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REPORT ON DMA'S PROTOTYPE GRAPHICS FROM ENHANCED  
LANDSAT IMAGERY FOR APPL. (U) DEFENSE MAPPING AGENCY  
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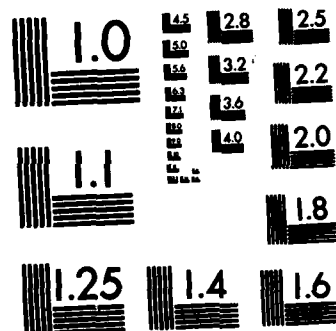
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| REPORT DOCUMENTATION PAGE                                                                                                                                   |                                     | READ INSTRUCTIONS<br>BEFORE COMPLETING FORM                           |  |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------|-----------------------------------------------------------------------|--|
| 1. REPORT NUMBER<br>N/A                                                                                                                                     | 2. GOVT ACCESSION NO.<br>AD-A124123 | 3. RECIPIENT'S CATALOG NUMBER<br>N/A                                  |  |
| 4. TITLE (and Subtitle)<br>REPORT ON DMA'S PROTOTYPE GRAPHICS FROM<br>ENHANCED LANDSAT IMAGERY FOR APPLICATIONS TO<br>HYDROGRAPHIC CHARTING                 |                                     | 5. TYPE OF REPORT & PERIOD COVERED<br>N/A                             |  |
|                                                                                                                                                             |                                     | 6. PERFORMING ORG. REPORT NUMBER<br>N/A                               |  |
| 7. AUTHOR(s)<br>ALONZO D. NAYLOR<br>WILLIAM H. LAFOLLETTE                                                                                                   |                                     | 8. CONTRACT OR GRANT NUMBER(s)<br>N/A                                 |  |
|                                                                                                                                                             |                                     | 10. PROGRAM ELEMENT, PROJECT, TASK<br>AREA & WORK UNIT NUMBERS<br>N/A |  |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>DMAHTC<br>6500 BROOKES LANE<br>BROOKMONT, MARYLAND 20315                                                     |                                     | 12. REPORT DATE<br>5-8 APRIL 1983                                     |  |
|                                                                                                                                                             |                                     | 13. NUMBER OF PAGES<br>31                                             |  |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>CODE HYT                                                                                                         |                                     | 15. SECURITY CLASS. (of this report)<br>UNCLASSIFIED                  |  |
|                                                                                                                                                             |                                     | 15a. DECLASSIFICATION/DOWNGRADING<br>SCHEDULE<br>N/A                  |  |
| 16. DISTRIBUTION STATEMENT (of this Report)<br><br>Approved for public release; distribution unlimited                                                      |                                     |                                                                       |  |
| 17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)<br><br>N/A                                                       |                                     |                                                                       |  |
| 18. SUPPLEMENTARY NOTES<br><br>N/A                                                                                                                          |                                     |                                                                       |  |
| 19. KEY WORDS (Continue on reverse side if necessary and identify by block number)<br><br>Landsat, Hydrographic Surveying, Survey Graphics, Digital, Analog |                                     |                                                                       |  |
| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br><br>SEE REVERSE SIDE                                                   |                                     |                                                                       |  |

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## 20. ABSTRACT

The Defense Mapping Agency (DMA) is currently developing prototype graphics from remotely sensed imagery for support to hydrographic survey planning and DMA's nautical chart maintenance program. The imagery for these prototypes is Landsat scenes that are enhanced by digital image processing techniques, or processed totally in an analog mode for quick response requirements. This paper discusses these processing approaches within the framework of the prototype efforts.

Landsat's multispectral scanner imagery in the Makassar Strait of Indonesia is computer enhanced to highlight hydrographic information such as shoals, uncover areas, land-water boundaries, and shallow water depth intervals. These enhancements are graphically presented in a variety of scales, formats, and color assignments representing three approaches to computer enhancements.

To produce quick response graphics, the analog approach to enhancement involves the use of a color additive viewer and multiscale projector/viewer for analysis of multispectral/multitemporal Landsat film. The prototype graphics using this approach were developed to support DMA's chart maintenance program, but could be used as a tool for survey planning in shallow waters. ←

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DEFENSE MAPPING  
HYDROGRAPHIC/TOPOGRAPHIC CENTER  
WASHINGTON, D.C. 20315

4 DECEMBER 1982

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FOR OPEN PUBLICATION

FEB 1 1983 16

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# REPORT ON DMA'S PROTOTYPE GRAPHICS FROM ENHANCED LANDSAT IMAGERY FOR APPLICATIONS TO HYDROGRAPHIC CHARTING

## I. INTRODUCTION

The Defense Mapping Agency (DMA) is charged with the responsibility of providing safe and adequate nautical chart coverage for all areas of the world outside the U.S. territorial waters. New vessels possessing greater speeds and deeper drafts demand more accurate and timely charts to support an increasing traffic volume in unsurveyed or poorly surveyed areas. Hydrographic survey data used to produce the DMA charts are collected by specially equipped survey vessels of the U.S. Naval Oceanographic Office (NAVOCEANO). At the present collection rates, survey ships will require hundreds of years to collect the needed data to produce current and accurate charts. In addition to the high cost of hydrographic surveying, the time from data collection to portrayal on a published, updated nautical chart is extensive. Electro-optical sensors such as the Landsat's multispectral scanner (MSS) can be used to augment the slow and expensive process of collecting hydrographic information; as well as for an analysis tool used in the chart compilation process, resulting in a nautical chart that is more responsive to the needs of the maritime community.

The Multispectral Scanner (MSS) onboard each of the Landsat 1, 2, and 3 systems contain<sup>s</sup> detectors which are sensitive to a narrow portion of the electromagnetic radiation (EMR) spectrum. The wavelengths of the 4 bands on the MSS are as follows:

- Band 4    0.5 - 0.6 micrometers
- Band 5    0.6 - 0.7 micrometers
- Band 6    0.7 - 0.8 micrometers
- Band 7    0.8 - 1.1 micrometers

Portions of the solar light spectrum pass through a water column, reflect off a seafloor or shoal and return to a detector where it creates a voltage signal, which is then transformed into a digital value. Propagation of light through water depends upon environmental conditions such as water clarity and bottom reflectance, and on wavelength. For the MSS system, the portion of the EMR spectrum detected by band 4 penetrates the water column to a depth of 40 meters under ideal conditions. Band 5 can detect to about 8 meters, band 6 to 0.5 meter and band 7 (used for shoreline definition) has no subsurface detection capability.

A radiometric problem in the first 3 Landsat MSS systems is known as "striping". The six detectors for each band do not respond to the same ground stimulus with equal intensity. This results in a pattern which repeats every six scan lines of a bank thus producing a striping effect in the resultant image. This striping is not uniform across the scene and is particularly troublesome in the most sensitive portions of the dynamic range of bands 4 and 5. Destriping algorithms have been developed that reduce, but do not remove, this MSS detector radiometric noise.

For several years, DMA and NAVOCEANO have been discussing the potential application of Landsat imagery to support the hydrographic survey program. In 1980, DMA launched a project to produce a set of graphics derived from enhanced Landsat imagery that could be used for presurvey planning or survey filed operations. Portions of the southern Makassar Straits in Indonesia were selected for this project to acquire ground truth from an ongoing NAVOCEANO survey.

Three distinctly different approaches were pursued to enhance Landsat imagery for the extraction of hydrographic information:

1. Contract with Environmental Research Institute of Michigan (ERIM) to derive relative water depths,
2. Contract with Earth Satellite Corporation (Earthsat) to derive enhanced depth penetration and shoal outline graphics, and
3. Inhouse processing on the Digital Image Processing System (DIPS) to create interpreted graphics.

All three processing approaches were completed in April 1982. During April-September 1982, DMA created a set of potential survey planning graphics from the combined set of enhanced Landsat graphics produced in each of the three approaches.

As surveying in the Makassar Straits is completed, ground truth will be used to refine the processing algorithms and sequence. The intent of this initial set of graphics is to provide a start-up processing capability which can be refined and improved as necessary.

## II. DESCRIPTION OF PROTOTYPE AREA AND DATA SET

ERIM and Earthsat processed the identical areas labeled Sites A/B and Site C, figures 1 and 2. Five Landsat scenes (2 unique scene centers) were used and collected in 1972, 1973, and 1978. The earliest scenes had considerable system noise. Landsat imagery tapes (CCT's) and film were provided for each scene. DMA Chart 72007 (at a scale of 1:750,000), and a DMA control manuscript (at a scale of 1:300,000), were the source documents used.

The area processed by DMA on the DIPS (figure 3), was a few degrees below sites A/B and C in the straits of Lombok. This area was mostly deep water with shallowing areas only near the major landforms of Bali and Lombok. DMA Charts 72222 (scale 1:200,000) and 72035 (scale 1:497,000) were used as the base documents. Only one Landsat image tape (dated 21 June 1973) was used although Landsat analog images were also obtained to provide some multitemporal analysis.

### III. PROCESSING AND GRAPHICS PRODUCED ON THE DIPS

In 1978, DMA began developing a digital image processing system which included software to extract hydrographic information from remote sensing platforms such as landsat. The experience gained and the processing techniques developed in the analysis of Landsat imagery of coastal areas will serve as the foundation for the digital production support to the nautical chart compilation process.

The essential hardware components of the DIPS include the following:

#### COMTAL Image processing station (Vision 1)

- Dual screen 512 by 512 displays
- 3 planes each of 512 by 512 by 8 bit refresh memory  
(6.3 Megabits total)
- Trackball cursor, keyboard
- 4 overlay planes
- Firmware and image processor

**- Plotters**

**- Versatec**

**- Applicon, Ink jet**

**- 5 Tape drives (800/1600 BPI, 125 IPS)**

**Disk drives**

**- 2 DEC RA60**

**- 1 DEC RA81**

**- 1 DEC RP04**

**- Terminals**

**- 2 DEC VT100**

**- 1 Tektronix 4014**

**- 1 LA36 Decwriter**

**- PDP 11/45 Minicomputer**

**- 128K main core**

**- floating point processor**

The software components include:

- RSX 11M, Version 4.0 operating system
- Menu driven application software for controlling image processing operations
- Water depth algorithms

Of the many presentations developed on the DIPS, the most useful sets of graphics were those derived from pseudo color processing and from infrared imagery. Reference 2 provides a full description of the processing performed and scaled down versions of all the graphics produced. Pre-processing steps included:

- a. Destriping (Constrained moving window average), and
- b. Contrast enhancement (look up table to define subsurface detail and land/water interface)

Both presentations were geometrically corrected to a transverse mercator projection (UTM grid) 1:80,000 scale. Sixteen subscenes (512 by 512 pixel) of the Landsat scene were separately processed and plotted. The plots were photographically scaled to 1:200,000.

The graphics derived from infrared imagery were produced using bands 4, 5, and 7; which produce a color scheme of vegetation - red, culture - grey, <sup>and</sup> water - blue. The pseudo color graphs were produced as a combination of bands 4 and

7 only. Band 4 was additionally enhanced by a technique known as "density slicing"; in which pixel grey level ranges were classified according to the hydrographic, environmental, or image "noise" information they represented. These classes were color coded and combined with a land mask overlay developed from band 7.

The pseudo color and infrared derived graphics were used to develop an interpreted graphic (figure 4). On this graphic, "deep water" is defined as areas where the depth is approximately 18 meters or greater. Subsurface hydrographic information depicted on this graphic is at depths less than 18 meters. This graphic will be a standard final product to be used by cartographers as a source in the chart compilation process. In Landsat scenes used to derive these graphics, environmental noise masked large areas so that no useful hydrographic information could be extracted. These areas are classified as "uninterpreted". This noise is in the form of clouds and surface turbidity. Also, system noise, mainly from the striping (or "banding") problem, was rather severe on this scene. The amount of hydrographic information extracted from this processing was reduced by a general lack of significant shallow water, reefs, shoaling areas and scene noise.

Over the next 2 years, additional hardware and software will be added to the DIPS. There remains several software processing limitations which must be addressed to make the most effective use of the DIPS. Reference 4 contains a detailed description of these limitations. It is the intention of DMA to eventually perform all image processing on the DIPS, rather than contracting out some of this work as in the Makassar project.

#### IV. CONTRACT WITH ERIM

Since 1975 ERIM has been developing, under contract to DMA, techniques and algorithms for deriving shallow water depths from multispectral imagery. These algorithms have been transferred to DMA and installed on the DIPS.

The calculation of water depth is based on the exponential attenuation of light with increasing water depth. This attenuation factor is dependent on wavelength (Landsat's MSS 4 having the deepest penetration) and on numerous environmental conditions (water quality, bottom reflectance, etc.). Two adjacent bottom areas at the same depth, but with distinctly different bottom types (grass versus sand), have different reflectances. This results in different pixel grey shade values for these areas and subsequent difference in the depth calculations. In shallow water areas where both MSS 4 and 5 penetrate to the bottom, ratios of MSS 4 and 5 can be used to minimize the effects of changing bottom types. In deeper waters (greater than 5-7 meters), MSS 5 attenuates completely so that only MSS 4 is receiving any return signal. In this case, since the water depth equations make the assumption that bottom types are uniform throughout, MSS 4 must be "modified" to account for these changing bottom reflectances. Areas of four different but uniform bottom types were estimated by DMA and used to compute an offset in the calculation of depth. In tidal areas where both bands 5 and 6 penetrated to the bottom, ratios of MSS 5 and 6 were also formed. Since all 4 Landsat bands contain noise, threshold values were determined for each band below which the signal return was judged to have attenuated.

The basic equations used in the depth calculations were as follows:

Single band (MSS 4) Method

$$V = V_s + (V_o) e^{-2KZ}$$

Ration (MSS 4/MSS 5) Method

$$\frac{V(4) - V_s(4)}{V(5) - V_s(5)} = \frac{V_o(4)}{V_o(5)} e^{-2(K(5) - K(4))Z}$$

where  $V$  = obs. signal (in band 4 or 5)

$K$  = water attenuation coefficient (for band 4 or 5)

$Z$  = depth

$V_s$  = deep water threshold signal

$V_o$  is coefficient dependent on the solar irradiance at the surface, the bottom reflectance, the atmospheric transmission, and the sensor.

The processing sequence and the graphics to be produced by ERIM are described in figure 5. The graphics for each of two test sites included water depth prints and transparencies from 2 processes and displayed in three formats.

Each graphic is a composite of the single band MSS 4 and the two ratio methods. (MSS 4/MSS 5 and MSS 5/MSS 6). When both bands MSS 4 and MSS 5 penetrated

to the bottom, depths were computed only from the ratio of MSS 4/MSS 5. In the very shallow water areas (e.g., uncovers) where MSS 6 penetrated also, only the ratio of bands MSS 5/MSS 6 was used. In the deeper waters where only band 4 receives reflected energy from the bottom, graphics were developed for comparison using both MSS 4 modified and unmodified for changing bottom reflectance.

Each graphic is color coded for a depth range of 0.6 meters using a color "look up" table described in table 1. Scales of 1:167,000 and 1:300,000 were used for final output.

Some details of the processing steps include:

a. Destriping

Using histogram normalization

b. Geometric Correction

The data was resampled to a 40 M by 40 M grid using a nearest neighbor technique. Resampling was done to a transverse mercator projection on a UTM grid. Control points were used to interactively adjust the Landsat ephemeris (roll, pitch, yaw, etc.).

**c. Removal of Varying Surface & Haze Effects**

The variation in band 7 above its threshold signal in deep water was used to determine sun glint, surface turbulence, etc., in bands 4, 5, and 6.

These graphics provided estimates of depth zones which were generalized and collapsed into fewer depth zones at DMA. This will be a standard product at DMA to be used in presurvey planning, survey operations, and as a source manuscript in the nautical chart compilation process.

**V. CONTRACT WITH EARTH SATELLITE CORPORATION**

The third approach was to enhance the imagery to maximize the extraction of hydrographic information from Landsat imagery. This was specified in a contract let to Earth Satellite Corporation in Bethesda, Maryland. The objective of this contract was to obtain a color enhanced mosaic of three Landsat scenes in the Makassar Straits. The graphics produced were at a scale of 1:300,000 on a transverse mercator projection and emphasized portrayal of the submerged features in the imagery.

The Earth Satellite Corporation performed all enhancements in a digital mode on their Grinnell image processing system, which contains the following components:

**H/W- GMR 270 image processing subsystem**

- 4 image channels
- 512 by 512 pixel refresh memory/channel
- 4 graphic overlay planes
- cursor controls (joysticks)

- Prime 750 minicomputer

**S/W- GEOPIC**

- menu driven interactive system
- Batch software

The description and sequence of processing steps performed were as follows:

**a. Destriping**

Performed radiometric recalibration to remove striping effects from the Landsat scene. This was done by a technique known as cumulative histogram matching in which a point by point connection is applied to each pixel value for each of the 6 Landsat detectors per spectral band.

**b. Decorrelation**

$$\text{Band } 4' = 0.9 * \text{Band } 4 - 0.1 * \text{Band } 5$$

$$\text{Band } 5' = 0.9 * \text{Band } 5 - 0.1 * \text{Band } 4$$

c. Geometric Correction

Correction for Landsat systematic errors

Cubic convolution sampling to UTM Grid

d. Contrast Stretch

e. Color Composite

Water area - decorrelated bands 4 and 5

Land area - band 7 and decorrelated bands 4 and 5

Three Landsat scenes were processed digitally in this sequence. Output of each scene was an Optronics plotted film image. These films were photographically mosaicked and photographed with a copy camera.

The final output product was a graphic which significantly improved the definition of shoaling areas in the scene. The color contrast between shallow water and deep water (completely attenuated light) areas was greatly enhanced permitting discrimination of shoals from environmental phenomena. This processing technique will become a standard enhancement for the DMA production system.

VI. COMBINED GRAPHICS OBTAINED FROM THE THREE APPROACHES

All graphics produced by DMA's image processing system (DIPS) and by

work performed under contract with ERIM and ESC were combined and generalized into 4 types of presentations:

- Enhanced shoals
- Interpreted overlays
- Residual overlays
- Color coded water depth

These presentations formats were determined to be most useful to DMA and NAVOCEANO in support of presurvey planning, survey operations, and they will be used as source documents in the chart compilation process. These graphics will be produced at the scale and projection of the base manuscript.

A. Enhanced Shoals: (figure 6) An enhanced Landsat graphic similar to that produced by the Earth Satellite Corporation that will depict shoals, reefs, and other submerged hazards. This graphic will supplement the "Interpreted Overlay" and the "Residual Overlay".

B. Interpreted Overlays: (figure 7) Overlays containing interpreted areas - shoals, reefs, hazards, deep water, etc. - derived from enhanced Landsat imagery. These overlays will also identify the limits of penetration (areas where depths are determined to be shallower than a determined value) as well as uninterpreted area due to cloud cover, haze, water turbidity, etc. The total area of the overlay will be labeled with descriptive identifiers.

C. Residual Overlay: (figure 8) This overlay will also be registered to the nautical chart. It will highlight only the differences between hydrographic information extracted from enhanced Landsat imagery and the existing nautical chart. As such, it will identify uncharted shoals, improperly charted soundings, and existence of hazards not identified on the chart.

D. Color Coded Water Depth: (figure 9) These graphics will be developed at scales no larger than 1:50,000. At scales of 1:50,000, Landsat derived manuscripts will be used only when no other reliable data exists. This data will be depicted on the chart as position approximate (P.A.). They will consist of zones of relative depths computed from an algorithm developed for DMA by ERIM. Constrasting colors will be assigned to each zone. A typical graphic will contain the following depth zones:

Land

Low tide (uncovers) to 5 meters

5 - 10 meters

10 - 20 meters

deep water, greater than 20 meters

This graphic will be developed only with digital processing and only when good quality landsat CCT's are available. A gridded overlay will be registered along with this graphic to the appropriate chart.

## **VII. DEVELOPMENT OF A PRODUCTION SYSTEM**

Production of graphics derived from Landsat imagery will be done on the Hydrographic Image Exploitation System (HIES), under development at DMA (figure 10). The analog subsystem of the HIES contains the following:

### **a. Color Additive Viewer (CAV)**

This is used to superimpose 3 spectral bands through red, blue, and green color filters onto a common screen. Adjustments to color assignments and intensity can be made to enhance selected details in the combined image. Features of this system include:

- 5 channels
- 70 mm film format for each channel
- individual potentiometers for each channel light
- X-Y and rotational controls
- 3X lens on each channel
- 4 filter options (red, blue, green, clear)

### **b. Multiscale Projection/Viewer (MSP/V)**

This rear projection system provides a means for rapid comparison between film imagery and an existing chart or manuscript of the same area. Features of this system include:

- film formats supported  
(35 mm & 70 mm both roll & chip, 241 mm chip)
- backlighted, tiltable table from  $0^{\circ}$  -  $35^{\circ}$
- rotation and magnification of film to match scale projection  
of chart mounted on table.
- enlargement from 2X to 82X
- metric accuracy to plus or minus 1 mm at chart scale

The analog/digital subsystem of the HIES is the Analog Image Manipulation and Analysis System (AIMAS) which is a LogE/ISI Views 200 System. Imagery can be scanned, digitized, enhanced, and output to film. This subsystem provides a means for rapid digital enhancement of analog Landsat imagery. Features include:

- vidicon Camera
- digitizing subsystem
- CRT display with refresh memory
- isometric projection subsystem
- Matrix camera subsystem

The digital subsystem of the HIES has already been described in section III.

Four presentations (section VI) developed from Landsat imagery will be end products of a production effort at DMA. However, as this program evolves, these graphics will expand and possibly change in format and content. As much processing as possible will be done at DMA on the HIES. However, some processing may be done under contractual arrangements until the HIES is fully developed. Routinely,

these graphics will be developed from Landsat imagery using analog processes. However, where fine detail is needed and where Landsat computer compatible tapes (CCT's) are available, these graphics will be developed from digital processing which is more rigorous and accurate. In either case, the largest scale routinely supportable is 1:100,000. A summary of the three image processing modes to be used at DMA and an estimate of relative processing times are given in figure 11.

## VIII. CONCLUSION

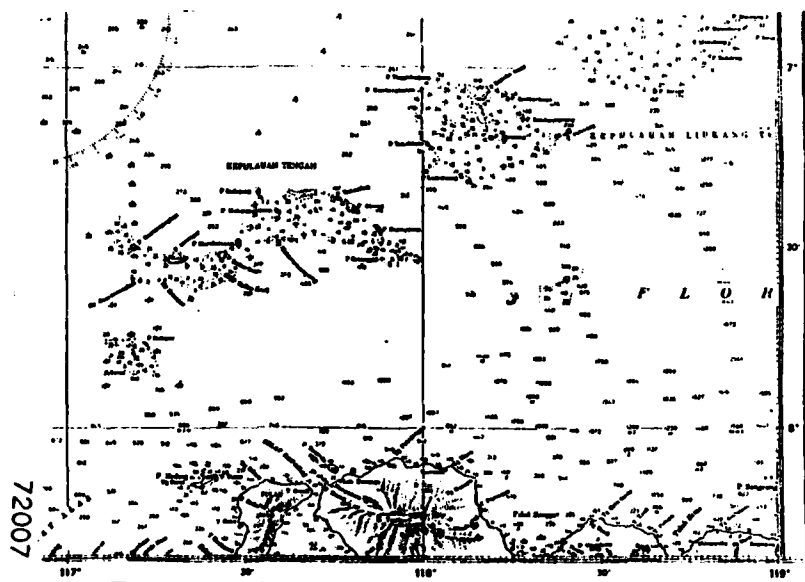
The major thrust of this project was to demonstrate Landsat imagery enhancement techniques, available in a digital mode to extract hydrographic information in support of nautical charting and surveying operations. The combined set of graphics and the techniques used to create them should provide a firm framework for a standard set of processing parameters, enhancement techniques, and display formats to be developed for the production environment at DMA.

The thematic mapper (TM) in Landsat 4 should be significantly more useful for hydrographic applications. The spectral range and wavelength of the TM bands, which are better suited for shallow water feature detection than MSS, combined with the improved spatial resolution of Landsat 4 offer great promise to the DMA charting program.

The application of remote sensors, such as Landsat, airborne active/passive scanners and Synthetic Aperture Radar (SAR), to hydrographic data collection represents a new and promising generation of technology that can and must be exploited to improve navigational safety for ocean travelers.

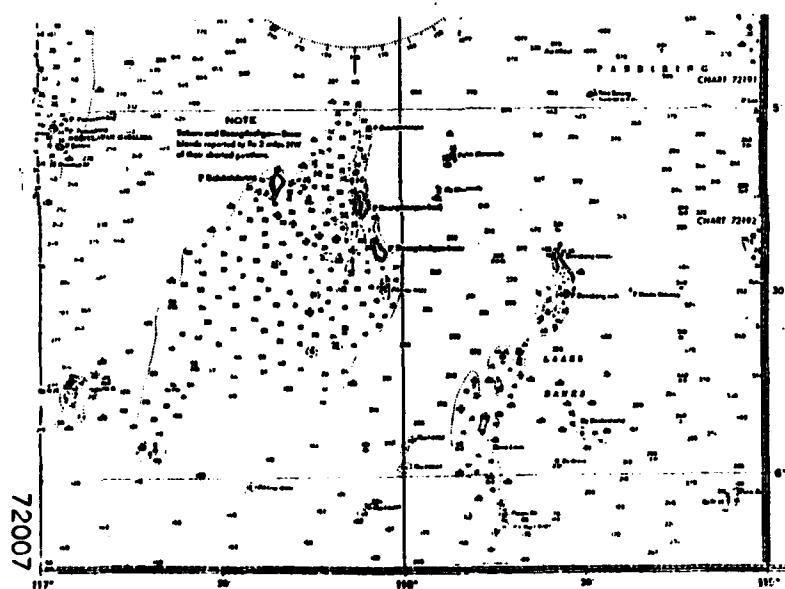
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6. DMAHTC, Statement of Work for contract award to the Environmental Research Institute of Michigan, February 1981.



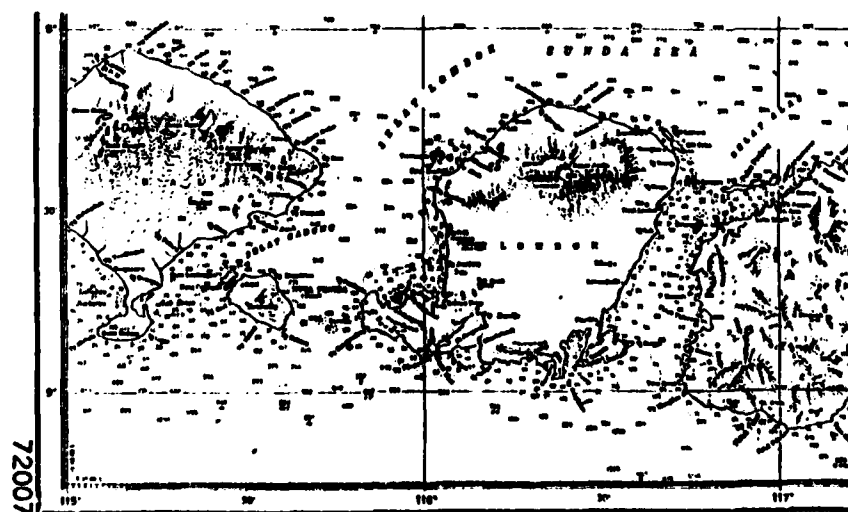
Indonesia  
Southern Part of  
Makassar Straits  
Chart Scale - 1:750,000  
Site A/B

Figure 1



Indonesia  
Southern Part of  
Makassar Straits  
Chart Scale - 1:750,000  
Site C

Figure 2



Indonesia  
Southern Part of  
Makassar Straits  
Chart Scale  
1:750,000

Figure 3

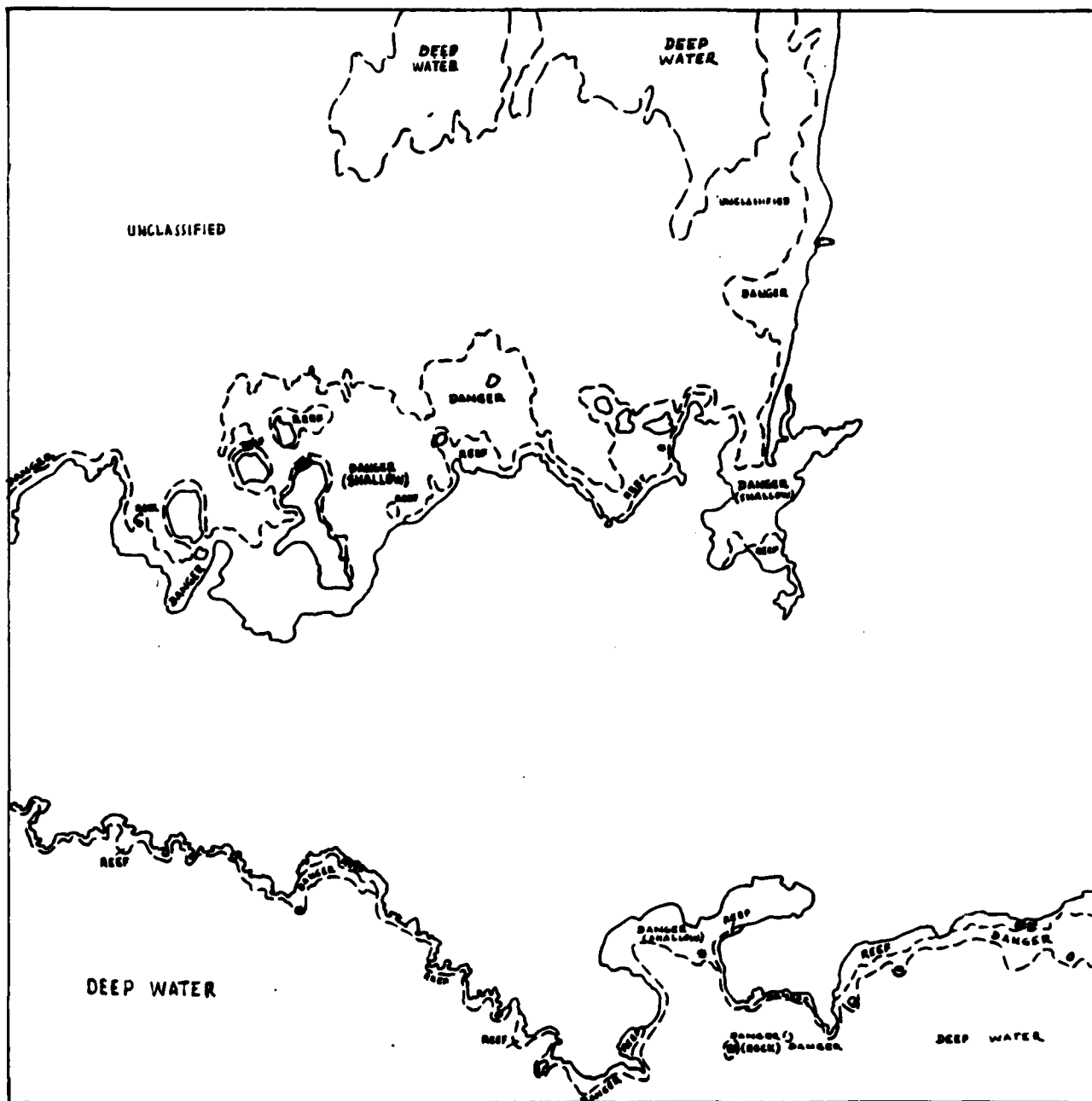
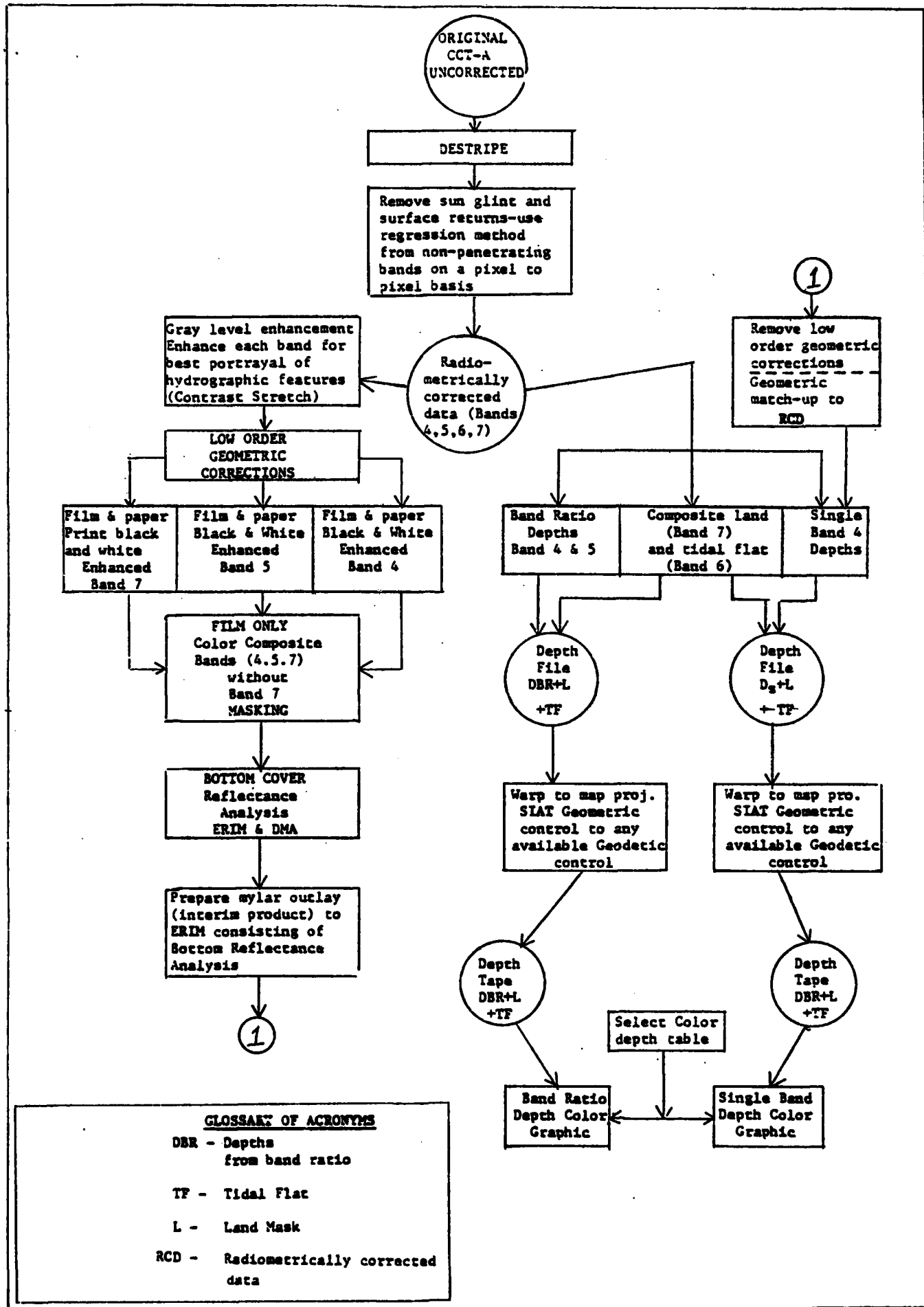


Figure 4

OVERLAY TO PSUEDO COLOR GRAPHICS



PROCESSING FLOW DIAGRAM FOR ERIM CONTRACT

Figure 5

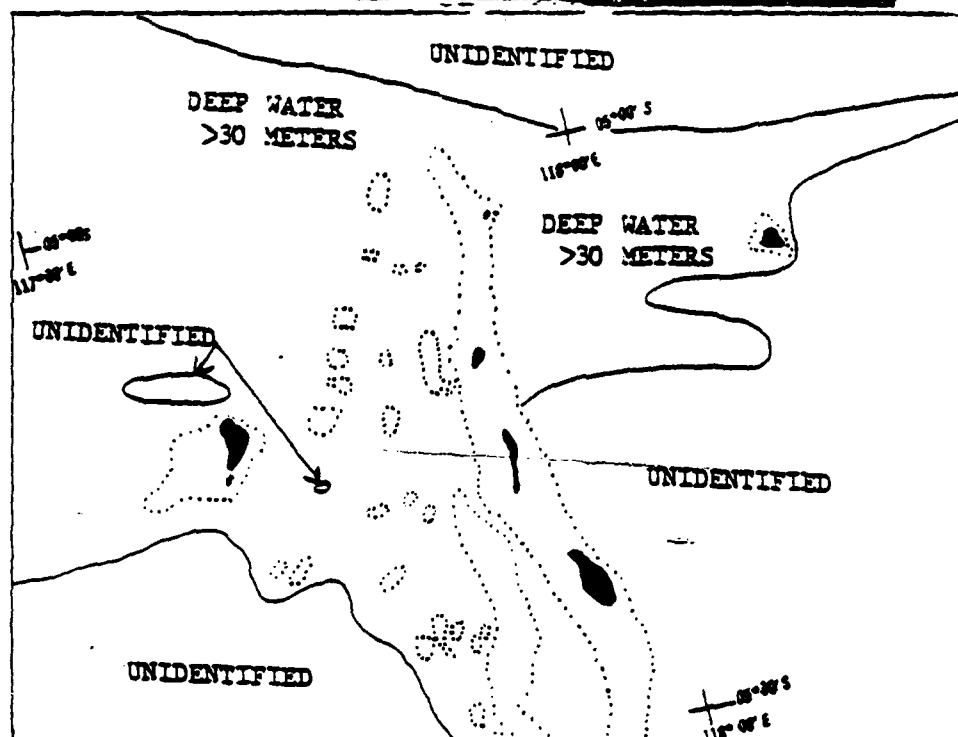
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|-----------------|-----|-----------------|-----|
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| 1.0 - 1.6       | 477 | 3.4 - 3.6       | 477 |
| 1.6 - 2.2       | 377 | 3.6 - 3.8       | 377 |
| 2.2 - 2.8       | 277 |                 |     |
| 2.8 - 3.4       | 177 |                 |     |
| 3.4 - 4.0       | 144 |                 |     |
| 4.0 - 4.6       | 133 |                 |     |
| 4.6 - 5.2       | 173 |                 |     |

| SS 4 Alone    |     | SS 4 Modified |     |
|---------------|-----|---------------|-----|
| 3.0 - 1.6     | 777 | 3.0 - 1.0     | 373 |
| 1.6 - 2.2     | 566 | 1.0 - 1.6     | 777 |
| 2.2 - 2.8     | 555 | 1.6 - 2.2     | 566 |
| 2.8 - 3.4     | 444 | 2.2 - 2.8     | 555 |
| 3.4 - 4.0     | 333 | 2.8 - 3.4     | 444 |
| 4.0 - 4.6     | 222 | 3.4 - 4.0     | 333 |
| 4.6 - 5.2     | 111 | 4.0 - 4.6     | 222 |
| 5.2 - 5.8     | 744 | 4.6 - 5.2     | 111 |
| 5.8 - 6.4     | 733 | 5.2 - 5.8     | 744 |
| 6.4 - 7.0     | 722 | 5.8 - 6.4     | 733 |
| 7.0 - 7.6     | 711 | 6.4 - 7.0     | 722 |
| 7.6 - 8.2     | 700 | 7.0 - 7.6     | 711 |
| 8.2 - 8.8     | 474 | 7.6 - 8.2     | 700 |
| 8.8 - 9.4     | 272 | 8.2 - 8.8     | 474 |
| 9.4 - 10.0    | 370 | 8.8 - 9.4     | 272 |
| 10.0 - 10.6   | 340 | 9.4 - 10.0    | 370 |
| 10.6 - 11.2   | 330 | 10.0 - 10.6   | 340 |
| 11.2 - 11.8   | 747 | 10.6 - 11.2   | 330 |
| 11.8 - 12.4   | 727 | 11.2 - 11.8   | 747 |
| 12.4 - 13.0   | 707 | 11.8 - 12.4   | 727 |
| 13.0 - 13.6   | 494 | 12.4 - 13.0   | 707 |
| 13.6 - 14.2   | 383 | 13.0 - 13.6   | 494 |
| 14.2 - 14.8   | 447 | 13.6 - 14.2   | 383 |
| 14.8 - 15.4   | 337 | 14.2 - 14.8   | 447 |
| 15.4 - 16.0   | 227 | 14.8 - 15.4   | 337 |
| 16.0 - 17.0   | 227 | 15.4 - 16.0   | 227 |
| 17.0 - 19.0   | 397 | 16.0 - 17.0   | 227 |
| 19.0 - 20.0   | 393 | 17.0 - 19.0   | 397 |
| 20.0 - 21.0   | 393 | 19.0 - 19.6   | 393 |
| 21.0 - 22.0   | 393 | 19.6 - 20.2   | 393 |
| 22.0 - 23.0   | 393 | 20.2 - 20.8   | 393 |
| 23.0 - 24.0   | 393 | 20.8 - 21.4   | 393 |
| 24.0 - 25.0   | 393 | 21.4 - 22.0   | 393 |
| 25.0 - 26.0   | 393 | 22.0 - 22.6   | 393 |
| 26.0 - 27.0   | 393 | 22.6 - 23.2   | 393 |
| 27.0 - 28.0   | 393 | 23.2 - 23.8   | 393 |
| 28.0 - 29.0   | 393 | 23.8 - 24.4   | 393 |
| 29.0 - 30.0   | 393 | 24.4 - 25.0   | 393 |
| 30.0 - 31.0   | 393 | 25.0 - 25.6   | 393 |
| 31.0 - 32.0   | 393 | 25.6 - 26.2   | 393 |
| 32.0 - 33.0   | 393 | 26.2 - 26.8   | 393 |
| 33.0 - 34.0   | 393 | 26.8 - 27.4   | 393 |
| 34.0 - 35.0   | 393 | 27.4 - 28.0   | 393 |
| 35.0 - 36.0   | 393 | 28.0 - 28.6   | 393 |
| 36.0 - 37.0   | 393 | 28.6 - 29.2   | 393 |
| 37.0 - 38.0   | 393 | 29.2 - 29.8   | 393 |
| 38.0 - 39.0   | 393 | 29.8 - 30.4   | 393 |
| 39.0 - 40.0   | 393 | 30.4 - 31.0   | 393 |
| 40.0 - 41.0   | 393 | 31.0 - 31.6   | 393 |
| 41.0 - 42.0   | 393 | 31.6 - 32.2   | 393 |
| 42.0 - 43.0   | 393 | 32.2 - 32.8   | 393 |
| 43.0 - 44.0   | 393 | 32.8 - 33.4   | 393 |
| 44.0 - 45.0   | 393 | 33.4 - 34.0   | 393 |
| 45.0 - 46.0   | 393 | 34.0 - 34.6   | 393 |
| 46.0 - 47.0   | 393 | 34.6 - 35.2   | 393 |
| 47.0 - 48.0   | 393 | 35.2 - 35.8   | 393 |
| 48.0 - 49.0   | 393 | 35.8 - 36.4   | 393 |
| 49.0 - 50.0   | 393 | 36.4 - 37.0   | 393 |
| 50.0 - 51.0   | 393 | 37.0 - 37.6   | 393 |
| 51.0 - 52.0   | 393 | 37.6 - 38.2   | 393 |
| 52.0 - 53.0   | 393 | 38.2 - 38.8   | 393 |
| 53.0 - 54.0   | 393 | 38.8 - 39.4   | 393 |
| 54.0 - 55.0   | 393 | 39.4 - 40.0   | 393 |
| 55.0 - 56.0   | 393 | 40.0 - 40.6   | 393 |
| 56.0 - 57.0   | 393 | 40.6 - 41.2   | 393 |
| 57.0 - 58.0   | 393 | 41.2 - 41.8   | 393 |
| 58.0 - 59.0   | 393 | 41.8 - 42.4   | 393 |
| 59.0 - 60.0   | 393 | 42.4 - 43.0   | 393 |
| 60.0 - 61.0   | 393 | 43.0 - 43.6   | 393 |
| 61.0 - 62.0   | 393 | 43.6 - 44.2   | 393 |
| 62.0 - 63.0   | 393 | 44.2 - 44.8   | 393 |
| 63.0 - 64.0   | 393 | 44.8 - 45.4   | 393 |
| 64.0 - 65.0   | 393 | 45.4 - 46.0   | 393 |
| 65.0 - 66.0   | 393 | 46.0 - 46.6   | 393 |
| 66.0 - 67.0   | 393 | 46.6 - 47.2   | 393 |
| 67.0 - 68.0   | 393 | 47.2 - 47.8   | 393 |
| 68.0 - 69.0   | 393 | 47.8 - 48.4   | 393 |
| 69.0 - 70.0   | 393 | 48.4 - 49.0   | 393 |
| 70.0 - 71.0   | 393 | 49.0 - 49.6   | 393 |
| 71.0 - 72.0   | 393 | 49.6 - 50.2   | 393 |
| 72.0 - 73.0   | 393 | 50.2 - 50.8   | 393 |
| 73.0 - 74.0   | 393 | 50.8 - 51.4   | 393 |
| 74.0 - 75.0   | 393 | 51.4 - 52.0   | 393 |
| 75.0 - 76.0   | 393 | 52.0 - 52.6   | 393 |
| 76.0 - 77.0   | 393 | 52.6 - 53.2   | 393 |
| 77.0 - 78.0   | 393 | 53.2 - 53.8   | 393 |
| 78.0 - 79.0   | 393 | 53.8 - 54.4   | 393 |
| 79.0 - 80.0   | 393 | 54.4 - 55.0   | 393 |
| 80.0 - 81.0   | 393 | 55.0 - 55.6   | 393 |
| 81.0 - 82.0   | 393 | 55.6 - 56.2   | 393 |
| 82.0 - 83.0   | 393 | 56.2 - 56.8   | 393 |
| 83.0 - 84.0   | 393 | 56.8 - 57.4   | 393 |
| 84.0 - 85.0   | 393 | 57.4 - 58.0   | 393 |
| 85.0 - 86.0   | 393 | 58.0 - 58.6   | 393 |
| 86.0 - 87.0   | 393 | 58.6 - 59.2   | 393 |
| 87.0 - 88.0   | 393 | 59.2 - 59.8   | 393 |
| 88.0 - 89.0   | 393 | 59.8 - 60.4   | 393 |
| 89.0 - 90.0   | 393 | 60.4 - 61.0   | 393 |
| 90.0 - 91.0   | 393 | 61.0 - 61.6   | 393 |
| 91.0 - 92.0   | 393 | 61.6 - 62.2   | 393 |
| 92.0 - 93.0   | 393 | 62.2 - 62.8   | 393 |
| 93.0 - 94.0   | 393 | 62.8 - 63.4   | 393 |
| 94.0 - 95.0   | 393 | 63.4 - 64.0   | 393 |
| 95.0 - 96.0   | 393 | 64.0 - 64.6   | 393 |
| 96.0 - 97.0   | 393 | 64.6 - 65.2   | 393 |
| 97.0 - 98.0   | 393 | 65.2 - 65.8   | 393 |
| 98.0 - 99.0   | 393 | 65.8 - 66.4   | 393 |
| 99.0 - 100.0  | 393 | 66.4 - 67.0   | 393 |
| 100.0 - 101.0 | 393 | 67.0 - 67.6   | 393 |
| 101.0 - 102.0 | 393 | 67.6 - 68.2   | 393 |
| 102.0 - 103.0 | 393 | 68.2 - 68.8   | 393 |
| 103.0 - 104.0 | 393 | 68.8 - 69.4   | 393 |
| 104.0 - 105.0 | 393 | 69.4 - 70.0   | 393 |
| 105.0 - 106.0 | 393 | 70.0 - 70.6   | 393 |
| 106.0 - 107.0 | 393 | 70.6 - 71.2   | 393 |
| 107.0 - 108.0 | 393 | 71.2 - 71.8   | 393 |
| 108.0 - 109.0 | 393 | 71.8 - 72.4   | 393 |
| 109.0 - 110.0 | 393 | 72.4 - 73.0   | 393 |
| 110.0 - 111.0 | 393 | 73.0 - 73.6   | 393 |
| 111.0 - 112.0 | 393 | 73.6 - 74.2   | 393 |
| 112.0 - 113.0 | 393 | 74.2 - 74.8   | 393 |
| 113.0 - 114.0 | 393 | 74.8 - 75.4   | 393 |
| 114.0 - 115.0 | 393 | 75.4 - 76.0   | 393 |
| 115.0 - 116.0 | 393 | 76.0 - 76.6   | 393 |
| 116.0 - 117.0 | 393 | 76.6 - 77.2   | 393 |
| 117.0 - 118.0 | 393 | 77.2 - 77.8   | 393 |
| 118.0 - 119.0 | 393 | 77.8 - 78.4   | 393 |
| 119.0 - 120.0 | 393 | 78.4 - 79.0   | 393 |
| 120.0 - 121.0 | 393 | 79.0 - 79.6   | 393 |
| 121.0 - 122.0 | 393 | 79.6 - 80.2   | 393 |
| 122.0 - 123.0 | 393 | 80.2 - 80.8   | 393 |
| 123.0 - 124.0 | 393 | 80.8 - 81.4   | 393 |
| 124.0 - 125.0 | 393 | 81.4 - 82.0   | 393 |
| 125.0 - 126.0 | 393 | 82.0 - 82.6   | 393 |
| 126.0 - 127.0 | 393 | 82.6 - 83.2   | 393 |
| 127.0 - 128.0 | 393 | 83.2 - 83.8   | 393 |
| 128.0 - 129.0 | 393 | 83.8 - 84.4   | 393 |
| 129.0 - 130.0 | 393 | 84.4 - 85.0   | 393 |
| 130.0 - 131.0 | 393 | 85.0 - 85.6   | 393 |
| 131.0 - 132.0 | 393 | 85.6 - 86.2   | 393 |
| 132.0 - 133.0 | 393 | 86.2 - 86.8   | 393 |
| 133.0 - 134.0 | 393 | 86.8 - 87.4   | 393 |
| 134.0 - 135.0 | 393 | 87.4 - 88.0   | 393 |
| 135.0 - 136.0 | 393 | 88.0 - 88.6   | 393 |
| 136.0 - 137.0 | 393 | 88.6 - 89.2   | 393 |
| 137.0 - 138.0 | 393 | 89.2 - 89.8   | 393 |
| 138.0 - 139.0 | 393 | 89.8 - 90.4   | 393 |
| 139.0 - 140.0 | 393 | 90.4 - 91.0   | 393 |
| 140.0 - 141.0 | 393 | 91.0 - 91.6   | 393 |
| 141.0 - 142.0 | 393 | 91.6 - 92.2   | 393 |
| 142.0 - 143.0 | 393 | 92.2 - 92.8   | 393 |
| 143.0 - 144.0 | 393 | 92.8 - 93.4   | 393 |
| 144.0 - 145.0 | 393 | 93.4 - 94.0   | 393 |
| 145.0 - 146.0 | 393 | 94.0 - 94.6   | 393 |
| 146.0 - 147.0 | 393 | 94.6 - 95.2   | 393 |
| 147.0 - 148.0 | 393 | 95.2 - 95.8   | 393 |
| 148.0 - 149.0 | 393 | 95.8 - 96.4   | 393 |
| 149.0 - 150.0 | 393 | 96.4 - 97.0   | 393 |
| 150.0 - 151.0 | 393 | 97.0 - 97.6   | 393 |
| 151.0 - 152.0 | 393 | 97.6 - 98.2   | 393 |
| 152.0 - 153.0 | 393 | 98.2 - 98.8   | 393 |
| 153.0 - 154.0 | 393 | 98.8 - 99.4   | 393 |
| 154.0 - 155.0 | 393 | 99.4 - 100.0  | 393 |
| 155.0 - 156.0 | 393 |               |     |
| 156.0 - 157.0 | 393 |               |     |
| 157.0 - 158.0 | 393 |               |     |
| 158.0 - 159.0 | 393 |               |     |
| 159.0 - 160.0 | 393 |               |     |
| 160.0 - 161.0 | 393 |               |     |
| 161.0 - 162.0 | 393 |               |     |
| 162.0 - 163.0 | 393 |               |     |
| 163.0 - 164.0 | 393 |               |     |
| 164.0 - 165.0 | 393 |               |     |
| 165.0 - 166.0 | 393 |               |     |
| 166.0 - 167.0 | 393 |               |     |
| 167.0 - 168.0 | 393 |               |     |
| 168.0 - 169.0 | 393 |               |     |
| 169.0 - 170.0 | 393 |               |     |
| 170.0 - 171.0 | 393 |               |     |
| 171.0 - 172.0 | 393 |               |     |
| 172.0 - 173.0 | 393 |               |     |
| 173.0 - 174.0 | 393 |               |     |
| 174.0 - 175.0 | 393 |               |     |
| 175.0 - 176.0 | 393 |               |     |
| 176.0 - 177.0 | 393 |               |     |
| 177.0 - 178.0 | 393 |               |     |
| 178.0 - 179.0 | 393 |               |     |
| 179.0 - 180.0 | 393 |               |     |
| 180.0 - 181.0 | 393 |               |     |
| 181.0 - 182.0 | 393 |               |     |
| 182.0 - 183.0 | 393 |               |     |
| 183.0 - 184.0 | 393 |               |     |
| 184.0 - 185.0 | 393 |               |     |
| 185.0 - 186.0 | 393 |               |     |
| 186.0 - 187.0 | 393 |               |     |
| 187.0 - 188.0 | 393 |               |     |
| 188.0 - 189.0 | 393 |               |     |
| 189.0 - 190.0 | 393 |               |     |
| 190.0 - 191.0 | 393 |               |     |
| 191.0 - 192.0 | 393 |               |     |
| 192.0 - 193.0 | 393 |               |     |
| 193.0 - 194.0 | 393 |               |     |
| 194.0 - 195.0 | 393 |               |     |
| 195.0 - 196.0 | 393 |               |     |
| 196.0 - 197.0 | 393 |               |     |
| 197.0 - 198.0 | 393 |               |     |
| 198.0 - 199.0 | 393 |               |     |
| 199.0 - 200.0 | 393 |               |     |



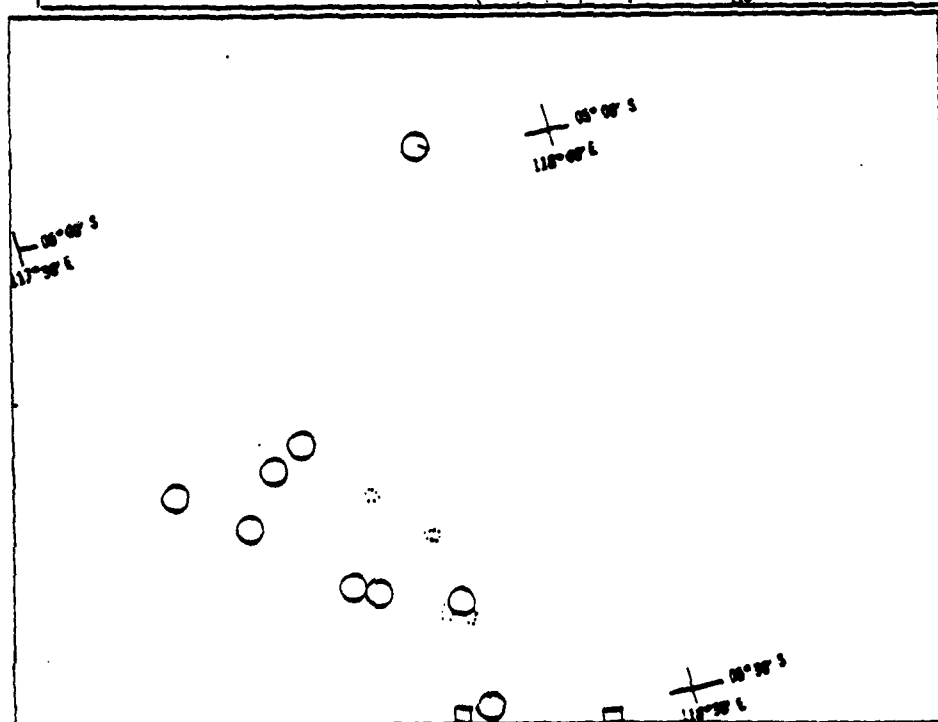
Makassar Strait:  
Original Landsat  
scene, July 1972  
composite of bands  
4, 5, 7

Figure 6



Interpreted Graphic  
derived from enhanced  
Landsat

Figure 7



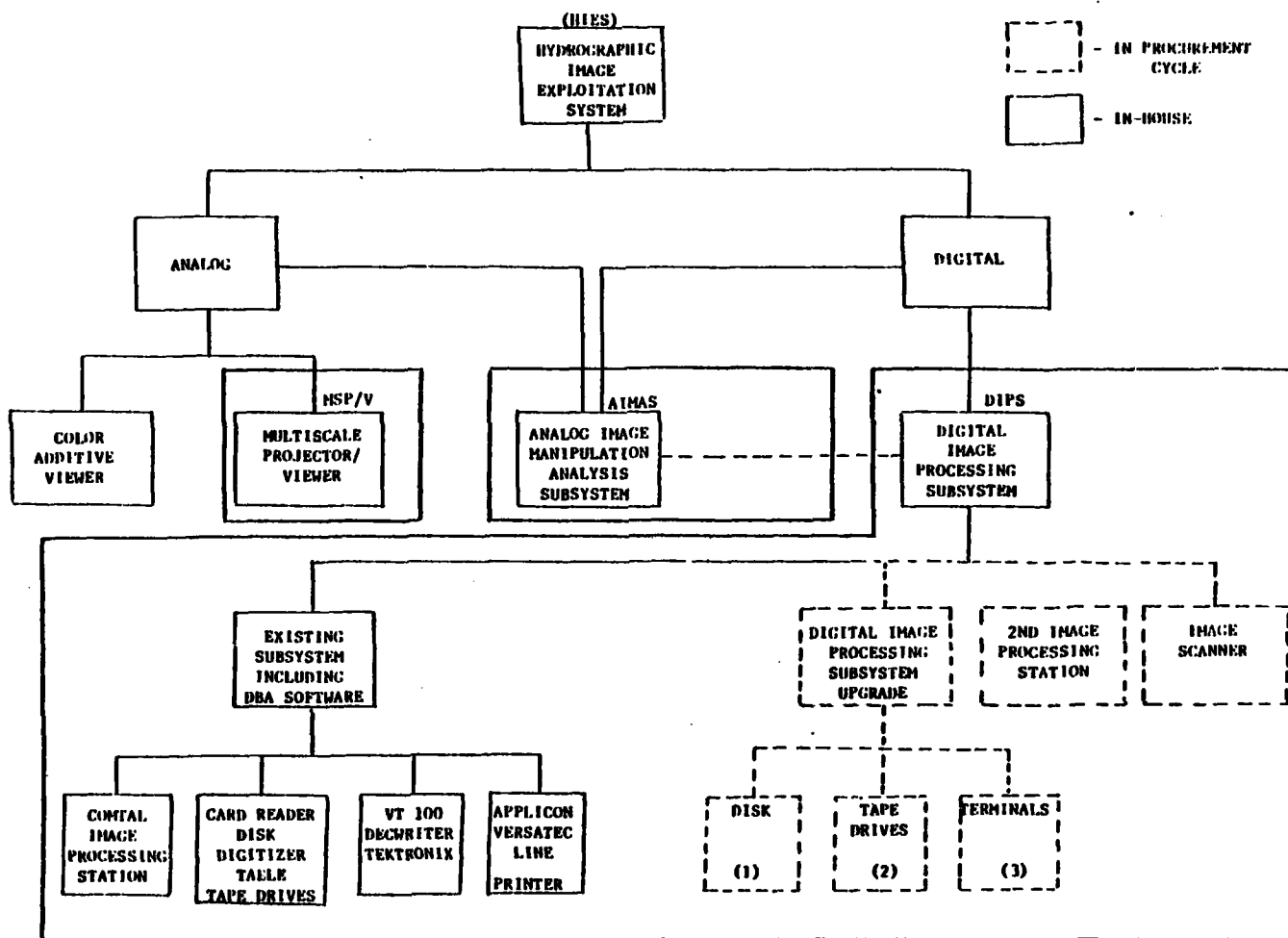
Residual Graphic  
● uncharted shoal  
○ misplotted soundings  
□ error in sounding

Figure 8



RELATIVE WATER DEPTH GRAPHIC

Figure 9



Hydrographic Image  
Exploitation System  
Block Diagram

Figure 10

TABLE OF ESTIMATED RELATIVE PROCESSING PARAMETERS  
IN THREE MODES

|                 | Analog Mode                                                                 |        |     |     | Analog/Digital Mode                                                         |        |        |     | Digital Mode                                                    |        |        |        |
|-----------------|-----------------------------------------------------------------------------|--------|-----|-----|-----------------------------------------------------------------------------|--------|--------|-----|-----------------------------------------------------------------|--------|--------|--------|
|                 | Deliverables                                                                |        |     |     | Deliverables                                                                |        |        |     | Deliverables                                                    |        |        |        |
|                 | 1                                                                           | 2      | 3   | 4   | 1                                                                           | 2      | 3      | 4   | 1                                                               | 2      | 3      | 4      |
| Preprocessing   | Acquire imagery, analysis, quality, shallow water extent, film lab support. |        |     |     | Acquire imagery, analysis, quality, shallow water extent, film lab support. |        |        |     | Acquire CRT's, store on disk, determine data "clean up" needed. |        |        |        |
| Process         | 2 hours                                                                     |        |     |     | 2 hours                                                                     |        |        |     | 16 hours                                                        |        |        |        |
| Tube            | 1-10 days                                                                   |        |     |     | 1-10 days                                                                   |        |        |     | 2 weeks - 4 months                                              |        |        |        |
| Main Processing | CAV, MSP/V                                                                  |        |     |     | CAV, MSP/V, AIMS, Contract                                                  |        |        |     | AIMS, DIPS, Contract                                            |        |        |        |
| Process         | 20 hrs                                                                      | 8 hrs  | N/A | N/A | 35 hrs                                                                      | 12 hrs | 8 hrs  | N/A | 80 hrs*                                                         | 16 hrs | 50 hrs | 50 hrs |
| Tube            | 4 days                                                                      | 2 days | N/A | N/A | 7 days                                                                      | 3 days | 2 days | N/A | 4 wks                                                           | 3 days | 2 wks  | 2 wks  |
| Quality         | 1                                                                           | 1      | N/A | N/A | 2                                                                           | 2      | 2      | N/A | 3                                                               | 3      | 3      | 3      |

Processing based on  
1 Landsat scene

Deliverables  
1-Interpreted Overlay  
2-Residual Overlay  
3-Imagery (Earth Sat type)  
4-Color Coded Water Depth

Quality (geometry, registration, level of detail)  
3-Best  
2-Good  
1-Acceptable  
\*-Applicon plotter 1mb/scene  
512 x 512 - 40/scene - 10 min plot, 40 min create tape

CAV - Color Additive Viewer  
MSP/V - Multiscale Projector/Viewer  
AIMS - Automated Image Manipulation/Analysis System  
DIPS - Digital Image Processing System

Figure 11

END

FILMED

3-83

DTIC