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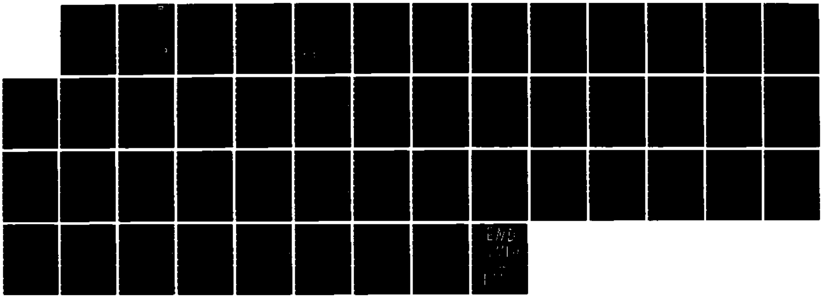

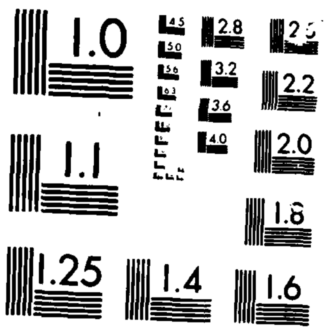

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Special Report 85-20

November 1985

US Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Potential of remote sensing in the Corps of Engineers dredging program

H.L. McKim, V. Klemas, L.W. Gatto and C.J. Merry

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The potential of remote sensing in the Corps of Engineers Dredging Program for providing data on channel surveys, sediment drift and dispersion during dredging, water quality and suspended sediment concentrations, and selection of disposal sites and monitoring environmental effects at disposal sites was reviewed. The recommended remote sensor combination for recording dredging and environmental changes was a small, single-engine aircraft equipped with at least two 70-mm or 35-mm cameras. The first camera should be loaded with color film and the second camera with color infrared film for vegetation or land use mapping, or panchromatic film with special filters for water studies. For bathymetric

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mapping, the cameras will have to be supplemented by airborne impulse radar or laser profilers, and possibly sonar depth finders. A combination of small aircraft and boats is optimum for mapping currents and observing plume dynamics. Additional research is required to study the use of multispectral scanners for bathymetric mapping of large coastal areas, for mapping sediment transport in shallow waters, for mapping concentrations of suspended matter of organic or inorganic origin, and for detecting vegetative stress and soil properties. Along with the acquisition of the multispectral data, ground truth needs to be taken to verify the interpretation of the data. Long-range plans, on the order of 30 to 50 years, are necessary for managing the disposal of dredged material.

PREFACE

This report was prepared by Dr. Harlan L. McKim, Research Physical Scientist and the Remote Sensing Program Manager, Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory; Dr. Vytautas Klemas, College of Marine Studies, University of Delaware, Newark; and Lawrence W. Gatto and Carolyn J. Merry, Geologists, Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. The work was funded under reimbursable order WRC-85-18, No. E8685D018 from the U.S. Army Water Resources Support Center, Dredging Division (WRSC-D).

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SUMMARY

The objectives of this study were 1) to review the application of existing remote sensing techniques for providing data in the Corps of Engineers dredging program, 2) to define promising new remote sensing techniques for monitoring and managing dredging and disposal, and 3) to recommend which remote sensing techniques should be used now and which techniques should be developed for the future. The topic areas in which remote sensing techniques were evaluated included: 1) doing channel surveys and other engineering work, 2) monitoring sediment drift and dispersion during dredging, 3) monitoring water quality and suspended sediment concentrations, and 4) selecting disposal sites and monitoring environmental effects at disposal sites.

The state of the art of remote sensing for dredging-related activities was summarized in tables. We recommended a remote sensor combination for observing and recording dredging and environmental changes -- a small, single-engine aircraft equipped with at least two 70-mm or 35-mm cameras. The first camera should be loaded with color film and the second camera with color infrared film for vegetation or land use mapping, or panchromatic film with special filters for water studies. For bathymetric mapping, the cameras will have to be supplemented by airborne impulse radar or laser profilers, and possibly sonar depth finders. The airborne profilers are less expensive for surveying large coastal areas, although research is required to improve their ability to penetrate turbid waters. A combination of small aircraft and boats is optimum for mapping currents and observing plume dynamics.

Additional research is required to study the use of multispectral scanners for bathymetric mapping of large coastal areas, for mapping sediment transport in shallow waters, for mapping concentrations of suspended matter of organic or inorganic origin, and for detecting vegetative stress and soil properties. Along with the acquisition of the multispectral data, ground truth needs to be taken to verify the interpretation of the data.

Long-range plans, on the order of 30 to 50 years, are necessary for managing the disposal of dredged material. A preliminary reconnaissance of

potential areas for depositing dredged materials is required. Regional criteria, including physical, biological, ecological and other important characteristics, should be developed to focus on appropriate sites to receive detailed investigation. Patterns of water currents, natural deposition and erosion, and sites important to wildlife should be mapped and intensively evaluated during the reconnaissance.

POTENTIAL OF REMOTE SENSING IN THE CORPS OF ENGINEERS DREDGING PROGRAM

by

H.L. McKim, V. Klemas, L.W. Gatto and C.J. Merry

INTRODUCTION

Background

The U.S. Army Corps of Engineers' mission includes a wide variety of water-related responsibilities; one of the most important is navigation. There are over 40,000 km of navigable inland waterways in the United States and over 400 ports and harbors. Present dredging requirements to maintain and improve this extensive Federal navigation system entail the disposal of over 230 million m^3 of dredged sediments each year. Another 75 to 115 million m^3 that is regulated by the Corps also requires disposal each year. Projected new dredging work for coal port development and defense may involve an additional 300 to 380 million m^3 spread over 3 to 6 years. The critical issue confronting the Corps is where to dispose of these large volumes of sediments in a way that is cost-effective and environmentally sound. Remote sensing techniques may well prove to be very useful for these objectives.

Dredging and dredged material disposal policies and practices for the Corps of Engineers include: reconnaissance and conditions surveys, after dredging surveys, maintenance of authorized channel dimensions, beach nourishment, channel clearing, and selection and maintenance of aquatic, upland and diked disposal areas. The Corps regulates all disposal activities within the United States under two Federal statutes: 1) the discharge of dredged and fill material into inland waters of the United States, under Section 404 of Public Law 92-500 (as amended), and 2) transportation for the dumping of dredged material into ocean waters, under Section 103 of Public Law 92-532. Technical terms used throughout this report are defined in Appendix A.

National marine pollution program

Over the last 3 years NOAA has been the coordinator of an extensive effort to develop the Federal Plan for Ocean Pollution Research, Development and Monitoring (Federal Plan 1981-85). The Corps of Engineers participated in compiling this plan, as a member of the Interagency Committee for Ocean Pollution Research, Development and Monitoring, which has the following goals (NOAA 1981):

- Describe marine pollution areas that are being examined by Federal agencies.
- Identify research topics that require additional effort and those that have been adequately addressed.
- Describe the relative importance of research in each area of concern by discussing existing information gaps, the potential severity of the pollution problem, and Federally mandated functions.
- Present specific recommendations for improving the program by redirecting existing resources toward the most productive and important areas, improving interagency coordination or anticipating future problems.

Of the eight major areas of concern shown in Figure 1, the Corps dredging program plays an active part in two:

- Marine waste disposal — Activities are directed at determining the effects of ocean disposal of wastes, including dredged materials, industrial wastes, sewage wastes, radioactive substances and brine generated by the strategic petroleum reserve.
- Coastal land use — Activities in this area increase our knowledge of how coastal land use practices and patterns affect marine ecosystems. Siting, construction and operation of coastal facilities, nonpoint source pollution, and increased use of coal are included.

Marine waste disposal

About $25.4 million (out of a total of $169.8 million) was collectively devoted to the marine waste disposal research and development area during fiscal year 1981 by the Federal government (Fig. 1) (NOAA 1981). It was considered the most important area by the Interagency Committee for Ocean Pollution Research, Development and Monitoring. One of the major categories in this area was the disposal of dredged material.

New channels must be dredged and existing channels maintained. However, channel dredging generates significant amounts of excavated sedi-

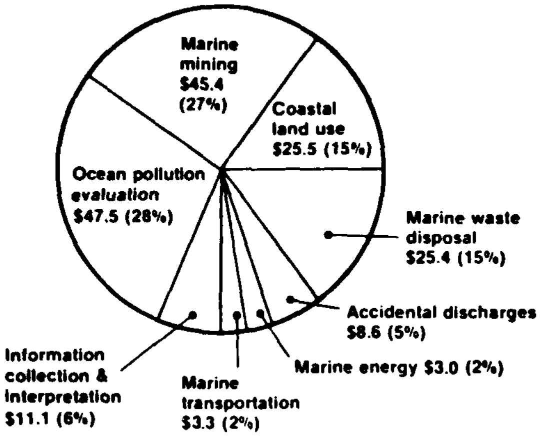

Figure 1. Federal expenditures in fiscal year 1981 (millions of dollars) for marine pollution concerns (after NOAA 1981).

ment. Based on volume, dredging is the largest single source of materials that are dumped into the ocean. In fiscal year 1981, about $9 million or 5% of the total marine pollution expenditure was allocated to research on dredged material disposal only. The Corps of Engineers funded more than 90% of this research and development.

In the NOAA (1981) report the following areas were reported as being of continuing importance and should receive emphasis in the future:

- Chemical effects on the ecosystems — The state of knowledge in this area must be assessed. Continuing studies are needed on the rates and mechanisms of pollutant releases, chemical forms that can be readily taken up by organisms, long-term fates, and acute and chronic effects. Continued research on the sediment geochemistry of dredged material was recommended.
- Disposal management -- Future studies of dredged-material disposal should provide information needed for long-term management of disposal activities. Potential disposal sites should be evaluated, future volume and quality of dredged materials estimated, alternative disposal methods assessed within coastal and offshore environments, and innovative dredging technologies evaluated for promoting development of long-term disposal strategies.

Coastal land use

Changes in land-use patterns and development in coastal areas can severely affect coastal and marine ecosystems. The effects of coastal facilities and nonpoint source pollution are two important areas that require thorough study. In addition, the effects of increasing coal use and export on the marine environment may become more important in the future. The effects of single actions are largely the concern of State and local governments and studies in this area should be supported by them. However, the cumulative effects of coastal land use are very important to the Nation, in terms of Corps and Federal projects, as well as to the Sections 404 and 103 regulatory programs and Section 10 permits.

Multiple uses of the ocean can also pose problems. Such uses as offshore mining, defense, navigation and ocean disposal require locating areas that either do not conflict or are compatible with other uses.

Ports, power plants, sewage treatment facilities, refineries, seafood and lumber processing plants, and many other industries tend to be concentrated in coastal areas. They depend on marine transport, use large volumes of cooling water or harvest marine life. All industries might dispose of their wastes in oceans and coastal environments. Any of these facilities or land use patterns can have detrimental effects on sensitive coastal ecosystems, and the combined effects of several different types of facilities can be substantial. In fiscal year 1981, it was estimated that $10,000,000 was spent on studies related to the environmental implications of facilities in coastal areas.

In the coastal zone the following areas are of continuing importance in the Corps 404 and 103 regulatory programs and the Section 10 permitting program. These areas should receive major emphasis by the Corps in the future:

- Importance of habitat alteration -- The loss and alteration of critical habitats are the most important effects of the construction and operation of coastal facilities. Additional information is needed on the extent and rate of habitat modification, and on its significance to commercial and recreational species and environmental quality in general. Habitat loss should be documented and monitored at the regional and national level, the significance of habitat loss should be determined in terms of effects on fishery stocks, and costs and benefits of restoration should be evaluated. Feedback into the overall management of dredged-material disposal is also necessary.

- Effects of coastal facilities -- The issues that have been identified for future research efforts include energy facility siting (OCS leasing and development refineries, coal ports, power plants), canal dredging in wetlands, effects of freshwater diversion from rivers and estuaries, and studies of the effects of timber harvesting on anadromous fish and their habitats in the Northwest and Alaska.

Objectives

The objectives of this report are: 1) to review the application of existing remote sensing techniques for providing data for efficient management of the Corps of Engineers dredging and related regulatory programs, 2) to define promising new remote sensing techniques for the same purposes, and 3) to recommend which remote sensing techniques can be used now and which should be developed for future use.

The Corps' definition of remote sensing includes in situ sensors where the millivolt output of the sensor can be telemetered via telecommunication satellites to a ground receiving station. Topic areas in which remote sensing techniques should be evaluated, developed or used in the Corps dredging program include: 1) doing channel surveys and other engineering work, 2) monitoring sediment drift and dispersion during dredging,3) monitoring water quality and suspended sediment concentration, 4) selecting disposal sites for dredged material and monitoring environmental effects at disposal sites, and 5) developing long-range management strategies for dredged material disposal.

The remaining part of this report will emphasize the research problems that need to be addressed in the dredging program, how remote sensing is currently being used in problem areas that are similar to the dredging program, and the definition of promising new techniques, remote sensing applications, and research and development needs. There are two specific areas in the dredging program that will be considered -- the traditional engineering and surveying problems, and the environmental and regulatory aspects.

There is also a need for effective management tools for long-term disposal strategies. Remote sensing techniques that can be applied to historical data available from previous aerial photo flights, present technology and the advancing state of the art for the future all need to be integrated into a dredging management system for obtaining timely data. These techniques need to be compared to the cost and accuracy of conventional methods of obtaining the same data.

CHANNEL SURVEYS AND ENGINEERING CONSIDERATIONS

Problems

Channel dredging generates significant amounts of a sediment and water mixture. During 1979, more than 55 million m^3 of dredged material was deposited in the marine environment (CEQ 1980). Of the 1979 total, 68% was disposed of in the Gulf of Mexico, 18% in the Atlantic Ocean and 14% in the Pacific Ocean. The total 55 million m^3 was nearly eight times the combined tonnage of industrial wastes, sewage sludge, construction debris and other waste materials disposed of in the marine environment during 1979 (CEQ 1980).

Both dredging new channels and maintenance dredging of existing channels are required and the Corps must be ready to respond quickly for defense and emergency dredging. It is also done to make a shipping channel align with the waterway's natural thalweg. The location and amount of material to be removed equate to dollars in cost, while the methods used to determine the amount of material to be dredged are sometimes very costly and can be inaccurate. Improved techniques are available that should be tested in this area.

It is evident that the public has been opposing disposal of dredged material on land because of its potentially negative effects on the environment. Also, land disposal is becoming difficult because of land costs and competition for disposal sites. As a result, alternative coastal and ocean disposal areas are being defined and new sites will be required soon. Remote sensing techniques are available to assist in the selection and monitoring of these sites.

Channel alignment is another Corps dredging problem. Remote sensing data can be useful in assisting the Corps during improvement of the channel and for follow-up monitoring for verification. Current circulation patterns need to be monitored over time. Natural thalwegs, the deepest part of the channel or the natural channel, need to be located.

Shoaling problem areas need to be identified, and the dimensions of channels and water depth need to be monitored. Vessels may run aground in areas where there has been severe and unpredictable shoaling, a particular concern for emergency and national defense dredging requirements. There also must be some type of routine monitoring of the channel dimensions for safe navigation. Remote sensing data must be assessed for use in shoaling problems, with quantitative recommendations made for Corps contract specifications.

Bathymetric charts are frequently outdated and not sufficiently accurate for planning a dredging operation. This is particularly true if one needs a precise bottom profile for defining the location and amount of sediment to be dredged, and for emergency and defense requirements. Traditional boat survey techniques for updating bathymetric charts, such as acoustic echosounders, are slow and expensive. Therefore, remote sensing techniques should be considered as alternatives to supply this information.

Useful remote sensing techniques

There are many ways of analyzing changes in coastlines. Two widely used methods are field surveys and analysis of historical data. Field surveys tend to be very expensive, and often the short-term field observations cannot be extrapolated over a long time. The analysis of historical field data is also limited because the accurate observations that would be needed to determine beach changes (such as erosion, accretion and sand dune migration) were not taken in the past because no one recognized the need for the observations. However, coastal erosion and coastal geomorphology have been studied successfully using aerial photography and Landsat imagery (Dolan 1973, Dolan et al. 1977) and could be used for analysis of erosion and accretion. Aerial photographic techniques described by Stafford and Langfelder (1971) provide the high resolution required for accurate measurement of beach erosion and accretion.

There are also ways to determine bottom profiles and channels caused by erosion and siltation. Active and passive remote systems can be used from aircraft for bathymetric surveys (Table 1). Active remote sensors, primarily lasers, are defined as sensors that supply their own source of energy to illuminate features of interest, whereas passive remote sensors will detect naturally available energy. Satellites rarely provide the necessary spatial resolution, even though Landsat 80-m data have been used for large area bathymetric charting (Rogers et al. 1982). Rogers et al. (1982) produced bathymetric charts of coastal areas in the Middle East, including the coast of Saudi Arabia near Al Bahrayn, using two computer algorithms, one for deep water and another for shallow water. The final maps showed color coded water depths in 2-m intervals, with a total of about 10 intervals.

During the last few years the performance of laser airborne depth sounding systems (Lidar) has improved significantly. The instrument's operation is based on measuring the time between the reflection of a laser beam from the sea surface and from the bottom, giving a measure of the water depth. When the laser beam is swept perpendicular to the aircraft

Table 1. Use of remote sensors in the Corps program (3 - reliable [operational] 2 - needs additional testing, 1 - limited value, 0 - not applicable).

Sensor	Platform**	Bathymetric mapping	Shoals, bars, deep channels	Bottom material, submerged vegetation	Currents, plume dynamics	Erosion, sediment transport	Suspended sediment concentration	Water quality, color	Onshore soil properties	Wetland vegetation type	Vegetation stress	Environmental impact on marine life
Panchromatic film camera	AC	1	2	1	2	3	2	1	2	1	0	1
	SC	0	1	1	1	2	1	1	1	1	0	0
Color film camera	AC	1	2	2	2	3	2	2	2	2	1	1
	SC	0	1	1	1	2	1	1	1	1	0	0
Color IR film camera	AC	0	1	1	1	2	1	1	2	3	2	1
	SC	0	0	0	1	1	0	0	1	2	1	0
Multispectral scanner	AC	2	3	2	2	3	3	3	2	3	2+	2
	SC	1	2	1	1	2	2	2	1	2	2	1
Thermal IR scanner	AC	0	0	0	2	0	0	0	1	1	0	1
	SC	0	0	0	1	0	0	0	0	1	0	0
Laser profiler	AC	3	3	1	1	3	1	0	0	0	0	0
Laser fluorosensor	AC	0	0	1	2	0	2	3	1	1	2	1
Imaging radar	AC	0	0	0	2	3	0	0	2	1	0	0
	SC	0	0	0	1	2	0	0	1	1	0	0
Microwave radiometer	AC	0	0	0	1	0	0	1	2+	1	0	1
	SC	0	0	0	0	0	0	0	1	0	0	0
Acoustic (sonar)	BT	3	3	2	2	2	2	0	0	0	0	2
	AC											
Surface † measurement requirement	BT	H	L	M	M	M	M	H				
	FD								M	L	M	H

* Ratings based on experience and literature reviews.
** Platform: AC - aircraft, SC - spacecraft, BT - boat, FD = field.
† Surface measurement requirement. H - high, M - medium, L - low.

path, an area beneath the aircraft is sounded that is much larger than the area covered by an echosounder in a boat.

In clear ocean water, laser bathymetric and spectroradiometry systems have been able to measure down to 10 to 22 m reliably, depending on the laser system employed (Hoge et al. 1980, McKim et al. 1980, Link 1981, Link and Collins 1981, Link et al. 1982). A major limitation of laser depth profiling systems is their inability to penetrate turbid water. The Airborne Oceanographic Lidar (AOL) system, which yielded depth measurements in oceans of 10 m, was able to penetrate only 4.6 m in turbid Chesapeake Bay waters (Hoge et al. 1980). Most of the laser systems in use perform satisfactorily when the penetration-performance product ($\alpha \times d$ -- beam attenuation coefficient, α, times depth, d) is from 6 to 10. Since the total attenuation coefficient (α) of the optical beam in the ocean and coastal waters varies from 0.5 to 5.0, attainable depths should range from 2 to 12 m, depending on the turbidity of the water. The AOL system has been able to attain a precision of ± 0.3 m.

Determining accurate positioning and location can be a problem during aircraft bathymetric surveys. Electronic navigation systems are generally not accurate enough. Therefore, aerial photos should be taken simultaneously to include shoreline or buoy reference markers. The location of the laser soundings can then be identified on the aerial photographs and referenced to the shoreline features or buoy markers.

At this time, echosounders and laser profilers are reliable sensors for bathymetric mapping in clear waters. In turbid waters, lasers frequently fail to penetrate to the bottom and only echosounders deployed from boats would work reliably. As more powerful lasers become available, some improvement in depth penetration can be expected, particularly in waters of moderate turbidity. It is clear that an aircraft can chart a greater area than can a hydrographic boat. For example, using an AOL, 31.5 km^2 can be mapped per hour, with an average spatial density of one laser depth reading per 43.5 m^2 (Hoge et al. 1980).

A reasonable approach would be to use a helicopter-mounted Lidar, imaging sonar systems and underwater acoustic tomography (another imaging system similar to CAT scanning for underwater measurements). The necessary hardware exists for all three systems. These techniques could be used to produce two-dimensional maps for a harbor or waterway. The data base can be stored in the computer and then coupled with existing software to produce maps. The interactive real-time system can also be used for monitoring, planning and modeling. We recommend a 1/2 man-year effort to address the following questions: 1) how much time, effort and expense goes into planning and monitoring for a typical waterway, 2) how much needs to be done to demonstrate the technology, and 3) how much is a preliminary engineering study worth. The preliminary study from this would 1) identify the existing systems and capabilities, 2) identify "missing" pieces of data, if any, and 3) prepare a cost estimate of a remote sensing demonstration project at some level.

Promising remote sensing systems and techniques

For bathymetric mapping of large coastal areas, or mapping in turbid waters, several new techniques must be further tested and developed. First, procedures must be developed for the use of laser bathymetry in turbid water. Users must be clearly told what the reliable penetration depth of each laser system is in waters of different turbidity. Beam attenuation coefficient and depth products ($\alpha \times d$) of about 10 are attainable. However, this product must be specified for each promising system so that knowing the α, a user can calculate the approximate depth to which the system is usable. The AOL system has shown that a single instrument package can be developed for a wide range of applications and turbidity conditions (Hoge et al. 1980, Link et al. 1982). To run such tests it should take about 2 years.

For bathymetric mapping of gross bottom features over large areas, the Landsat Multispectral Scanner Subsystem (MSS) and Thematic Mapper (TM) sensors appear particularly attractive. Bathymetric mapping with these multispectral scanners should be further investigated to obtain more data on reliability and accuracy. A 2-year effort is required to do this.

Airborne laser profilers and radar instruments and SPOT stereo photography could also be used for profiling beach topography and mapping coastal landforms. However, resolution and accuracy requirements of a project would have to be defined before the potential use of these techniques could be evaluated for specific purposes. Field tests and sensor evaluations should be done in conjunction with the bathymetric mapping tests mentioned above.

ENVIRONMENTAL CONSIDERATIONS

Monitoring sediment drift and dispersion during dredging operations

Problems

Predictive sediment transport models are not overly quantitative, therefore, monitoring is sometimes required for effective site management. A general lack of information on net current direction to assist in designing monitoring programs (for example, sediment movement) is another major problem. Monitoring is sometimes required for effective site management.

It is necessary to obtain data on the size and location of areas where habitats could be altered as a result of sediment that is resuspended in the water during dredging. These data would be used to verify the predictive model. Techniques are required to monitor the extent of resuspended and dispersed sediment and to observe the long-term changes in coastal and estuarine ecosystems caused by the sediment. The information would provide adequate warning signals of potentially serious changes, important to site and resource management and decision making.

Useful remote sensing techniques

During both dredging and the disposal of dredged material in the water, remote sensing can see the drift and dispersion of resuspended sediments because of increased concentrations and discoloration as compared to background water. A few boat measurements would be required to calibrate the remotely sensed data and to monitor subsurface movement of the dredged materials. Remote sensing techniques can also be used to verify models for predicting where the dredged materials will be deposited (Klemas et al. 1974b, 1977; Klemas and Philpot 1981).

Many remote sensing instruments are available that can measure surface current directions and approximate velocities, circulation patterns and suspended sediment gradients (Keller 1963; Carlson 1976; Coker et al. 1976; Barrick et al. 1977; Legeckis 1975, 1978; Shuchman et al. 1979; Klemas 1980). These include thermal infrared scanners, Landsat MSS and TM data, airborne radiometers, aerial photography and airborne or shore-based high-frequency radar. These sensors usually provide data from the upper part of the water column. Currently, the data from the aircraft or satellite sensors must be coupled with sensors mounted on ships, which collect data on bottom characteristics and the lower portion of the water profile.

Underwater cameras and acoustic systems (echosounders or sonar) have been used to monitor the settling and distribution of dredged material in shallow coastal waters. Sewage sludge was tracked in the ocean using 80-W, 200-khz and 20-khz echosounders mounted within streamlined hydrodynamic towbodies that were towed at a 2-m depth (Proni et al. 1976). Data collected concurrently from sonar-equipped boats and from remote sensors would be useful for monitoring the drift and dispersion of dredged material.

In summary, remote sensing techniques are available to track dredged material in the upper portion of the water column. However, research to date shows that the bottom portion of the water column is also important and must be monitored. More work is required on acoustic techniques to monitor subsurface and bottom sediment movement.

Promising remote sensing techniques

The echosounders are the most promising for monitoring near-bottom and bottom movement of dredged materials. Transducers implanted at specific locations can supply point data on sediment accumulation. A 2-year program would be required to demonstrate the utility of acoustic systems. More complete monitoring would be available by using echosounding and boats for sampling in conjunction with aerial surveillance. This approach would provide data on surface and bottom transport and would serve as ground truth for calibration of aircraft and satellite data. A sequence of aerial and satellite photographs could document net current direction. A procedure documenting the steps to be used and data analysis techniques to be followed for this integrated approach could be prepared.

Monitoring water quality and suspended sediment concentration

Problems

When dredged material has toxic or harmful constituents, water quality can be changed after disposal. In instances where dredged material must be contained within a given area, information on the contaminant is essential when evaluating disposal alternatives. The ability to qualitatively and quantitatively determine the amount and location of suspended dredged sediment is also important. A system that has in-situ, airborne and satellite sensors should be set up.

Regional studies conducted by NOAA have shown that marine waste disposal is of primary importance (NOAA 1981). One major area that needs improvement was ecological monitoring techniques and another was examination of open coastal and insular current patterns and their variations over time. Any site-specific or regional monitoring program could use remote sensing techniques.

One of the major problems in calculating suspended sediment concentration from a measured flux is the difference in absorption and scattering of light in the atmosphere from one time to another. Because of many variables, it may not be practical to determine an atmospheric correction directly, but a combination of dark object subtraction and band ratios may provide an adequate correction.

The other major problem is that a backscattered flux may represent a mix of water color, bottom reflectance, turbidity produced by plankton, and turbidity caused by suspended sediment. In many cases, however, a change in flux is caused simply by a change in the concentration of one constituent.

Useful remote sensing techniques

Remote sensing techniques for this area are most useful for shallow dredging because ocean disposal principally affects the bottom.

An optical measure of water color and turbidity can be obtained with remote sensing. Pollutants must affect color or turbidity to be detectable, although dissolved luminescent constituents can be detected by Fraunhofer line discrimination techniques. Dissolved colored materials increase the absorption of light in water and decrease the remote signal; suspended materials increase the backscatter of light and increase the remote signal.

Several studies have shown that many substances can be identified by their optical properties. Using cruise data, Kalle (1966) was one of the first to associate Gelbstoff (yellow substance) with principally terrigenous materials and dissolved organic compounds. Baker and Smith (1982) have developed a scheme for classifying open ocean water based on the attenuation of light, especially blue and green light, by chlorophyll and dissolved organic matter. Moore (1978) indicates that clay-sized material will preferentially scatter different wavelengths, whereas coarse silt scatters light achromatically. Working with remotely sensed data, Philpot and Klemas (1979) distinguished different types of material in the water, based on "color" differences produced by the four Landsat bands (using an eigenvector analysis). They found that they could distinguish waste acid from suspended sediment, and even old acid waste from fresh waste. Grew (1977) has also used characteristic vectors to identify both chlorophyll and acid waste in multispectral data from aircraft. It must be kept in mind that these findings were for sewage and industrial wastes disposed of in the ocean, with the effects largely within the water column -- not necessarily the case for dredged material.

Promising remote sensing techniques

Most studies that obtained good correlation between remotely sensed radiance data and concentration data from ships included a calibration of the radiance values based on water sample analyses for sediment concentration, size distribution and composition (Klemas et al. 1974b; Johnson 1975a,b; Ritchie et al. 1976; Munday and Alfoldi 1979; McKim et al. 1980, 1984). Since sediment concentration is not uniquely related to backscattered radiance, a prior knowledge of grain size, composition and layering is required before radiance maps can be converted into suspended sediment concentration maps (Moore 1978, Amos and Alfoldi 1979, Whitlock et al. 1982). Considerable progress is being made in the development of optical models of the water column to discriminate organic from inorganic suspended matter, to map substances having varying concentrations (layers) as a function of depth, to eliminate bottom reflections, and to improve atmospheric corrections (Wilson and Austin 1978, Philpot and Ackleson 1981). It is in these areas that more research is urgently required.

Selecting disposal sites and monitoring environmental effects at disposal sites

Problems

The problem addressed has two parts, the selection of acceptable disposal sites and the management of the sites after disposal, including monitoring where appropriate. Information on the environmental setting and conditions at and adjacent to candidate sites is required for site selection. In addition, data on changes in the ecosystems adjacent to the sites after disposal are required for proper management.

Useful remote sensing techniques

Remote sensing techniques can be used to collect data required for on-land site selection and for inventorying site characteristics such as land cover, vegetation types, soil characteristics, terrain features and

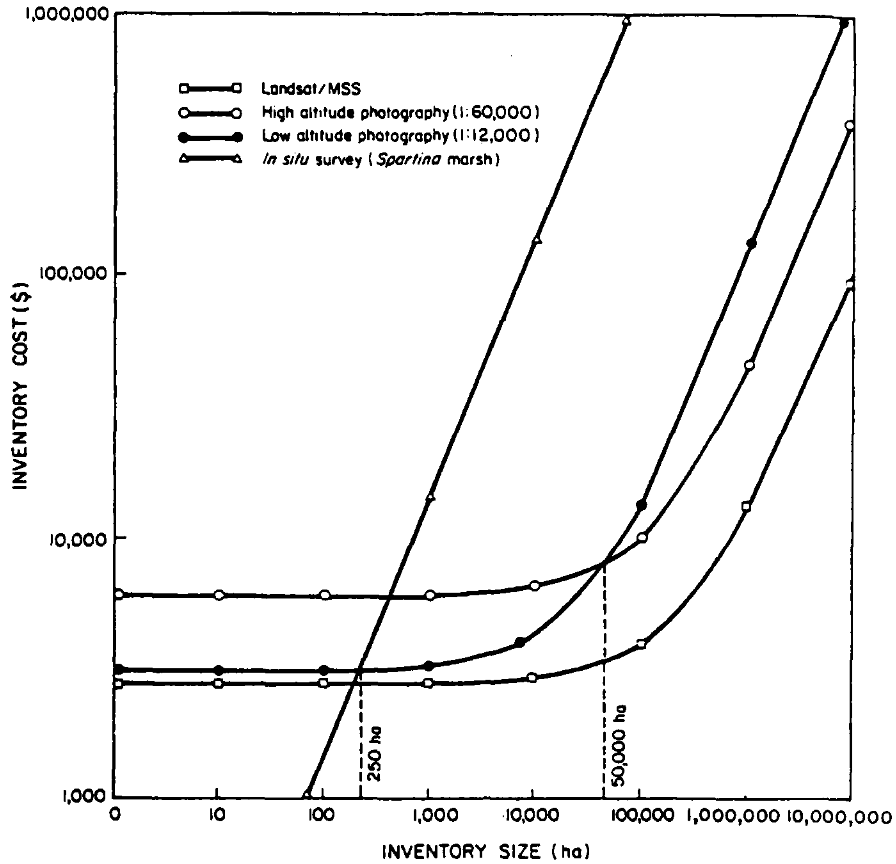

Figure 2. Inventory costs vs total area of wetlands inventoried for three remote sensing platforms and in-situ survey.

topography, hydrologic features and geology (Klemas et al. 1975, Bartlett and Klemas 1981, Hardisky et al. 1983a,b). Costs of vegetation inventories for areas of various sizes are shown in Figure 2.

Remote sensing methods also provide data on environmental changes. Loss and alteration of critical habitats are probably the most significant changes caused by disposal of dredged material. Estuarine and coastal habitats such as grass beds, marshes, mangrove swamps, and the nearshore and tidal zones serve as breeding and nursery grounds for the majority of recreational and commercial marine species. The boundaries and extent of these critical habitats can be determined by remote sensing.

The resolution of Landsat data is limited, so their value for statutory wetland inventories is minor (Penney and Gordon 1975). In addition, spectral similarities between wetlands and uplands can limit categorization accuracy (Klemas et al. 1975, Bartlett et al. 1977). Examination of the physical basis of wetlands reflectance using in situ radiometry, and application of data collected by the Landsat MSS and TM, could provide information on the condition of a habitat (biomass, etc.) and aid in using seasonal changes in reflectance signatures to improve mapping the various species and changes in their distribution. However, for general habitat mapping, Landsat MSS and TM data alone would be quite useful.

The most effective method for monitoring the environmental effects of dredged material disposal on land is to use vegetation as an indirect indicator of the stresses induced by the materials (Weber and Polcyn 1972; Philipson and Sangrey 1975, 1977; Murtha 1978). Wetland grasses have been studied by multispectral sensors to determine their biomass and the stresses induced by wastes dumped on wetlands (Gallagher and Wolf 1980; Bartlett and Klemas 1981; Hardisky et al. 1982; Gallagher and Kibby, in press). While film cameras and thermal infrared scanners have been used to locate seeps and gross discoloration at waste disposal sites, only airborne multispectral scanners give us the opportunity to assess the degree of environmental degradation caused by dredged material disposal. They do this by detecting subtle spectral reflectance changes in vegetation stressed by pollutants in the soil. Levees could also be monitored using multispectral scanners. Pollutants leached from disposed material could change vegetation in the immediate area of a disposal site, and multispectral scanners can be used to detect their changes (Klemas et al. 1975, Bartlett and Klemas 1981, Hardisky et al. 1983a, 1983b).

Little progress has been made in analyzing the distribution of submerged aquatic vegetation in potential shallow water disposal sites. Visual interpretation of aerial photography has been used in delineating the distribution and, occasionally, for species differentiation within submerged grass beds. It has provided limited data on detailed species distributions, standing crop or plant vigor. Such data are necessary if accurate assessments and inventories of existing submerged aquatic vegetation are to be made.

Airborne multispectral scanners have been used to identify submerged features to a depth of 5 m in Lake Ontario (Lyzenga 1981). Classification accuracies for sand, shoal grass and mud ranged from 82% at a depth of 1 m to 57% at 2-m depth in St. Andrew Bay, Florida (Lyzenga et al. 1979). The best results for classifying land and water features were obtained by applying a ratioing technique between two bands for which attenuation was similar. These techniques would be useful for quick surveys to acquire data on bottom topography and conditions, which is required in areas considered as in-water disposal sites. These quick surveys are also useful to locate areas where detailed site surveys are required.

Remote sensing systems are also available for collecting wave data required for designing diked shallow water disposal areas. Sea state and wave spectra are best obtained using laser profilers from aircraft, radar mappers (Synthetic Aperture Radar, SAR) and radar altimeters (Ross et al. 1970, Schule et al. 1971, Panicker 1974, Born et al. 1979). Imagers such as synthetic aperture radar or film cameras are particularly effective for wave studies if the data are analyzed using optical Fourier analysis techniques (Stilwell 1969).

Promising remote sensing techniques

Vegetation types can be readily mapped using aerial photography. More work is required with Landsat MSS and TM and future SPOT High Resolution Visible (HRV) sensor data to improve reliability in detecting vegetation biomass and stress. However, simple maps of habitat areas would still be useful to the Corps of Engineers. Specifically, we recommend that the Corps establish a 3-year research project to study the effectiveness of multispectral scanners, including the Thematic Mapper, for monitoring the environmental changes to soils, vegetation and water quality, caused by disposing of dredged material on land. This task would include the monitoring of new marsh grasses or uplands plants growing on dredged-material disposal sites.

We also need a more complete understanding of how light interacts with a submerged canopy of vegetation, allowing us to develop a usable radiative-transfer model. Then multispectral scanners, including the Thematic Mapper, and field spectroradiometers should be used in conjunction with the model to describe the morphology and other characteristics of submerged aquatic vegetation. To do this, we recommend a 3-year study.

While laser fluorosensors have been suggested for submerged vegetation studies, their high cost and limited coverage do not justify the small improvement they offer.

LONG-RANGE MANAGEMENT STRATEGIES FOR DREDGED-MATERIAL DISPOSAL

At present, Corps of Engineers Districts often approach the problem of dredged material disposal from year to year. However, site-specific investigations for regional management plans have been developed in some cases and have received widespread public acceptance. We recommend that the long-term (30- to 50-year) planning be used in more Corps Districts.

Klesch (1983) summarized what four Corps Districts were doing in long-term planning for the disposal of and containment of dredged material. This section summarizes the findings from his report.

In the Mobile District, a preliminary disposal plan spanning 40-45 years included the following: 1) making the most use of existing disposal areas through good site managment, 2) taking into account environmental factors, such as marsh creation, 3) making all new site developments compatible with a management plan, 4) pursuing local sponsors for disposal areas, and 5) proposing the open water disposal of dewatered "clean" dredged material into the Gulf of Mexico.

For the Mississippi Sound and Adjacent Areas Study, a regional computerized data base on the biological resources of the Sound and a two-dimensional, depth-integrated hydrodynamic model will be used to evaluate the physical effects within the Sound. There is an advantage to using the regional approach to dredged materials disposal. When the Corps analyzes a potential site by itself, there are normally enough objections raised that the site will eventually be dropped from further consideration. However, if sites were selected on a regional basis, uniform and consistent criteria could be applied that would lessen the negative aspects.

In the Philadephia District two large mathematical models have been used in a regional approach for the Delaware River Dredging Disposal Study. One, an attractiveness model, uses spatial techniques as a preliminary screening step. Potential sites in a 5-mile (8 km) band on both sides of an approximately 200-mile (322-km) long reach of the Delaware River are considered. A grid cell size of 18.4 acres (75,000 m^2) was used in the model. There were 14 parameters considered important in the selection of sites that were digitized for use in the model. Each parameter was subdivided into a number of variables that were weighted (from 0 to 10) or rejected because of some overriding negative feature. Sites selected from the process served as input for the next level of intermediate manual screening. The results of the manual screening were used as input for the systems model.

The systems model considered the alternative sites to determine their usefulness to the District's disposal problems. The systems model also picks the best sites based on the lowest cost. The model output will indicate such items as the optimal year for each site to come on line, the total cost of the plan, the volumes within each site, etc. In addition, the model can be used to consider alternatives, such as what happens if the District were constrained to use only existing sites.

In the Norfolk District, only long-term solutions will be considered. The District examines, only once and in detail, any proposal submitted by a potential local sponsor.

The New York District is developing a plan, scheduled for completion by the end of 1985, to manage the disposal of all dredged material from the New York Harbor. There are eight disposal alternatives that are being considered: disposal in the Atlantic Ocean, use of sea bottom pits that will be capped with a layer of "clean" material, upland disposal, containment islands, beach nourishment, landfill cover, wetland creation, and disposal in an open water area in Long Island Sound.

Regional criteria should be established to aid the Districts in disposal site selection by helping them to identify physically and biologically sensitive areas and critical resource areas, and to assess potential hazards. The sources of sediment pollutants and contaminants must be identified and the Districts must work closely with those interests responsible for preventing, reducing or eliminating these problems. All research findings should be incorporated into management plans for long-term dredged material disposal.

CONCLUSIONS AND RECOMMENDATIONS

The state of the art of remote sensing for dredging-related applications is shown in Table 1. It is very important that the rating categories in this table be fully understood. A rating of 3 means that the remote sensing technique can, if properly used, reliably provide data on the specified topic. For instance, a film camera used on aircraft can reliably map coastal erosion. A rating of 2 means that useful results can be obtained with the specified sensor and platform, but that the results will be less accurate or applicable than most users desire. For instance, a multispectral scanner on a satellite can map suspended sediment concentrations only to an accuracy of about ± 100% because of atmospheric attenuation and variations in grain size and type of suspended matter. Techniques rated 1 provide only qualitative data of limited value. For instance, thermal infrared scanner data are difficult to interpret for vegetation type analysis, but may provide interesting new data on vegetation if used in conjunction with data in the visible range. A rating of 0 means the technique will provide no data of any value for that application. The ratings in Table 1 indicate that remote sensing techniques should be considered for the five areas of dredging activities discussed in this report.

A combination of remote sensors recommended at this time for observing and recording dredging-related activities and environmental changes should

Table 2. Recommended remote sensors for dredging-related applications.

<u>Dredging site selection and bathymetric mapping</u>

- Aircraft camera (color film)
- Aircraft camera (panchromatic film and filters)
- Airborne laser profiler (additional research)
- Boat with depth sounder
- Multispectral scanner (additional research)

<u>Monitoring currents and sediment transport</u>

- Aircraft camera (color film)
- Aircraft camera (panchromatic film and filters)
- Boat with drogues and dye
- Thermal infrared scanner (limited use)
- Multispectral scanner (additional research)

<u>Mapping water quality and suspended sediment concentration</u>

- Aircraft camera (color film)
- Aircraft camera (panchromatic film with filters)
- Multispectral scanner (additional research)
- Water sampling from boats

<u>Mapping vegetation and dredge waste impact</u>

- Aircraft camera (color film)
- Aircraft camera (color infrared film)
- Multispectral scanner (research on vegetative stress detection and soil properties)

<u>Monitoring dredging effects on aquatic life</u>

- Aircraft camera (color film)
- Aircraft camera (panchromatic film and filters)
- Divers to observe marine life
- Biological sampling from boats
- Sonar tracking of fish schools (additional research)

include a small, single-engine aircraft equipped with at least two 70-mm or 35-mm cameras. The first camera should have color film and the second should have color infrared film for vegetation or land use mapping, or panchromatic film with special filters for water property studies. Any dredging operation, regardless of funding level and availability of sophisticated ground, airborne or spaceborne monitoring platforms, should include a small aircraft to observe and record activities and environmental changes.

Table 2 describes remote sensor combinations most useful for dredging-related applications. For bathymetric mapping, film cameras will have to be supplemented by airborne laser profilers and, possibly, sonar depth finders. The airborne laser profiler offers cost advantages for surveying large coastal areas, although research is required to improve the sensor's ability to penetrate turbid waters. Similarly, more research needs to be done on multispectral scanners for bathymetric mapping of large coastal areas.

A combination of small aircraft and boats is optimum for mapping currents and observing plume dynamics. As shown in Table 2, the boat will launch drogues and dyes to be tracked by the aircraft, and the aircraft cameras may also observe the dynamics of turbid plumes and fronts. The boat may also do transmissivity, fluorescense and Secchi depth measurements. More research is required to improve the ability of multispectral scanners to map sediment transport in shallow waters.

To obtain a quantitative measure of water properties, a multispectral scanner will have to be used and some water samples analyzed. Although turbidity patterns and gross current circulation can be recorded on film cameras, according to Table 2, multispectral scanners (which include spectroradiometers) offer the only hope of mapping concentrations of suspended matter of organic or inorganic origin. As more research is done in this area, fewer boat samples will need to be collected.

Color and color infrared film cameras are quite effective for mapping vegetation changes induced by waste disposal. More research is required on the use of multispectral scanners for detecting vegetative stress and soil properties. This could potentially be tied into the ongoing Corps wetland program.

Echosounders have been used to track fish movements during dredging and waste plume dispersion during waste disposal in water. These applications of echo sounding techniques should be further investigated.

Specifically, we recommend that the following research be conducted in the future to develop various remote sensing techniques for use in Corps of Engineers dredging-relating activities.

1. Test the accuracy and reliability of the Landsat MSS and TM for coastal bathymetry and surveying channel conditions. A 2-year effort is required.

2. Compare bathymetric accuracy for disposal sites and turbid water penetration depths of various laser bathymetric systems. This effort will take about 2 years.

3. Prepare a guide on the procedures for mapping currents and tracking disposed of dredged materials in coastal waters. The guide should include: discussions on current drogue design and dye selection; dye and drogue injection from an aircraft and boats; optimum films and filters and altitude selection for tracking drogues, dyes and wastes; water sample acquisition from boats; correlation of field data to remote sensing data; available and potentially available remote sensing systems for determining bottom currents important for ocean disposal site selection and prediction of sediment movement. This task would take 1 year.

4. Test and prove the application of acoustic systems for tracking dredged material dispersion in the water column and its distribution on the bottom. This would be a 2-year project.

5. Develop and test optical models to help interpret multispectral scanner data of suspended matter and pollutants in the water column, to discriminate organic from inorganic suspended substances, for mapping concentrations of suspended sediments, to account for flocculation and layering of suspended material, and to eliminate bottom reflectance and improve atmospheric correction techniques. Tests should include spectroradiometers in laboratory tanks, followed by multispectral scanner flights with aircraft over water containing suspended sediment plumes. These tasks would take 3 years.

6. Study the effectiveness of multispectral scanners, including the TM, for mapping of various habitat types and their productivity, and land use changes, for selecting disposal sites, and for monitoring the environmental effects on vegetation from dredged-material disposal in wetlands.

Analysis would include the monitoring of wetland grasses or upland plants growing in areas being considered for dredged material dump sites. This project would take 3 years.

7. Analyze the interaction of light with the submerged canopy of vegetation for quantitative monitoring techniques. A usable radiative transfer model for an inhomogeneous water column overlying a canopy of submerged aquatic vegetation needs to be developed. Multispectral scanners, including the TM, and field spectroradiometers should be used in conjunction with the models to ascertain morphological and other characteristics of submerged aquatic vegetation. Qualitative mapping of submerged vegetation is necessary with species differentiation required. We recommend a 3-year study.

LITERATURE CITED

Amos, C.L. and T.T. Alfoldi (1979) The determination of suspended sediment concentrations in a macrotidal system using Landsat data. Journal of Sedimentary Petrology, 49:159-173.

Baker, K.S. and R.C. Smith (1982) Bio-optical classification and model of natural waters. Limnology and Oceanography, 27:500-509.

Barrick, D.E., M.W. Evans and B.L. Webber (1977) Ocean surface currents mapped by radar. Science, 198:138-144.

Bartlett, D., V. Klemas, R. Rogers and N. Shah (1977) Variability in wetland reflectance and its effect on automatic categorization of satellite imagery. Procedings of the American Society of Photogrammetry, American Congress on Surveying and Mapping, Annual Meeting, February 27-March 5, Washington, D.C., pp. 70-89.

Bartlett, D.S. and V. Klemas (1981) In situ spectral reflectance studies in tidal wetland grasses. Photogrammetric Engineering and Remote Sensing, 47(12):1695-1703.

Born, G.H., J.A. Dunne and D.B. Lane (1979) Seasat mission overview. Science, 204(4400):1405-1406.

Carlson, P.R. (1976) Mapping surface current flow in turbid nearshore waters of the Northeast Pacific. In ERTS-1: A New Window on Our Planet (R.S. Williams and W.D. Carter, Ed.). U.S. Geological Survey Professional Paper 929, pp. 328-329.

Caron, L., J. Minor and M. Meyer (1976) Upper Mississippi River underwater feature detection capabilities of water-penetrating aerial photography. St. Paul: University of Minnesota, College of Forestry.

CEQ (1980) Environmental Quality. The Eleventh Annual Report of the Council on Environmental Quality, Washington, D.C.

Coker, A.E., A.L. Higer and C.R. Goodwin (1976) Detection of turbidity dynamics in Tampa Bight. In ERTS-1: A New Window on Our Planet (R.S. Williams and W.D. Carter, Ed.). U.S. Geological Survey Professional Paper 929, pp. 330-331.

Dolan, R. (1973) Coastal processes. Photogrammetric Engineering, 39(2): 255-260.

Dolan, R., B. Hayden, J. Heywood and L. Vincent (1977) Shoreline forms and shoreline dynamics. Science, 197(4298):49-51.

Gallagher, J.L. and P.L. Wolf (1980) Field bioassays for the role of plants as vectors in contaminant transfer from dredged material. In Contaminants and Sediments (R.A. Baker, Ed.). Vol. 2, Chemistry, biology, toxicology. Ann Arbor: Science Publishers, Inc.

Gallagher, J.L. and H.V. Kibby (in press) Marsh plants as vectors in trace metal transport in Oregon tidal marshes. American Journal of Botany.

Grew, G.W. (1977) Characteristics analysis as a technique for signature extraction of remote ocean color data. 6th Annual Remote Sensing of Earth Resources Conference, Tullahoma, Tennessee. University of Tennessee Space Institute.

Hardisky, M.A. (1978) Marsh restoration on dredged material, Buttermilk Sound, Georgia. Proceedings of the Sixth Annual Conference on the Restoration and Creation of the Wetlands, pp. 143-173.

Hardisky,, M.A., V. Klemas and F.C. Daiber (1982) Remote sensing salt marsh biomass and stress detection. Presented at Committee on Space Research meeting in Ottawa, Canada. COSPAR Paper No. 10.6.1.

Hardisky, M.A., V. Klemas and R.M. Smart (1983a) The influence of soil salinity, growth form and leaf moisture on the spectral radiance of Spartina alterniflora canopies. Photogrammetric Engineering and Remote Sensing, 49(1):77-84.

Hardisky, M.A., R.M. Smart and V. Klemas (1983b) Seasonal spectral characteristics and aboveground biomass of the tidal marsh plant, Spartina alterniflora. Photogrammetric Engineering and Remote Sensing, 49(1): 85-92.

Hoge, F.E., R.N. Swift and E.B. Frederick (1980) Water depth measurement using an airborne pulsed neon laser system. Applied Optics, 19(6): 871-883.

Johnson, R.W. (1975a) Quantitative sediment mapping from remotely sensed multispectral data. Proceedings of 4th Annual Remote Sensing of Earth Resources Conference, March 24-26, Tullahoma, Tennessee (F. Shahrokhe, Ed.). University of Tennessee, Space Institute, pp. 565-576.

Johnson, R.W. (1975b) Quantitative suspended sediment mapping using aircraft remotely sensed multispectral data. Earth Resources Survey Symposium, June 9-12, Houston, Texas. Lyndon B. Johnson Space Center, pp. 2087-2098.

Kalle, K. (1966) The problem of the Gelbstoff in the sea. Oceangraphic and Marine Biology: An Annual Review, 4:91-104.

Keller, M. (1963) Tidal current survey by photogrammetric methods. Photogrammetric Engineering, 29(5):824-832.

Kelly, M.G. and A. Conrad (1969) Aerial photographic studies of shallow water benthic ecology. The Second Symposium on Remote Sensing in Ecology, June 19, Madison, Wisconsin, Athens, Georgia: University of Georgia Press, pp. 173-184.

Kelly, M.G. (1971) Studies of benthic cover in nearshore waters using aerial photography. Symposium on Remote Sensing in Marine Biology and Fisheries Resources, January 25-26, College Station, Texas. Remote Sensing Center, Texas A&M University, pp. 227-249.

Klemas, V. (1980) Remote sensing of coastal fronts and their effects on oil dispersion. International Journal of Remote Sensing, 1(1): 11-28.

Klemas, V., M. Otley, W. Philpot and R. Rogers (1974) Correlation of coastal water turbidity and circulation with ERTS-1 and Skylab imagery. Proceedings of 9th International Symposium on Remote Sensing of Environment, April 15-19, Ann Arbor, Michigan. Ann Arbor: Environmental Research Institute of Michigan, pp. 1289-1317.

Klemas, C., F.D. Daiber, D.S. Bartlett and R.H. Rogers (1975) Coastal zone classification from satellite imagery. Photogrammetric Engineering and Remote Sensing, 40(4):499-513.

Klemas, V., G. Davis, J. Lackie, W. Whalen and G. Tornatore (1977) Satellite, aircraft and drogue studies of coastal currents and pollutants. IEEE Transactions on Geoscience Electronics, GE-15(2):97-108.

Klemas, V. and W.D. Philpot (1981) Drift and dispersion studies of ocean-dumped waste using Landsat imagery and current drogues. Photogrammetric Engineering and Remote Sensing, 47(4):533-542.

Klesch, W.L. (1983) Summary of the long-range planning workshop presented to Chief of Engineers' Environmental Advisory Board concerning beneficial environmental aspects of the Corps' Dredging Program. In Beneficial Environment Aspects of the Corps' Dredging Program, 34th Meeting of the Environmental Advisory Board, 1-3 March. Office of the Chief of Engineers.

Legeckis, R. (1975) Application of synchronous meteorological satellite data to the study of time dependent sea surface temperature changes along the boundary of the Gulf Stream. Geophysical Research Letters, 2:10.

Legeckis, R. (1978) A survey of worldwide sea surface temperature fronts detected by environmental satellites. Journal of Geophysical Research, 83(C9):4501-4522.

Link, L.E. (1981) Airborne laser mapping systems for Corps hydrogeometric surveys. Proceedings of the Remote Sensing Symposium, 30 November-2 December, Nashville, Tennessee. Washington, D.C.: U.S. Army Corps of Engineers, pp. 74-89.

Link, L.E. and J.G. Collins (1981) Airborne laser systems use in terrain mapping. Proceedings of the 15th International Symposium on Remote Sensing of Environment, 11-15 May, Ann Arbor, Michigan. Ann Arbor: Environmental Research Institute of Michigan, pp. 95-110.

Link, L.E., W.B. Krabill and R.N. Swift (1982) A prospectus on airborne laser mapping systems. Proceedings of the 24th Plenary Meeting COSPAR, Workshop on the selection and impact of spectral bands for Earth resources analyses from space, Ottawa, Ontario, Canada. Committee on Space Research.

Lohmann, P. and H. Van Der Piepen (1980) Evaluation of ocean bottom features from ocean color scanner imagery. Proceedings of the 14th Congress of the International Society for Photogrammetry and Remote Sensing, Hamburg, West Germany, pp. 13-25.

Lyzenga, D.R. (1981) Remote bathymetry using active and passive techniques. Proceedings of the International Geoscience and Remote Sensing Symposium (IGARSS'81), June 8-10, Washington, D.C. IEEE Geoscience and Remote Sensing Society, pp. 779-786.

Lyzenga, D.R., R.A. Schuchman and R.A. Arnone (1979) Evaluation of an algorithm for mapping bottom features under a variable depth of water. Proceedings of the 13th International Symposium on Remote Sensing of Environment, 23-27 April, Ann Arbor, Michigan. Ann Arbor: Environmental Research Institute of Michigan, pp. 1767-1780.

McKim, H.L., C. Merry and R. Layman (1980) Remote sensing of water using an airborne spectroradiometer. Proceedings of the 14th International Symposium on Remote Sensing of Environment, 23-30 April, San Jose, Costa Rica. Ann Arbor: Environmental Research Institute of Michigan, pp. 1353-1362.

McKim, H.L., C.J. Merry and R.W. Layman (1984) Water quality monitoring using an airborne spectroradiometer. Photogrammetric Engineering and Remote Sensing, 50(3):353-360.

Moore, G.K. (1978) Satellite surveillance of physical water quality characteristics. Proceedings of the 12th International Symposium on Remote Sensing of Environment, April 20-26, Ann Arbor, Michigan. Ann Arbor: Environmental Research Institute of Michigan, pp. 445-462.

Munday, J.C., Jr. and T.T. Alfoldi (1979) Landsat test of diffuse reflectance models for aquatic suspended solids measurement. Remote Sensing of Environment, 8:169-193.

Murtha, P.A. (1978) Remote sensing and vegetation damage: a theory for detection and assessment. *Photogrammetric Engineering and Remote Sensing*, 44:1147-1158.

NOAA (1981) National marine pollution program plan, federal plan for ocean pollution research, development, and monitoring in fiscal years 1981-1985. Washington, D.C.: National Oceanic and Atmospheric Administration.

Panicker, N.N. (1974) Review of techniques for directional wave spectra. *Proceedings, International Symposium on Ocean Wave Measurement*. New York: American Society of Civil Engineers.

Penney, M. and H. Gordon (1976) Remote sensing of wetlands in Virginia. Publishers: Environmental Research Institute of Michigan, Ann Arbor, Michigan. *Proceedings, 10th International Symposium on Remote Sensing of Environment, October 6-10, Ann Arbor, Michigan*. Ann Arbor: Environmental Research Institute of Michigan, pp. 495-503.

Petrov, K.M. (1968) Landscape method of interpreting aerial photographs of the bottom of shallow sea water. *Interpretation of Aerial Photographs in Theory and Practice* (selected articles), p. 29.

Philipson, W.R. and D.A. Sangrey (1976) Remote sensing of ground and surface water contamination of leacheate from landfill. *Proceedings International Conference on Environmental Sensing and Assessment, September 14-19, Las Vegas, Nevada*. Washington, D.C.: U.S. Environmental Protection Agency.

Philipson, W.R. and D.A. Sangrey (1977) Aerial detection techniques for landfill pollutants. *Proceedings, 3rd Annual EPA Research Symposium on Management of Gas and Leacheate in Landfills*, Washington, D.C.: U.S. Environmental Protection Agency.

Philpot, W.D. and V. Klemas (1979) Remote detection of ocean waste. In *Ocean Optics VI. Proceedings of the Society of Photo-Optical Instrumentation Engineers*. Vol. 208, pp. 189-197.

Philpot, W.D. and S.G. Ackleson (1981) Remote sensing of optically shallow, vertically inhomogeneous waters: a mathematical model. Newark: University of Delaware, Report DEL-SG-12-81.

Proni, J.R., F.C. Newman, R.L. Sellers and C. Parker (1976) Acoustic tracking of ocean-dumped sewage sludge. *Science*, 193:1005-1007.

Ritchie, J.C., F.R. Schieve and J.R. McHenry (1976) Remote sensing of suspended sediments in surface waters. *Photogrammetric Engineering and Remote Sensing*, 42(12):1539-1545.

Rogers, R.H., D.R. Lyzenga and C.L. Wilson (1982) Mapping water depth and land features in the coastal zone by processing of Landsat-MSS data. *Proceedings of the International Symposium on Remote Sensing of Environment, First Thematic Conference, January 19-25, Cairo, Egypt*. Ann Arbor: Environmental Research Institute of Michigan, pp. 425-433.

Ross, D.B., V.J. Cardone and J.W. Conaway, Jr. (1970) Laser and microwave observations of sea-surface conditions for fetch-limited 17- to 25-m/s winds. IEEE Transactions on Geoscience Electronics, GE-8(4):326-336.

Schule, J.J., L.S. Simpson and P.S. DeLeonibus (1971) A study of fetch limited wave spectra with an airborne laser. Journal of Geophysical Research, 76:4160-4171.

Shuchman, R.A., C.L. Rufenbach, F.I. Gonzalez and A. Klooster (1979) The feasibility of measurement of ocean surface currents using synthetic aperture radar. Proceedings of 13th International Symposium on Remote Sensing of Environment, 23-27 April, Ann Arbor, Michigan. Ann Arbor: Environmental Research Institute of Michigan.

Stafford, D.B. and J. Langfelder (1971) Air photo survey of coastal erosion. Photogrammetric Engineering, 37(6):565-575.

Stilwell, D. (1969) Directional energy spectra of the sea from photographs. Journal of Geophysical Research, 74(8):1974-1986.

Weber, F.P. and F.C. Polcyn (1972) Remote sensing to detect stress in forests. Photogrammetric Engineering, 38:163-175.

Whitlock, C.H., C.Y. Kuo and S.R. LeCroy (1982) Criteria for the use of regression analysis for remote sensing of sediment and pollutants. Remote Sensing of Environment, 12:151-168.

Wilson, W.H. and R.W. Austin (1978) Remote sensing in ocean color. Ocean Optics V. Vol. 160. Arlington, Virginia: Society of Photo-Optical Instrumentation Engineers, pp. 23-30.

SELECTED BIBLIOGRAPHY

Bathymetric mapping

AVCO Everett Research Laboratory (1975) Airborne Oceanographic Lidar System, Final report. Contract No. NAS6-2653. Wallops Island, Virginia: National Oceanic and Atmospheric Administration.

Boone, G. (1981) Airborne laser shoreline mapping. Proceedings of the Remote Sensing Symposium, 30 November-2 December, Nashville, Tennessee. Washington, D.C.: U.S. Army Corps of Engineers, pp. 100-101.

Brown, W.L., F.C. Polcyn, and S.R. Stewart (1971) A method for calculating water depth, attenuation coefficients and bottom reflectance characteristics. Proceedings of the 7th International Symposium on Remote Sensing of Environment, May 17-21, Ann Arbor, Michigan. University of Michigan, pp. 663-682.

Caron, L., J. Minor and M. Meyer (1976) Upper Mississippi River underwater feature detection capabilities of water-penetrating aerial photography. St. Paul: University of Minnesota, College of Forestry.

Colvocoresses, A.P. (1979) Depth determination of Colvocoresses Reef, Indian Ocean. U.S. Geological Survey Open File Report 79-726.

Colvocoresses, A.P. (1980) Status of USGS efforts towards water depth determination with Landsat. Reston, Virginia: U.S Geological Survey.

Davis, P.A., Jr., P.T. Eliason, M.J. Grolier and P.A. Schultejann (1982) Analysis of bathymetry and submarine topography off the coast of East Central Tunisia with Landsat multispectral data. Proceedings of the International Symposium on Remote Sensing of Environment, January 19-25, Cairo, Egypt. Ann Arbor: Environmental Research Institute of Michigan, pp. 859-876.

Faig, W. (1978) Photogrammetry surveys of underwater objects. Proceedings of the Coastal Mapping Symposium, August 14-16, Rockville, Maryland. American Society of Photogrammetry, pp. 183-187.

Gierloff-Emden, B.G. (1977) Orbital remote sensing of coastal and offshore environments: transparency of clear oceanic waters and mapping of submarine topography, using satellite photography. In Orbital Remote Sensing of Coastal and Offshore Environments. Hawthorne, New York: Walter De Gruyter and Company.

Goodman, L.R. (1975) Minutes of the laser hydrography use requirements workshop. Wallops Island, Virginia: NOAA.

Gordon, H.R. (1980) Ocean remote sensing using lasers. NOAA Technical Memorandum ERL PMEL-18. Seattle, Washington: Pacific Marine Environmental Laboratory.

Halley, P. (1981) Special topics in optical propagation. Presented at 28th Meeting of the Electromagnetic Wave Propagation Panel, Monterey, California.

Harris, W.D. and M.J. Umbach (1972) Underwater mapping. Photogrammetric Engineering, 38(8):765-773.

Helgeson, G.A. (1970) Water depth and distance penetration. Photogrammetric Engineering, 36:164-173.

Hickman, G.D. (1973) Recent progress in the hydrographic applications of A N_2/Ne laser. Proceedings of the American Society of Photogrammetry, Fall Convention, Lake Buena Vista, Florida. Falls Church, Virginia: American Society of Photogrametry.

Hickman, G.D. and Hogg, J.E. (1969) Application of an airborne pulsed laser for near shore bathymetric measurements. Remote Sensing of Environment, 1:47-58.

Kelly, M.G. and A. Conrod (1969) Aerial photographic studies of shallow water benthic ecology. Second Symposium on Remote Sensing in Ecology, June 19, Madison, Wisconsin. Athens, Georgia: University of Georgia Press, pp. 173-184.

Kelly, M.G. (1971) Studies of benthic cover in nearshore waters using aerial photography. Symposium on Remote Sensing in Marine Biology and Fisheries Resources, January 25-26, College Station, Texas. Texas A&M University, Remote Sensing Center, pp. 227-249.

Kim, H.H., P.O. Cervenka and C.B. Lankford (1975) Development of an airborne laser bathymeter. NASA Technical Note, NASA TN D-8079. Washington, DC: National Aeronautics and Space Administration.

Krabill, W.B., J.G. Collins, R.N. Swift and M.L. Butler (1980) Airborne laser topographic mapping results from initial joint NASA/U.S. Army Corps of Engineers Experiment. NASA Technical Memorandum 73287. Wallops Island, Virginia: National Aeronautics and Space Administration.

Lohmann, P. and H. Van Der Piepen (1981) Evaluation of ocean bottom features from ocean color scanner imagery. Photogrammatria, 36(3):81-89.

Lyzenga, D.R. (1978) Passive remote sensing techniques for mapping water depth and bottom features. Applied Optics, 17(3):379-384.

Lyzenga, D.R. (1979) Shallow water reflectance modeling with applications to remote sensing of the ocean floor. Proceedings of the 13th International Symposium on Remote Sensing of Environment, April 23-27, Ann Arbor, Michigan. Ann Arbor: Environmental Research Institute of Michigan, pp. 23-27.

Lyzenga, D.R. (1981) Remote bathymetry using active and passive techniques. International Geoscience and Remote Sensing Symposium (IGARSS'81), Washington, D.C. IEEE Geoscience and Remote Sensing Society, pp. 779-783.

Lyzenga, D.R., R.A. Schuchman, and R.A. Arnone (1979) Evaluation of an algorithm for mapping bottom features under a variable depth of water. Proceedings of 13th International Symposium on Remote Sensing of Environment, 23-27 April, Ann Arbor, Michigan. Ann Arbor: Environmental Research Institute of Michigan, pp. 1767-1780.

Petrov, K.M. (1968) Landscape method of interpreting aerial photographs of the bottom of shallow sea water. Interpretation of Aerial Photographs in Theory and Practice (Selected Articles), pp. 29.

Polcyn, F.C. (1976) NASA/Cousteau ocean bathymetry experiment - remote bathymetry using high gain Landsat data - final report. Greenbelt, Maryland: Goddard Space Flight Center.

Polcyn, F.C. and I.J. Sattinger (1969) Water depth determinations using remote sensing techniques. Proceedings of the 6th International Symposium on Remote Sensing of Environment, October 13-16, Ann Arbor, Michigan. Ann Arbor: University of Michigan, pp. 1017-1023.

Polcyn, F.C. and D.R. Lyzenga (1975) Remote bathymetry and shoal detection with ERTS: ERTS water depth - final report for project 193302. Ann Arbor: Environmental Research Institute of Michigan.

Polcyn, F.C. and D.R. Lyzenga (1975) Nearshore coastal mapping. Proceedings of the NASA Earth Resources Survey Symposium, June 9-12, Houston, Texas. Lyndon B. Johnson Space Center, NASA TM X-58168, JSC-09930.

Rosenhein, J.S., C.R. Goodwin and A. Jurado (1977) Bottom configuration and environment of Tampa Bay. Photogrammetric Engineering and Remote Sensing, 43(6):693-700.

Ross, D.S. (1969) Color enhancement for ocean cartography. In Oceans from Space. Houston, Texas: Gulf Publishing Co., pp. 50-63.

Rudder, C.L. and J.L. Berrey (1972) Aerial photography for nearshore water depth determination. Proceedings of the Fall Convention of the American Society of Photogrammetry, 11-14 October, Columbus, Ohio, pp. 293-409.

Specht, M.R., D. Needler and N.L. Fritz (1971) A new color film for water penetration photography. Photogrammetric Engineering 39(4):359-369.

Tyler, J.E. (1977) Light in the Sea. Benchmark Papers in Optics/3. Stroudsburg, Pennsylvania: Dowden, Hutchinson and Ross, Inc.

Warne, D.K. (1978) Low cost hydrographic mapping. Proceedings of the 12th International Symposium on Remote Sensing of Environment, 20-26 April, Manila, Phillipines. Ann Arbor: Environmental Research Institute of Michigan, pp. 1063-1072.

Warne, D.K. (1978) Landsat as an aid in the preparation of hydrographic charts. Photogrammetric Engineering and Remote Sensing, 44(8): 1011-1016.

Wezernak, C.T. and D.R. Lyzenga (1975) Application of passive multispectral scanner techniques for mapping bottom features. Ann Arbor: Environmental Research Institute of Michigan.

White, M.B. (1981) Laser for hydrographic applications. Naval Research Reviews, Summer 1981, vol. 33, no. 3. Arlington, Viginia: Office of Naval Research.

Currents, sediment transport and plume dynamics

Kelley, J.T. (1982) Satellite and field observations of suspended sediment movement near Cape May, New Jersey. Geological of America Program Abstracts, 14(1&2):30.

Klemas, V., D. Maurer, W. Leatham, P. Kinner and W. Treasure (1974) Dye and drogue studies of spoil disposal and oil dispersion. Journal of Water Pollution Control Federation, 46(8):2026-2034.

Klemas, V. and W.D. Philpot (1980) The use of satellites in environmental monitoring of coastal waters. Final Report on NASA Grant NSF 1433. Newark: University of Delaware, Report CRS-1-80.

Noble, V.E. (1970) Ocean swell measurements from satellite photographs. Remote Sensing of Environment, 1:151-154.

Reimold, R., J. Gallagher and D. Thompson (1972) Coastal mapping with remote sensors. Proceedings Coastal Mapping Symposium, 5-8 June Washington, D.C. Falls Church, Virginia: American Society of Photogrammetry, pp. 99-112.

Swift, C.T. (1980) Passive remote sensing of the ocean-a review. Boundary Layer Meteorology, 18:25-54.

Water quality, turbidity and color

Abiodun, A.A. (1976) Satellite survey of particulate distribution patterns in Lake Kainji. In Remote Sensing of Environment. New York: American Elsevier Publishing Co., pp. 109-123.

Bartlett, D.S., C.H. Whitlock, E.A. Gurganu, J.W. Usry and R.C. Harris (1982) Laboratory optical measurements of waters containing particulate organic detritus. Transactions, American Geophysical Union, 63(3):60.

Blackwell, R.J. and D.H.P. Boland (1979) Trophic classification of selected Colorado lakes. Pasadena, California: Jet Propulsion Laboratory, Pub. 78-100.

Bowker, D.E., P. Fleischer, T.A. Gosnik, W.J. Henna and J. Ludwick (1973) Correlation of ERTS mulitspectral imagery with suspended matter and chlorophyll in lower Chesapeake Bay. NASA SP-327. Greenbelt, Maryland: Goddard Space Flight Center, pp. 1291-1298.

Chase, P.E., L. Reed and V.E. Smith (1973) Utilization of ERTS-1 to monitor and classify eutrophication of inland lakes. Greenbelt, Maryland: Goddard Space Flight Center. NASA Publication SP-327, pp. 1597-1605.

Clark, D.K., J.G. Zaitseff, L.V. Strees and W.S. Glidden (1974) Computer derived coastal waters classifications via spectral signatures. Proceedings of the 9th International Symposium on Remote Sensing of Environment, April 15-19, Ann Arbor, Michigan. Vol. II. Ann Arbor: Environmental Research Institute of Michigan, pp. 1213-1239,

Colwell, R.N., A.W. Knight and S. Khorram (1979) Remote sensing analysis of water quality and the entrapment zone of the San Francisco Bay and Delta. Berkeley: University of California, Space Sciences Laboratory.

Davis, C.F., R.A. Shuchman and G.H. Suits (1978) Remote sensing investigation for beach reconnaissance. Ann Arbor, Michigan: Environmental Research Institute of Michigan.

Egan, W.G. (1980) Optical remote sensing of the sea -- a Caribbean example. Proceedings of the 14th International Symposium on Remote Sensing of Environment, 23-30 April San Jose, Costa Rica. Ann Arbor: Environmental Research Institute of Michigan, pp. 563-586.

Hill, J.M. and D.S. Grahm (1981) Using enhanced Landsat images for calibrating real time estuarine water quality models. Baton Rouge: Louisiana State University, Division of Engineering Research.

Hovis, W.A., Jr. (1981) U.S. Coastal water studies with the NIMBUS-7 Coastal Zone Color Scanner (CZCS) data. Proceedings, Remote Sensing Symposium, 30 November-2 December, Nashville, Tennessee. Washington, D.C.: U.S. Army Corps of Engineers, pp. 72-73.

Hovis, W.A., Jr. (1977) Remote sensing of water pollution. Proceedings of the 11th International Symposium on Remote Sensing of Environment, April 25-29, Ann Arbor, Michigan. Ann Arbor: Environmental Research Institute of Michigan, pp. 361-362.

Jarrett, O., Jr., C.A. Brown Jr., J.W. Campbell, W.M. Houghton and L.R. Poole (1979) Measurement of chlorophyll-A fluorescence with an airborne fluorosensor. Proceedings of the 13th International Symposium on Remote Sensing of Environment, April 23-27, Ann Arbor, Michigan. Ann Arbor: Environmental Research Institute of Michigan, pp. 703-710.

Khorram, S. (1981) Water quality mapping from Landsat digital data. International Journal on Remote Sensing, 2(2):145-153.

Klemas, V., D. Bartlett and R. Rogers (1975) Coastal zone classification from satellite imagery. Photogrammetric Engineering and Remote Sensing, 41(3):499-513.

Klemas, V., W. Philpot and G. Davis (1978) Determination of spectral signatures of substances in natural waters. Final Report of NASA Grant NS61149. Newark: University of Delaware, College of Marine Studies.

Kritikos, H., L. Horinks and H. Smith (1974) Suspended solids analysis using ERTS-A data. Remote Sensing of the Environment, 3:69-78.

Lee, W.T. (1922) The face of the earth as seen from the air. New York: American Geological Society.

Mangiaracina, L. (1977) The Chesapeake Bay program: an opportunity to use an innovative monitoring technique. Proceedings of the Application of Remote Sensing to the Chesapeake Bay Region Conference. NASA Conference Publication No. 6, pp. 11-15.

Maul, G.A., R.L. Charnell and R.H. Qualset (1974) Computer enhancement of ERTS-1 images for ocean radiances. Remote Sensing of Environment, 3:1347-1386.

Moniteq Ltd. (1981) Water quality remote sensing - scientific report. Concord, Ontario: Moniteq Ltd.

Moore, G.K. (1980) Satellite remote sensing of water turbidity. Hydrological Sciences-Bulletin-des Sciences Hydrologiques, 25:407-421.

Mueller, J.L. (1976) Ocean color spectra measured off the Oregon coast: characteristic vectors. Applied Optics, 15(2):394-402.

O'Neil, R.A., L. Buja-Bijunas and D.M. Bayner (1980) Field performance of a missing laser fluorosensor for the detection of oil spills. IEEE Journal of Quantral Electronics, 15(9):16.

Polcyn, F.C. and D.R. Lyzenga (1973) Multispectral sensing of water parameters. Ann Arbor: Environmental Research Institute of Michigan.

Scherz, J.P. (1977) Water quality parameters associated with remote sensing. Madison: Institute for Environmental Studies, University of Wisconsin.

Sydor, M. (1980) Remote sensing of particulate concentrations in water. Applied Optics, 19(16):2794-2800.

Ulanowicz, R.E. (1976) Eutrophication in the Chesapeake Bay. College Park: University of Maryland, Center for Environmental and Estuarine Studies.

Wertz, D.L., W.T. Mealor, M.L. Steele and J.W. Pinson (1976) Correlation between multispectral photography and near-surface turbidities. Photogrammetric Engineering and Remote Sensing, 42(5):695-701.

Wezernak, C.T. and F.C. Polcyn (1972) Eutrophication assessment using remote sensing techniques. Ann Arbor: Research Institute of Michigan.

Whitlock, C.H., L.R. Poole, J.W. Usry, W.M. Houghton, W.G. Witte, W.D. Morris and E.A. Gurganus (1981) Comparison of reflectance with backscatter and absorption parameters for turbid waters. Applied Optics, 20(3):517-522.

Williamson, A.N. and W.E. Grabau (1973) Sediment concentration mapping in tidal estuarines. Proceedings, Third ERTS-1 Symposium, Washington, D.C. Vol. 3. NASA, Goddard Space Flight Center, pp. 1347-1386.

Wilson, W.H., R.W. Austin and R.C. Smith (1978) Optical remote sensing of chlorophyll in ocean waters. Proceedings of 12th International Symposium on Remote Sensing of Environment, 20-26 April, Manila, Phillipines. Ann Arbor: Environmental Research Institute of Michigan, pp. 1103-1113.

Yasuoka, Y. and T. Meyanzaki (1979) A study of the use of remote sensing to assess water quality of Lake Kasumigaura. Japan National Institute for Environmental Studies.

Environmental effects of dredging on wetlands and uplands, and wetlands mapping

Anderson, R.R., V. Carter and J. McGinness (1973) Applications of ERTS to coastal wetland ecology with special reference to plant community mapping and impact of man. Proceedings Third ERTS-1 Symposium, Washington, D.C. NASA, Goddard Space Flight Center, pp. 1225-1242.

Bartlett, D.S. (1979) Spectral reflectance of tidal wetland plant canopies and implications for remote sensing. Ph.D. Dissertation, University of Delaware, Newark.

Bartlett, D.S. and V. Klemas (1980) Evaluation of remote sensing techniques for surveying coastal wetlands. Final Report of National Marine Fisheries Service Contract NA79-GA-C-0007. University of Delaware, Newark, Report CRS-2-80.

Bartlett, D.S. and V. Klemas (1980) Quantitative assessment of tidal wetlands using remote sensing. Environmental Management, 4(4):337-345.

Carter, V. (1978) Coastal wetlands: role of remote sensing. Proceedings Coastal Zone '78, Symposium on Technical Environmental, Socioeconomic and Regulatory Aspects of Coastal Zone Management, March 14-16, San Francisco. New York: American Society of Civil Engineers, pp. 1261-1283.

Carter, V. and J. Schubert (1974) Coastal wetlands analysis from ERTS-MSS digital data and field spectral measurements. Proceedings, 9th International Symposium on Remote Sensing of Environment, April 15-19, Ann Arbor, Michigan. Ann Arbor: Environmental Research Institute of Michigan, pp. 1241-1259.

Chapman, V.J. (1960) Salt Marshes and Salt Deserts of the World. New York: Interscience Publishing.

Drake, B.G. (1976) Seasonal changes in reflectance and standing crop biomass in three salt marsh communities. Plant Physiology, 58:696-699.

Hardisky, M.A. and V. Klemas (1981) Remote sensing salt marsh biomass and stress detection. Proceedings of the Remote Sensing Symposium, 30

November-2 December, Nashville, Tennessee. U.S. Army Corps of Engineers, p. 155.

Hardisky, M.A., V. Klemas, and R.M. Smart (1983) The influence of soil salinity, growth form, and leaf moisture on the spectral radiance of Spartina alterniflora canopies. Photogrammetric Engineering and Remote Sensing, 49(1):77-83.

Hardisky, M.A., R.M. Smart, and V. Klemas (1983) Seasonal spectral characteristics and aboveground biomass of the tidal marsh plant, Spartina alterniflora. Photogrammetric Engineering and Remote Sensing, 49(1): 85-92.

Hardisky, M.A. (1978) Marsh restoration on dredged material, Buttermilk Sound, Georgia. Proceedings of the Sixth Annual Conference on the Restoration and Creation of Wetlands, pp. 143-173.

Odum, E.P. (1961) The role of tidal marshes in estuarine production. New York State Conservation, 16:12-15.

Odum, E.P. (1971) Fundamentals of Ecology. Philadelphia: W.B. Saunders Co.

Pearson, R.L. and L.D. Miller (1972) Remote spectral measurements as a method for determining plant cover. Technical Report No. 167. U.S. International Biological Program, Colorado State University.

Pfeiffer, W.J., R.A. Linthurst and J.L. Gallagher (1973) Photographic imagery and spectral properties of salt marsh vegetation as indicators of canopy characteristics. Proceedings, Symposium on Remote Sensing in Oceanography, Lake Buena Vista, Florida. Falls Church, Virginia: American Society of Photogrammetry, pp. 1004-1016.

Press, N.P. (1974) Remote sensing with special reference to agriculture and forestry. Washington, D.C.: National Academy of Sciences.

Rogers, R., K. Peacock and N. Shah (1973) A technique for correcting ERTS data for solar and atmospheric effects. Third ERTS Symposium. NASA SP-351. Greenbelt, Maryland: Goddard Space Flight Center, pp. 1787-1804.

Seevers, P.M., J.V. Drew and M.P. Carlson (1975) Estimating vegetative biomass from Landsat-1 imagery for range management. Proceedings Earth Resources Survey Symposium, June 9-12, Houston, Texas. Vol. IA. Houston: Lyndon B. Johnson Space Center, pp. 1-8.

Stoll, J.K. (1981) Mapping wetlands in the Corps of Engineers using Landsat MSS data. Proceedings of the Remote Sensing Symposium, 30 November-2 December, Nashville, Tennessee. U.S. Army Corps of Engineers, pp. 157.

Teal, J.M. and M. Teal (1969) Life and Death of the Salt Marsh. Boston: Little Brown and Co.

Tucker, C.J., J.E. Elgin and J.E. McMartney III (1979) Relationship of red and photographic infrared spectral radiances to corn and soybean biomass, percent cover, plant height, chlorosis and leaf loss. Remote Sensing of the Environment, 8(3).

Monitoring dredging operations and effects on aquatic life

Gordon, R.B. (1974) Dispersion of dredge spoil dumped in near-shore waters. Estuarine and Coastal Marine Science, 2:349-358.

Harmon, P.L., P.L. Smith, D.C. Smith and E.C. Raney (1975) Monitoring of fishes in March and April 1975 during the excavation blasting in the Delaware River near Marcus Hook, Pennsylvania. Final report prepared for U.S. Army Corps of Engineers, Philadelphia District, Contract No. DACW 61-75-C-0066.

Hayden, B. and R. Dolan (1974) Impact of beach nourishment on distibution of emerita talpodia, the common mole crab. Journal of the Waterways, Harbors and Coastal Engineering Divison, American Society of Civil Engineers, 100(WW2).

Martin Marietta Corporation (1976) Monitoring fish migration in the Delaware River. Prepared for Department of the Army, Philadelphia, Pennsylvania, Contract No. DACW 61-75-C-0264.

Sustar, J.F. and R.M. Ecker (1972) Monitoring dredge disposal on San Francisco Bay. Offshore Technology Conference, 1-2 May, Houston, Texas. Paper No. OTC-1660. Dallas, Texas: Offshore Technology Conference.

APPENDIX A. GLOSSARY OF TECHNICAL TERMS

Absorptance -- ratio of the radiant flux lost from a beam by means of absorption vs the incident flux.

Absorption coefficient — internal absorptance of an infinitesimally thin layer of the medium normal to the beam, divided by the thickness of the layer.

Albedo — ratio of the radiation reflected from the earth vs the total amount incident upon it.

Algorithm -- a detailed computational procedure that converts instrument readings (data) into geophysical measurements.

AOL — Airborne Oceanographic Lidar.

Attenuation coefficient — internal attenuance of an infinitesimally thin layer of the medium normal to the beam, divided by the thickness of the layer.

Backward scatterance — ratio of the radiant flux scattered through angles 90°-180° from a beam vs the incident flux.

Band ratioing techniques -- multispectral images may be enhanced by taking ratios of individual spectral components and displaying ratios as color composites. This suppresses brightness variations from topographic relief and enhances subtle color differences in the picture.

Beam attenuation coefficient -- attenuation coefficient for a light beam whose diameter is small compared to its length.

Beam transmittance — transmittance for a beam whose diameter is small compared to its length.

Dark object subtraction -- atmospheric correction technique used in remote sensing where "dark objects" such as water bodies that absorb infrared (IR) wavelengths are used to estimate atmospheric contribution to the signal by assuming they reflect no IR.

Densitometric -- techniques based on measurement of optical or film density.

Echosounder -- a device that emits sound pulses and measures their round-trip travel time to a target or ocean bottom from which they are reflected. Depth or range can be calculated from propagation velocity of sound.

Eigenvector analysis — eigenvector (or eigenvalue) is a special mathematical measure computed in the process of deriving a discriminant function. The eigenvalue is a measure (or relative percentage) of the importance of the discriminant function.

Enhancement (multi-image) -- multi-images convey more information than monochrome images. Multi-images are obtained by imaging a scene in more than one spectral band or by monitoring a scene over a period of time. Multi-image enhancement techniques involve contrast enhancement of the component images. The enhanced components may be displayed as false-color composites.

Fluorescing -- detection of organic substances (oil slicks, algae, etc.) causing them to absorb energy (e.g. laser) at one wavelength and emit it via fluorescence at another wavelength which is measured by detectors with narrow filters optimized for the emitted wavelengths.

Forward scatterance -- ratio of the radiant flux scattered through angles 0-90° from a beam vs the incident flux.

Fraunhofer lines -- absorption lines in the sun's spectrum due to elements in the sun's atmosphere.

Gelbstoff -- yellow substance that consists primarily of carbohydrate-humanic acids and is distinguished from other dissolved organic matter through its light absorption which starts in the yellow and rapidly grows towards shorter wavelengths (blue).

HF (High Frequency) -- radio frequency band from 3 to 30 MHz (wave-length of 10 to 100 m).

IR (Infrared Radiation) -- that portion of the electromagnetic spectrum between the limiting wavelengths of 0.7 and 1000 μm.

Irradiance (at a point of the surface) -- radiant flux incident on an infinitesimal element of surface containing the point under consideration, divided by the area of that element. (Units of wattsper square metre).

Irradiance ratio -- ratio of the upward to the downward irradiance at a depth in the sea.

Irradiation (at a point of a surface) -- the product of an irradiance and its duration. (Units of joules per square metre).

Landsat -- five satellites launched in 1972, 1975, 1978, 1982 and 1984, respectively, into near-polar, sun-synchronous, 900-km circular orbits, with an observation repeat cycle of 18 days. (16 days for Landsat-4 and -5, which contain MSS and TM systems).

Landsat MSS bands -- spectral bands of Landsat multispectral scanner at an 80-m resolution.

Band 4 (Green)	0.5-0.6 μm
Band 5 (Red)	0.6-0.7 μm
Band 6 (near-IR)	0.7-0.8 μm
Band 7 (near-IR)	0.8-1.1 μm

Lidar -- light detection and ranging - a laser radar type device.

MSS -- multispectral scanner subsystem - an instrument onboard the Landsat satellites that images a scene 185 km on a side in more than one spectral band.

Multispectral -- consisting of many spectral channels or bands (such as multispectral scanner).

Near IR -- infrared radiation from 0.7 to 3.0 μm (predominantly reflected energy).

Optical length -- geometrical length of a path multiplied by the total attenuation coefficient associated with the path.

Pixel -- picture element, smallest resolvable element of an image.

Quantity of radiant energy -- quantity of energy transferred by radiation. (Units of joules or ergs).

Radiance -- radiant flux per unit solid angle per unit projected area of a surface. (Units of watts per square metre per steradian).

Radiant flux -- time rate of flow of radiant energy. (Units of watts).

Radiant intensity (of a source in a given direction) -- the radiant flux emitted by a source, or by an element of a source, in an infinitesimal cone containing the given direction, divided by the solid angle of that cone. The steradian is the solid-angle unit of measure.

Radiative transfer model -- a mathematical-physical model that describes the behavior (fate) of electromagnetic waves (or protons) as they transit and interact with constituents of a medium such as air or water.

Reflectance -- ratio of the reflected radiant flux to the incident radiant flux.

Refractive index -- phase speed of radiant energy in free space divided by the phase speed of the same energy in a specified medium.

Resolution -- ability of an instrument to form distinguishable images of objects separated by small angular distances; the smallest length distinguishable by an instrument.

Scatterance -- ratio of the radiant flux scattered from a beam vs the incident flux.

Scattering coefficient -- the internal scatterance of an infinitesimally thin layer of the medium normal to the beam, divided by the thickness of the layer.

Secchi depth -- depth at which Secchi disk becomes invisible to human eyes.

Secchi disk -- white disk of 15 to 60 cm diameter that is used to estimate water clarity (turbidity) by lowering it on a measured line and observing at what depth it becomes invisible.

SPOT -- Système Probatoire d'Observation de La Terre. The SPOT satellite is scheduled for launch by the French government on 3 October 1985. The satellite will carry two High Resolution Visible (HRV) instruments that can acquire data in two modes -- 20-m multispectral or 10-m panchromatic.

Thalweg -- line connecting the lowest or deepest points along a streambed.

TM -- Thematic Mapper -- multispectral scanner launched in July 1982 on Landsat-4. The TM has the following spectral bands at a 30-m resolution (120-m for the thermal band):

Band 1 (Blue)	0.45-0.52 μm
Band 2 (Green)	0.52-0.60 μm
Band 3 (Red)	0.63-0.69 μm
Band 4 (Near-IR)	0.76-0.90 μm
Band 5 (Near-IR)	1.55-1.75 μm
Band 6 (Thermal IR)	10.40-12.50 μm
Band 7 (Middle IR)	2.08-2.35 μm

Thermal IR -- infrared radiation having wavelength longer than 3.0 μm (predominantly emitted energy used for surface temperature mapping, usually in 8 to 12 μm band).

Tomography -- a technique using x-ray photographs in which the shadows of structures before and behind the section under scrutiny do not show.

Transmittance — the ratio of the transmitted radiant flux to the incident radiant flux (in either irradiance or radiance form).

Volume scattering function -- the radiant intensity (from a volume element in a given direction) per unit of irradiance on the volume and per unit volume.

Wavelength -- the distance between two successive points of a periodic wave in the direction of propagation, for which the oscillation has the same phase.

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