'
26°10'
26°08'
26°06'
26°04'
26°02'
Lower Laguna Madre
Texas
Block K
Bottom Type
Grass
Mud
Sand
Kilometer
1 0 1 2
Universal Transverse Mecator (1983)
Zone 14
US Army Engineer District Galveston
1997



-97°18'
-97°16'
-97°14'
-97°12'
-97°10'
26°10'
26°08'
26°06'
26°04'
26°02'
Lower Laguna Madre
Texas
Block K
Brown Tide
Kilometer
1 0 1 2
Universal Transverse Mecator (1983)
Zone 14
US Army Engineer District Galveston
1997
BROWN TIDE CONCENTRATION
high
low