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Assessment of the Role of Remote Sensing in the Study of Inland and Coastal Waters

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I. STUDY OBJECTIVES

The inland, coastal, and continental shelf waters have been the subject of numerous studies, workshops, and legislation. Each has identified problem areas which require a knowledge of water properties for their understanding and solution. Because NASA has a responsibility for the research and development of remote sensing technology, an initial objective of this study was to assess the current state of remote sensing technology in meeting the measurement requirements defined for the identified problem areas. A second, and closely related, objective was to assess of the potential of remote sensing technology in meeting those measurement needs presently beyond current capabilities. A final objective was to propose a research and development program that will contain priority items of remote sensing technology advancement that are responsive to the defined science and applications needs. The program plan as presented maintains a focus on the relevant science and applications for which remote sensing can provide a direct contribution. This approach is in harmony with and, indeed, enhances and enlarges the objectives in the current 10-year plan for this important part of the aquatic environment. This plan may serve as a framework for organizing the NASA contributions toward those problems and processes in the Great Lakes, estuarine, coastal, and continental shelf waters.

II. STUDY METHODOLOGY

This study has been a joint effort of the Lewis Research Center, the Wallops Flight Center, and the Langley Research Center. The objectives previously presented were agreed to by the three Centers and a team of one representative from each Center was selected for performing the study with other support being solicited as required.

The study began with problem identification. Problems were identified for the Great Lakes, estuarine, coastal, and shelf waters by reviewing relevant symposia, workshops, Congressional reports, program plans, and other documents. Enough information was gathered so that the required water property measurements could be compiled. In the presentation of these selected problems, it is intended that the descriptions be of a reasonable length so as to do justice to the problem but not necessarily contain all of the background and justification existing in the source documents. It is acknowledged that while some of the problem description material is nearly verbatim from some other document, it has been shortened and specific quotations and detailed references have not been attempted.

After the problem material had been organized, an assessment was made concerning the present and potential capability of remote sensing to measure each identified water property. It must be emphasized that this assessment was based solely on the capability or potential to infer the water properties with remote-sensing techniques. It has not been the intent here to describe the remote-sensing techniques in depth. This plan does not contain the details of measurements such as accuracy requirements, spatial resolution, frequency of coverage, or any other operational considerations. Although some of these details can be found in references (such as those contained later herein), too often the needed information is not adequately documented, and these factors will have to be considered in detail in further planning.

Along with an assessment of present and potential capabilities, two sets of recommendations are the outgrowth of this study. First is a set of important, needed technology advancements and second a research and development program to help satisfy the need in this area.

III. ASSESSMENT OF REMOTE SENSING CAPABILITIES AND POTENTIALS

The objective of this section is to provide an assessment of present and future remote-sensing capabilities for obtaining measurements of the water parameters required in addressing problems relevant to the Great Lakes, estuarine, and coastal waters. In the first part, the topic areas and problems will be presented with a tabular assessment of the remote-sensing capability shown for each problem discussed. The second part will be a discussion of this assessment in greater detail.

A. PROBLEMS AND REMOTE SENSING ASSESSMENT

For convenience of presentation, the problem discussions will be presented under six topical headings: Productivity, Sedimentation, Water Dynamics, Eutrophication, Hazardous Substances, and Other. Following a brief description of the individual topic, several specific problems are selected as being representative. It is not intended that the problems represent an exhaustive list of activities that would completely address the scientific and application issues under the particular heading. Rather, the problems were selected as representative enough to define the scope of measurement parameters which might be anticipated for most problems under such a heading. As noted earlier, the problems are real ones having been identified by the scientific and user community through various workshops, symposia, and other documentation. Appendix A is a listing of those documents reviewed for topical discussion and specific problem definition. For each problem, a tabulation is presented of measurement requirements vs. remote-sensing capability (present and potential). In these tabulations the present capability is indicated by two letters, A and B. Those marked A do not require any on site supplementary measurement (surface truth) for the interpretation of the remotely sensed data; those marked B do and are, therefore, site or scene specific.

Productivity

A fundamental concern of aquatic science is the enormous scope of activities related to productivity. Criteria defining the "health" of aquatic ecosystems always include aspects of productivity. Consequently, the understanding of these bioprocesses has been and will continue to be of prime scientific importance.

Productivity must be viewed in a dynamic sense. Variations in productivity occur on time scales as short as a few hours and as long as a few months, with diurnal and monthly variations being very significant. The study of these bioprocesses in the Great Lakes, coastal, and shelf waters must also include the relevant spatial scales, a variable with a dynamic range of as much as six orders of magnitude. When the many inputs (e.g. nutrients, pollutants) to the fresh and marine waters are combined with the natural aquatic and meteorological driving forces, it is evident that the dynamicbioprocesses throughout the food chain, from the phytoplankton to the upper trophic levels, require the attention and cooperation of biological chemical, physical, and geological specialists to address the multitude of factors which influence productivity.

Productivity (like so many other things) is not all positive, but also has its negative side. There are biomass increases that are viewed as undesirable. For example, blue-green species of algae are usually considered to be "nuisance" species because of their tendency to form thick mats and surface scums. Blue-greens have been implicated as causative factors in taste and odor problems at water treatment plants. Since blue-greens are not assimilated into the food chain, they tend to be very persistent, and they contribute a disproportionate share to the depletion of dissolved oxygen upon death and decomposition. Such algal blooms are a principal manifestation of the problem of eutrophication. In areas, such as the Great Lakes, the excessive nutrients are of anthropogenic origin. This topic of eutrophication is addressed in a separate section of this report.

In fresh, brackish, and marine waters, major concerns in food chain studies include the determination of stresses on lower trophic levels and of the degree of coupling between various trophic levels. Factors controlling the abundance and distribution of phytoplankton and the dynamics of patchiness of phytoplankton need to be understood. Patchiness in zooplankton and ichthyoplankton are major factors in coupling primary and secondary production. Numerous questions remain in our understanding of phytoplankton communities, including (1) the size spectra, (2) seasonal changes in size structure, (3) patchiness effects on larval fish success, (4) the three-dimensional structure, and (5) characterizations based on pigments (greens vs. blue-greens in diatoms vs. dinoflagellates) and size (nanoplankton vs. net plankton).

The following are a few problems related to productivity that have been selected as representative of this study.

<u>PROBLEM</u>: Dynamics of Phytoplankton Patches

Understanding the causes and ramifications of plankton patchiness is one of the overriding concerns of marine ecosystems research. The dynamics of patches are functions of physical processes (advection and diffusion) interacting with biological processes (such as growth and herbivory). At small spatial scales, phytoplankton distributions are reflections of the small scale turbulence, whereas at larger scales (15 km) biological processes become dominant. Temporal changes in spatial structure at larger scales can be related to plankton growth rates. However, these statistical studies do not adequately address causal relationships that have been found between phytoplankton distributions and mesoscale oceanographic phenomena such as oceanographic fronts and topographic/tidal mixing.

The study of patchiness at these mesoscale (1 - 100 km) levels is limited by a fundamental problem relating to sampling using conventional oceanographic techniques. Very significant interactions between physical processes such as tidally induced mixing and upwelling and biological processes such as phytoplankton growth, distribution, and abundance, and secondary production occur at varying space and time scales which demand sampling through joint *in situ* (buoy), ship, and aircraft/spacecraft programs. Areas where mesoscale processes require these joint efforts are the major river and estuarine plume regions, much of the nearshore coastal and continental shelf region, oceanic frontal regions, and tidally dominated regions.

Measurements Required:

Parameter		Remote Sensing Capability	
		Present	Potential
Temperature:	Surface	A	
	Profile		Limited
Chlorophyll:	Surface	B	
	Profile		Medium (for upper photic zone)
Phytoplankton Species			None Identified
Species Diversity		B	
Species Growth Rates			None Identified
Nutrients:	Profile		Low
Light Attenuation		B	
Salinity:	Surface	A	
	Profile		Low
Total Suspended Solids:	Surface	B	
	Profile		High
Conductivity:	Profile		None Identified
Surface Wind:	Speed	A	
	Direction	B	
Currents:	Surface	A	
	Profile		Medium (in photic zone)

PROBLEM: Quantitative Linkage Between Primary Productivity and Upper Trophic Levels

Existing research has shown the qualitative relationship between primary productivity and the upper trophic levels. Since annual quotas are part of the legislatively mandated fishery management plans, the need for a quantitative assessment is required. Quotas are generally derived from yield models that assume a steady-state environment. The recruitment input to these models is often from shipboard station data (trawl or plankton net). In some cases, it has been shown that physical processes such as surface Ekman transport or primary biologic processes such as dinoflagellate/diatom bloom ratios contribute substantially to the success or failure of recruitment. Ship-collected data are discontinuous and sampling may miss areas of abundance--or may fortuitously cover sample patches of high abundance. These data on adult stock abundance and recruitment (larval abundance) are so variable that their use as input in yield models often results in serious errors in yield estimates and hence quotas. Public Law 95-264 (Fisheries Conservation and Management Act of 1976) is a Congressionally mandated statute requiring the development and operation of management plans for each fished stock. Realistic stock assessments of recruitment and abundance are difficult to secure yet are required so that the annual mandated quotas can be generated.

The goal of this research is to contribute to fisheries forecasting by using remote-sensing data as a primary input source. In the assessment of the role of multispectral remote sensing techniques for fishery forecasting and management, the attempt will be to relate the behavior and spawning success to circulation, frontal history, and primary productivity, and to cross-correlate any apparent relationships with driving mechanisms such as insolation, winds, etc. Remotely sensed data on the location, size, and duration of eddies, upwelling, surface windfields, and planktonic blooms used in conjunction with shipboard stock assessments will reduce the patchiness of the data, provide criteria for more efficient surface sampling, and will allow repeated synoptic measurements of these features. The most significant U.S. coastal fisheries lie within 300 km of the coast line over the continental shelf. Remotely sensed assessment data from the Bering Sea, Gulf of Mexico, Atlantic Bight, and Georges Bank would provide the most significant inputs.

The use of remote sensing in the eventual forecasting of distribution, availability, and abundance levels of coastal fisheries would increase the efficiency of harvesting and processing. Such forecasting would maximize the economic benefits to commercial fleets by increasing the catch per unit effort and decreasing labor and fuel costs. In addition, remote sensing might identify new fishing areas in nearshore or offshore waters.

Measurements Required:

Parameter		Remote Sensing Capability	
		Present	Potential
Phytoplankton concentration:	Surface	B	
	Profile		Low
	Areal Extent	A,B	
	Species		None Identified

Parameter	Remote Sensing Capability	
	Present	Potential
Chlorophyll: Surface	B	
Profile		Medium (for upper photic zone)
Temperature: Surface	A	
Depth		Limited
Pycnocline Topography		None Identified
Salinity: Surface	A	
Profile		Low
Currents: Surface	A	
Profile		Medium (in photic zone)
Surface Wind: Speed	A	
Direction	B	
Eddies: Location	A	
Size	A	
Duration	A	
Front Locations:		
Temperature	A	
Color	A	
Bathymetry	A (within limits)	
Fish Schooling:		
Species		None Identified
Location		(See Note 1)
Quantity		None Identified

Note 1 - Related research is continuing with the potential for ship location and monitoring within the 200-mile limit, and especially within the fisheries zones, which may ultimately be used to provide fish catch location data.

<u>PROBLEM</u>: Wetlands Interactions with Estuaries and Coastal Waters

Traditionally wetlands have been regarded as wasted areas; not land-like enough to travel into on foot, but not water-like enough to use a boat easily. The response to the presence of a wetland area in the past has often been to fill it in and develop it as water front property.

As wetland areas have been studied, however, we have realized that this is an important part of the coastal region. They serve as flood control regions, as places to trap sediment, and probably most importantly as sources of food for many organisms. The wetlands that are often flooded are particularly useful as sources of detritus.

Measurements that can contribute to understanding the wetland's place in the coastal ecology include the areal extent of the wetland, the productivity of the wetland and its tendency for flooding. Productivity is perhaps the most difficult of these measurements because unlike, for example, a corn field where measuring the corn grown provides the desired result a chain of organisms should be monitored to specify this variable completely. It is becoming possible, however, to measure the biomass associated with standing, emergent vegetation which may have a high enough correlation with total productivity to be a sufficient measurement. The areal measurement of the wetlands needs only the appropriate resolution in an imaging device, and the flooding properties can be measured if repetitive images can be obtained of the area.

Measurements Required:

Parameter	Remote Sensing Capability	
	Present	Potential
Areal Extent	A	
Flora and Fauna Inventory		
Standing Vegetation: Species	A,B	
Biomass	B(Limited)	
Flooding	A	High
Particulate Organic Carbon (POC)		None Identified
Dissolved Organic Carbon (DOC)		Medium
Topography	A (within Limits)	

PROBLEM: Sources and Foods for Estuarine Organisms

An estuary is not only the home for an incredibly diverse collection of organisms, but it is also the nursery for many more. This diversity seems to be correlated with the health of the estuary; for example, when one species of algae is able to outbreed its competitors that usually has meant a change for the worse at that location affecting other higher organisms even leading to their death. Balance in the food chain is a critical item in an estuary.

At the base of the food chain are the phytoplankton. Their growth is dependent upon the distribution of temperature, nutrients, and light in the water. The phosphate concentration is thought to be the limiting nutrient in an estuary or lake with nitrogen limiting growth in the ocean. Growth under natural conditions is more complex than that; sediment laden waters, for example, do not usually support large algal growth because of light attenuation by the sediment. Zooplankton feed on the phytoplankton and detritus from wetlands as well as on other zooplankton.

At the bottom of the estuary the benthic population grows. These organisms vary due to the type of sediments present and the water dynamics on the bottom. In warm areas with poor circulation an anaerobic zone may be formed. Fishes feed on these organisms and in turn are eaten by other fishes which are caught by man and other animals living on land.

These higher trophic levels of organisms are difficult to detect by remote sensing; there may be indirect indicators, however, such as surface films from fish. However, the lower trophic levels, the phytoplankton especially, may be monitored remotely. Because they are the start of the food chain they are important.

Measurements Required:

Parameter	Remote Sensing Capability	
	Present	Potential
Temperature: Surface	A	
Temperature: Profile		Limited
Chlorophyll: Surface	B	
Chlorophyll: Profile		Medium (for upper photic zone)
Phytoplankton Species		None Identified
Species Diversity	B	
Species Growth Rates		None Identified
Nutrients: Profile		Low
Light Attenuation	B	
Salinity: Surface	A	
Salinity: Profile		Low
Total Suspended Solids: Surface	B	
Total Suspended Solids: Profile		High
Conductivity: Profile		None Identified

Parameter	Remote Sensing Capability	
	Present	Potential
Surface Films		High
Currents: Surface	A	
Profile		Medium (in photic zone)

Sedimentation

Particles are added to the marine environment by streams, rivers, lakes, estuaries, the atmosphere, shore erosion, biological activity, and by municipal and industrial discharges. The particles are both organic, living and dead; and inorganic, naturally occurring and anthropogenic. Man has clearly modified the flow of natural particles in the marine ecosystem by land-use practices - deforestation, agriculture, urbanization - and by water-use practices - construction of dams and reservoirs, diversion of rivers and streams, construction of shore protection devices, etc. His practices have also introduced significant quantities of anthropogenic particulate matter.

Aquatic effects from high or abnormal particulate loading are generally of two principal types: (1) those related to turbidity and sediment disposition, and (2) those caused by sediment-associated chemical parameters. Both types of aquatic effects are well documented, though very few studies have been actually conducted.

Turbidity causes reduced light penetration and subsequent interference with photosynthesis, interference with heat transfer, flocculation of algae, and general deterioration of the aesthetic quality of water. Fish behavior may also be affected. Accumulation of sediment on the lake bottom can alter benthic communities, interfere with macrophyte growth, and destroy fish spawning areas. Economic effects of sediment accumulation and turbidity include increased dredging of navigational channels and harbors and the increased cost of removing turbidity from drinking water.

Interactions between sediment and chemical pollutants are complex, but it is clear that suspended particulates can act as both a source and a sink for many chemical constituents. Fine-grained sediment, with its high adsorptive capability, is a significant transport mechanism for nutrients, trace metals, and organic materials (pesticides, etc.,) from the land surface to the aquatic environment. On the other hand, finely divided clay particles suspended in waters may act as sorption sites for solutes already present. Thus, suspended solids may actually result in an overall decrease in the concentration of chemical pollutants in the lake by transporting the contaminants to the bottom sediments.

PROBLEM: Sediment Source, Transport and Fate

Because particulate matter can strongly affect the quality of the aquatic environment in a variety of ways, the ability to monitor and predict its source, transport, fate and effect is of great scientific and practical importance.

The primary source of sediment to the aquatic environment is freshwater runoff from nonpoint sources such as agricultural land, urban areas, forest and other land uses (e.g. coastal development, surface mining, etc.) as well as shoreline erosion. The absolute loads of sediments to the aquatic environment should, however, be interpreted with caution when considering ecological impacts. Sediments derived from shoreline erosion do not usually contain any man-made substances or anthropogenic elements prior to erosion. Sediments derived from agricultural land have been found to contain elevated levels of phosphorus, nitrogen and some toxic organic compounds. Sediments derived from urban construction activities have also been found to contain elevated levels of these substances as well as trace elements. These pollutants become adsorbed onto the sediment particle, either while part of the parent soil material or in transport. In terms of overall pollution loading, sediment associated fractions of many pollutants constitute a substantial proportion of the total loading of that pollutant, especially in the Great Lakes.

A full assessment of the impact of various land use activities on water quality requires information not only on the relative sediment loads of the various nonpoint sources, but an understanding of the transport and fate of the various particulates into the aquatic environment.

Since certain sediment particles have a high absorptive capability for nutrients, heavy metals and organic materials (pesticides, PCB's, etc.) the movement of sediments, then, at transfer points or mixing zones (e.g. where tributaries or estuaries enter a lake or ocean) is important to the understanding of the fate of many pollutants, particularly from land sources.

Suspended sediments have also been recognized as a good natural tracer of water flow providing information on water circulation patterns, river plumes, upwellings, etc.

Understanding the movement and fate of particulate matter is of significant importance in the development of water quality management models, particularly for the Great Lakes. At the present time, mathematical models describing the transport of particulate matter and sediments throughout the Great Lakes System are in a preliminary stage of development.

Many estuarine processes and plume dynamics can be studied by tracing the distribution of suspended matter. Such studies, however, require spatial and temporal resolutions not easily obtained by standard oceanographic sampling techniques.

Relatively little is known about the routes and rates of sediment transport on the continental shelves of the world. This is particularly true of the fine-grained fraction, the silt and clay-sized particles. Aside from the obvious scientific reasons for wanting to understand the dispersal of sediments on continental shelves, there are important practical reasons. With the increasing potential for use of our continental shelves for energy-related activities - for oil exploitation and siting of floating nuclear power plants - and with increasing exploitation of sand and gravel resources, it will become increasingly important to be able to predict the routes and rates of sediment transport. Fine particles are the principal pathway for carrying particle-associated contaminants (e.g., oil, radionuclides, and metals) in continental shelf waters back to the continents and therefore, to man. The mobility of the bottom must be considered in the siting of facilities, laying of pipelines, etc.

Measurements Required:

Parameter	Remote Sensing Capability	
	Present	Potential
Total Suspended Solids:		
Surface	B	
Profile		High
Organic/Inorganic		Medium
Size Distribution		None Identified
Input Fluxes	B (Limited)	
Discharge Fluxes	B (Limited)	
Resuspension	B	
Bedload Changes	A (within limits)	
Settling Rate	Note 1	
Particle Associated Contaminants:		None Identified
Shoreline Changes:	A	
Deposition Location	A (within limits)	
Currents: Surface	A	
Currents: Profile		Medium (in photic zone)
Salinity: Surface	A	
Salinity: Profile		Low
Waves: Signif. Wave Height	A	
Waves: Length	A	
Waves: Direction	A	
Bathymetry	A (within limits)	

Note 1 - The technique of using changes in surface concentration as a function of time may not be acceptable. However, remote sensing from shipboard using acoustic techniques is well developed.

PROBLEM: Sediment/Pollution Partitioning

Another ecological concern related to sediments is their role as pollutant carriers on one hand and pollutant sinks or traps on the other. Sediment can bind phosphorus, heavy metals, pesticides and other organic compounds (such as PCB's).

Sediment particles can transport pollutants to the marine environment and thus be a pollutant source when the pollutants become bound to the particle surface, especially on clay-sized particles. The pollutant-laden particles can then be carried to the marine environment where the pollutant may be released either immediately or over time from the particle surface under certain biochemical conditions in the water. As a general rule, pollutants are released from sediments under chemically reducing conditions in the water, such as occur under conditions of oxygen depletion. Phosphorus, for example, is usually released from sediments in substantial quantities when such anoxic conditions occur in the hypolimnetic waters of Lake Erie's central basin. Metals are also released under these conditions. These and other pollutants may then be available for biological uptake.

On the other hand, pollutant-laden sediment particles may not release the pollutant to the water. Sediment particles may also absorb pollutants from the water itself. In these cases the sediment is acting as a pollutant trap or sink by rendering the pollutant unavailable for uptake by aquatic organisms. The bound pollutant may remain unavailable essentially permanently when the sediment particle sinks to the bottom. Oxygenated water conditions generally cause pollutants to remain attached to sediment particles, or if any release does occur, it is usually very slow.

The estuarine zone often is the site of precipitation of hydrated iron oxides which are very strong adsorbers of metals and many other pollutants. The river clay mineral fraction, which contains most of the metallic pollutants, may "flocculate" at the sea/river interface and be carried in a strong flow along the sea bed. Much of its heavy metal load may redistribute itself in the precipitating iron oxides, and hence be fixed in the nearshore sediment.

The resuspension of bottom sediments may chemically or physically affect water quality. When bottom sediment is resuspended associated pollutants may be returned to the overlying water through resuspension of sediment particles, dispersal of interstitial water and desorption from the resuspended solids. Conversely, the resuspended sediment may adsorb dissolved contaminants from the overlying water, thereby decreasing the amount of pollutants in the water.

Thus the movement, deposition, and resuspension of suspended particles may serve as a tracer of various pollutants in the marine environment.

Measurements Required:

Parameter	Remote Sensing Capability	
	Present	Potential
Total Suspended Solids:		
Surface	B	
Profile		High
Organic/Inorganic		Medium
Size Distribution		None Identified
Input Flux	B (Limited)	
Discharge Flux	B (Limited)	
Bed Load Changes		Low
Particle Associated Contaminants		None Identified
Deposition Changes (Bathymetry)	A (within limits)	

PROBLEM: Episodic Events

Recent studies have shown that events such as floods and hurricanes can dominate the sedimentation of coastal systems. For example, after tropical Storm Agnes (June 1972), the Susquehanna River - the principal source of fluvial sediment to the Chesapeake Bay - discharged more suspended sediment in one week than it does during 25 years of average runoff. Two floods, Agnes in 1972 and the Great Flood of 1936, account for more than one-half of all sediment deposited in the upper Chesapeake Bay since 1900. Other investigators have shown that inlets cut during hurricanes can completely alter the circulation and sedimentation of bar-built estuaries and lagoons. It is clear that while they have a low frequency of occurrence, episodic events can dominate the natural evolution of coastal water bodies.

Synoptic observations are desirable during such events because water properties frequently change rapidly in time and space during and immediately following events. Shipboard observations during this period are, at best, difficult to make because of weather and sea conditions and synoptic observations by ships over relatively large areas are virtually impossible. While cloud cover may frequently rule out satellite observation during episodic weather events, low flying aircraft might be useful. Because of their very nature, episodic events frequently cannot be predicted very far in advance, if at all. The key to effective studies is rapid response. Aircraft that could be deployed quickly with tailored remote sensing packages could provide very valuable data for science and management.

Among the more important geological questions relating to episodes are:

1. During floods, how much sediment is discharged to the coastal zone?

2. Where are the principal sources of this material, upland areas, bank erosion, purging of reservoirs, etc.?

3. What is the ultimate fate of the materials? How is it partitioned among different segments of an estuary or other coastal embayment?

4. How rapidly does the system recover to normal levels of total suspended solids?

5. What changes in shoreline configuration are produced: erosion, deposition, formation of new islands, cutting of new inlets, etc.? Does the system recover, and over what time scales?

6. How much sediment is discharged to the ocean and what is its fate?

7. What is the importance of episodes, relative to average conditions, in determining the natural geological evolution of coastal systems?

Although the emphasis here has focused on sedimentation processes and impacts resulting from episodic events, it must be remembered that there are also potential effects on productivity. High turbidity reduces photosynthesis, and large sediment deposits can kill benthic biota. Hurricane induced upwelling may also be important in oceanic productivity. Productivity factors have not been emphasized in the measurement requirements which follow, however, investigations of episodes should not overlook productivity concerns.

Measurements Required:

Parameter	Remote Sensing Capability	
	Present	Potential
Total Suspended Solids:		
Surface	B	
Profile		Low (Note 1)
Recovery Time	A	
Input Fluxes	B (Limited)	
Discharge Fluxes	B (Limited)	
Size Distribution		None Identified
Bedload Changes	A (within limits)	
Shoreline Changes	A	

Parameter	Remote Sensing Capability	
	Present	Potential
Inlet Formation	A	
Current: Surface	A	
Profile		Medium (in photic zone)

Note 1 - Low potential is noted here while elsewhere the potential of laser systems for profiling TSS was listed as high. This is because the extreme turbidity associated with episodes will reduce the potential of getting information down to the bottom.

PROBLEM: Siltation and Dredge Material Disposal

Substantial pollution problems in the aquatic environment result from the effects of benthic deposits. Siltation and sedimentation are caused by both natural and human factors. Although probably not as dangerous to human health as industrial and domestic waste contamination, sediment pollution is extremely costly. Hundreds of millions of dollars are spent annually in the U.S. to dredge sediment deposits in major waterways and harbors. In addition, silt deposits can significantly alter normal hydrological characteristics. Excessive sediment loads can modify marine ecosystems by physically covering benthic habitats and by reducing light penetration. In the Chesapeake, half of the former upper estuary spawning areas for fish and shellfish beds for oysters have been destroyed or shifted downstream by sediment deposits.

Since most of the nation's seaports are located on estuaries and since most estuaries are characterized by relatively rapid sedimentation rates, dredging has been a persistent activity of coastal areas since colonial days. Dredging is conducted to maintain, improve, or extend navigable waterways or to provide natural resource construction material. Throughout the U.S. more than 400 x 10^6 cubic yards of material are dredged annually by the U.S. Army Corps of Engineers. Over the past decade, an additional 75 x 10^6 cubic yards have been dredged each year by non-federally financed projects.

There are two general categories of dredge disposal: open-water and land disposal. Open-water disposal results in sediment deposition that frequently changes productive geographical locations, reduces marine species diversity, and changes or eliminates the vegetative cover of the submerged aquatic plants. In addition, the open-water method frequently changes water chemistry by adding toxic substance to the system.

Land disposal has been developed to overcome the possible problems associated with open-water spoil disposal. Land disposal most often means disposal in wetlands, marshes, or swamps, as opposed to land such as forests or pasture land. A conflict arises over where the spoil should be placed (if land disposal is chosen), since these wet-lands and marshes are among the most biologically productive systems known to man. These marshes, which serve as breeding areas, zones of maximum biological productivity, and nurseries, are only marginally understood by scientists.

In addition, land disposal raises several concerns related to the possible pollution of groundwater reservoirs. Land disposal also alters vertical elevation and, consequently, vegetative patterns, and these modifications can create significant changes in drainage patterns and other hydrographic features.

Open-water disposal of dredged material is the most common mode of disposal. This method has created a number of environmental problems. Several important questions relating to this type of disposal are: How extensive and persistent are plumes of suspended solids produced during open water disposal operations? How stable are open-water deposits of fine grained dredged material? Are they confined to the disposal sites or are they resuspended by waves and currents and dispersed? If they are dispersed, what are the areas affected?

New and improved ways of measuring sedimentation rates, including model studies to evaluate methods of curtailing sediment deposition and more effective and beneficial means of sediment removal and disposal also need to be developed. Levels of sedimentation rates tolerated by organisms, and levels damaging to desirable organisms are needed. Since organisms are affected differentially by sedimentation processes, rates of change would have to be suited specifically for key individual species.

The monitoring and prediction of the turbidity near a dredging site is a very important step in assessing the environmental impact. Monitoring the spatial and temporal variations of the suspended sediment concentration downstream of the dredging site would be useful in predicting the sediment settling rate.

Measurements Required:

Parameter	Remote Sensing Capability	
	Present	Potential
TSS: Surface	B	
Profile		High
Organic/Inorganic		Medium
Size Distribution		None Identified
Input Fluxes	B (Limited)	
Discharge Fluxes	B (Limited)	
Resuspension	B	
Settling Rates	Note 1	

Parameter	Remote Sensing Capability	
	Present	Potential
Dump Plume Characteristics:		
Dispersion	A	
Persistence	A	
Settling Rate	Note 1	
Resuspension	B	
Currents: Surface	A	
Profile		Medium (in photic zone)
Surface Winds: Speed	A	
Direction	B	
Waves: Signif. Wave Height	A	
Length	A	
Direction	A	
Bathymetry	A (within limits)	

Note 1 - The technique of using changes in surface concentrations as a function of time may not be acceptable. However, remote sensing from shipboard using acoustic techniques is well developed.

Water Dynamics

Fundamental to the understanding of all of the topic areas included in this study is the basic movement of the water. It is within this framework that the other physical, biological, and chemical processes are superimposed. The transport of dissolved and particulate material and the need for estimating these fluxes have been identified by all study groups. It is also recognized that relevant time and spatial scales apply for the individual processes of concern.

Currently available methods of measuring bulk transport are based on direct measurements of velocities and concentrations at discrete points in space (Eulerian measurements) or tracking drogues (Lagrangian measurements). Both of these methods have their limitations. Current meter measurements are usually of limited spatial coverage which severely restricts the ability to interpolate and extrapolate a comprehensive transport pattern. Tracking drogues provide integrated measurements of velocity; however, because of the expense involved, they are usually few in number and the period of tracking is less than desired.

The ability to make improved measurements of synoptic circulation would greatly add to the reliability of mathematical models that combine transport and kinetic processes. The transport structure of large lakes and coastal waters is an integral part of these calculations, the results of which can be used as an aid to decision making and rational water quality management.

Another factor influencing the reliability of mathematical models is the quality and validity of input and/or boundary conditions. Of particular importance are meteorological parameters, especially surface winds. Surface temperature may serve as a calibration variable for the numerical models while other variables may reduce the complexity of the models or afford intermediate checks, such as wave heights as a component of sediment scour and resuspension calculations.

It is difficult to overemphasize the value of mathematical models. They are used in large measure to express our quantitative understanding of the basic phenomena, be it physical, chemical, or biological. Yet for the concerns of coastal and inland waters, it will be the basic water movements which will define the spatial scale of most of the topics of interest, including both the vertical and the horizontal. Additionally, the model results can afford an insight into the sampling requirements for surface monitoring as well as for truth measurements for remote-sensing needs.

The following are a few problems related to water dynamics and considered as representative for this study.

PROBLEM: Modeling Requirements

Mathematical models exist in various forms and require different data and information for their use. Empirical models often require large quantities of data to give confidence in their formulation. Models describing the physics of the situation may require a significantly different set of data in the definition of boundary conditions and forcing functions. In each case, however, the derived quantities and those parameters required for model validation are the same, viz., the current, temperature, and density field along with the mapping of the concentration distribution of the dissolved or particulate material of special interest. The parameters for physical models will be of primary emphasis here:

Measurements Required:

Parameter	Remote Sensing Capability	
	Present	Potential
Temperature: Surface	A	
Profile		Limited
Salinity: Surface	A	
Profile		Low
Wave Climate: Signif. Wave Height	A	
Direction	A	
Dominant Wavelength	A	
Spectra	A	
Surface Wind: Speed	A	
Direction	B	
Meteorological: Surface Air Temp.	A	
Surface Air Pressure		Low
Precipitation:		
Type	A	
Rate	A	
Particulate Settling Rate		None Identified
Particulate Size Distribution		None Identified
Chemical Reaction Rates		None Identified
Species Growth Rates		None Identified
Light Attenuation Coeff.	B	
Bathymetry	A (within limits)	
Currents: Surface	A	
Profile		Medium (in photic zone)
TSS: Surface	B	
Phytoplankton: Surface Concen.	B	

PROBLEM: Shoreline Modifications and Effects

An estuary is not constant but continually changing. One of the basic variables is the shoreline; it may grow in one region through deposition of sediments while receding in other places. While these processes occur naturally, management decisions can perturb them for both better and worse. This is a synoptic problem because cause and effects may be far apart.

The problem of determining the shoreline, however, is complicated first by the many possibilities for defining the shoreline. The estuary will have a different shoreline as the tide changes; the appropriate choice, therefore, will be somewhat arbitrary and often inconsistent among groups needing this information. Another complication comes in choosing the scale on which to measure the basin. A jagged shoreline can have a remarkable range in measured length depending upon the resolution chosen for the measurement.

Metric space/aerial imagers, usually cameras, can be used in attacking this problem. The appropriate resolution must be chosen, and this may vary depending upon the application. The choice made will determine the best combination of instrument, platform and altitude. In general, there will be a trade-off between resolution and area covered. The analysis of the data can be automated.

Measurement Required:

Parameter	Remote Sensing Capability	
	Present	Potential
Land/Water Interface	A	

PROBLEM: Location and Characterization of Fronts

Fronts are features characterized by sharp gradients in physical and biochemical variables in aquatic environments. The length scales of fronts range from 10^2 meters for some estuarine plume fronts to 10^6 meters for some continental shelf fronts. Fronts persist on the order of hours for some tidal fronts to years for the shelf break front in the Bering Sea. Factors which interact to cause frontogenesis are not well understood, therefore frontogenesis is currently an active research area in physical oceanography. Salinity gradients associated with shelf break fronts suggest that a balance between freshwater input from rivers along the northeast coast of North America and in the Bering Sea and offshore oceanic water are important in frontogenesis. The tides are known to be a primary source of energy for frontogenesis in shelf waters around the British Islands. All of the evidence to date suggests that fronts may be an important site for energy dissipation on continental shelves. Research in localized, readily available sites where regular physical dynamics occur is very important in attempts to understand the dynamics of the upper ocean.

Major fisheries along the east coast of the North American continent and in the Bering Sea are associated with continental shelf fronts. Enhanced dynamics of phytoplankton and zooplankton have been reported in fronts relative to dynamics in shelf waters not influenced by fronts. Distinct pelagic and benthic food webs appear to be associated with different regions along a cross-shelf transect through several fronts in the Bering Sea shelf waters. These food webs are coupled to the fronts which are stable features throughout the spring and summer. The fronts afford specific sites in which to investigate dynamics of significantly different food webs. Factors which control nutrient input to the photic zone in fronts are poorly understood.

Measurements Required:

Parameter	Remote Sensing Capability	
	Present	Potential
Synoptic Location	A	
Extent	A	
Frontal Motion:		
Long Term	A	
Tidal	A	
Surface Gradients:		
Temperature	A	
Salinity	A	
Color	A	
Reflectance	A	
Roughness	A	
TSS	B	
Chlorophyll	B	
Dissolved Organic Carbon (DOC)		Medium
Diffuse Atten. Coeff.		High
Surface Wind:		
Speed	A	
Direction	B	

Eutrophication

Eutrophication is generally associated with aesthetic and water quality deterioration. Excessive aquatic plant growth and changes in water quality, resulting from eutrophication, can cause significant changes in the composition of aquatic plant and animal populations in a water body. In addition, water quality deterioration can hinder the use of the water for domestic and industrial water supplies, for irrigation and for recreational pursuits.

Eutrophication is a natural aging process generally describing the fertility (mainly plant productivity) of lakes. Over time, a lake will become filled with sediment and organically-derived materials from streams draining its watershed, as well as from rain and dustfall directly onto its surface and in its water shed. On a geological time scale, all lakes will presumably cease to exist because of this natural process. However, man's activities within a drainage basin can alter natural processes in the watershed and accelerate this extinction process to a human, rather than geological, time scale. This latter phenomenon is frequently referred to as 'cultural' eutrophication to distinguish it from the natural aging process that occurs in the absence of man's activities.

Cultural eutrophication is caused by the excessive loads of aquatic plant nutrients (usually phosphorus) to natural waters. These nutrients, in turn, can produce nuisance growths (i.e. growths that interfere with man's use of the water) of algae and higher aquatic plants. While some lakes are naturally eutrophic, in that they receive a sufficient supply of phosphorus and other nutrients from natural sources to produce nuisance growths, an increased nutrient load to a water body has most often been associated with an intensification of human activity in the drainage area surrounding the water body.

In the Great Lakes, cultural eutrophication has probably been the greatest cause of environmental degradation. The problem is further complicated in the Great Lakes by the large time scale for response to detrimental and remedial measures, making control policy much more critical and far reaching. International implications also arise because the Great Lakes are a shared resource with our Canadian neighbors and span a large section of our international boundary.

The term "eutrophication" as such, does not apply to estuarine or tidal systems. However, eutrophication for these areas can be broadly defined as "an increase in nutrients and the ensuing progressive deterioration of the water quality due to the increased growth of phytoplankton with its repercussions on the overall metabolism of the water affected." In the eutrophication or over-enrichment of lakes, estuarine or tidal environments, the phytoplankton composition frequently changes from beneficial forms to obnoxious weed forms - from forms that can be utilized by animals at the higher trophic levels to forms which apparently have little, if any, value in the system.

The abatement of eutrophication (over-enrichment) is of high national concern and would improve the value of the Great Lakes as well as our estuaries and coastal water zones in many ways: decreased cost for treatment of drinking water, improved sport and commercial fishing, increased opportunity for high quality recreation and more generally increased aesthetic appreciation of our shore areas by all who live near or visit these areas.

<u>PROBLEM</u>: Algal Blooms (Great Lakes, Estuaries, and Coastal Zones)

The problem of cultural eutrophication takes somewhat different forms in different areas. Because different areas have quite varied concentrations of the important nutrients, the nutrients likely to cause enrichment problems will vary with locations. Compositional and functional relations vary greatly among ecosystems, therefore, the biological consequences of overenrichment can be site specific.

One of the first biological indications of cultural eutrophication is the excessive production of phytoplankton biomass in direct response to increased nutrient loadings. In addition, the phytoplankton composition frequently changes from beneficial forms to less desirable algal forms. In the nearshore coastal environments, nutrient stimulation may also affect macrophytes leading to enhanced production and expanded range.

Phytoplankton are the base of the marine food chain. Consequently, changes in standing stock, species composition, rate of production and areal distribution of phytoplankton populations will have profound effects on the biological resources and upper trophic levels of the entire marine environment. Runaway phytoplankton growths can lead to respiratory and decompositional oxygen demand that drives the available oxygen levels to catastrophically low values (<4ppm) thereby threatening or killing the higher trophic level species. In the coastal areas, high productivity or marked change in species composition in one area may have profound effects tens to hundreds of kilometers along the coast or along the entire estuarine system. This is a result of continuous undercurrents and subsequent upwelling in the case of coastal systems, or density gradient circulation in the case of estuaries. Thus coastal and estuarine circulation patterns must be taken into account in evaluating the capacity of the coastal ocean to assimilate excess nutrients.

A probable, but poorly understood, example of eutrophication in coastal waters on a relatively large scale is the so-called red tide. Although it is probable that the red tide is a phenomenon of the eutrophic type, it is not a simple case of excess inputs of nitrogen or phosphorus.

Oceanographers and limnologists are often unable to recognize changes in biomass or species composition until they have reached fairly dramatic levels. At the heart of the problem is our inability to synoptically monitor large areas for quantity and quality of algal biomass. The parameters which must be measured are the amount of biomass in the water column, its species composition, its rate of production, numerous environmental factors which regulate productivity (light, temperature, salinity, currents, and nutrients), and most importantly, the time and space scales of the variability of these features. Spatial scales of importance range from a few to hundreds of kilometers. The scales of time which are important in eutrophication can be as short as days since the organisms replicate in periods of this length.

Classical ground-based water quality measurement methods are inadequate, due to their limited area and frequency coverage, to characterize the water quality of even a small area if it is heterogeneous or dynamic in nature.

Elaborate strategies have been devised to optimize surface sampling efficiency and effectiveness, but in general their results are not suitable for large area assessment. For example, in the Great Lakes, a sampling program has been instituted to coordinate the activities of the responsible organizations by concentrating ship and laboratory resources on a single lake for one or two years so the entire Great Lakes are covered in a nine year period. Unfortunately, this program cannot address basinwide problems or account for interlake exchanges. The nine year repeat frequency is also longer than many of the Lake ecosyste time scale cycles. Even within the Lake scheduled for sampling, there are many measurement deficiencies. To avoid confusion and provide historical trends, the ships sample at a fixed grid of stations, covering them all in a period of about a week. While this is adequate for well distributed conservative parameters such as chlorine, it is severely limiting when studying many important phenomena such as phytoplankton dynamics, sediment resuspension, or storm induced fluxes from rivers. Remote sensing imagery has shown that because of the spatial patchiness of phytoplankton growth, ships have sampled within several hundred meters of heavy biological activity and yet missed it completely in their characterization of the area.

Of course, this Great Lakes discussion is only a sample; the problems of surface measurements increase in complexity when areas of interest become larger such as in the coastal zone and open ocean.

Measurements Required:

Parameter	Remote Sensing Capability	
	Present	Potential
Chlorophyll: Surface	B	
Profile		Medium (for upper photic zone)
Temperature: Surface	A	
Profile		Limited
Salinity: Surface	A	
Profile		Low
Dissolved Oxygen: Surface		None Identified
Profile		None Identified
Nutrients: Profile		Low
Plankton: Biomass		High
Species Diversity	B	
Areal extent	A,B	
Growth Rate		(Related to Biomass)
TSS: Surface	B	
Profile		High

Parameter	Remote Sensing Capability	
	Present	Potential
Light Attenuation:	B	
Current: Surface	A	
Profile		Medium (in photic zone)
Surface Wind: Speed	A	
Direction	B	
Synoptic Location	A	
Total Organic Carbon (TOC)		Medium

PROBLEM: Nutrient Source Identification

In the study of the Great Lakes, estuarine and coastal eutrophication, the identification of the sources and sinks of nutrients as well as their rate of input, transport, diffusion, residence time, and ultimate fate are essential. The sources of critical nutrients in primary productivity in the marine ecosystem are from both point and nonpoint sources.

Point sources of water pollution such as municipal and industrial wastewater discharge into the marine environment are generally well known. Past remedial programs have placed a major emphasis on point source control. It has long been recognized, however, that nonpoint sources (NPS) (including excessive nutrient loading) are the major factor in determining marine ecosystem pollution loads. The control of NPS nutrient input is hampered not only by the magnitude of the problem, but also by a lack of understanding of the relative importance of the different NPS contributors and how they interact. Although the primary nonpoint sources are identified with urban, agriculture, forestry, construction, mining, and hydrological modifications, other sources exist such as atmospheric fallout. Although we understand the general principles and mechanisms involved in sources and sinks of nutrient inputs, information is needed to quantify the rate of input and the total volume of these materials. Various NPS runoff models have been developed with varying success and some can now be used to indicate on a gross scale those areas where corrective action needs to be defined and implemented. Before these models can be further developed to provide accurate estimates of the quantitative loadings delivered to receiving water, a number of problems centering on nutrient source and transport must be addressed such as: What are the specific loading characteristics of the different land cover classifications and what levels of detail are required in land use inventories to maximize model prediction accuracies? What measurements are necessary to separate naturally occurring runoff loadings from cultural impacts? What is the relationship between specific nutrients and stream sediment loadings and what are the controlling factors in this relationship? What percent of the nutrient loading is retained in the stream bottom sediment and what conditions are required for resuspension and further transport?

A major factor limiting resolution of the above issue is the lack of a suitable data base for model initialization, manipulation, and verification.

In the estuaries and coastal zones issues on dispersion and circulation modeling of nutrients must also include the effects of tides and the density/temperature differences between the fresh water inflow and saline ocean water. In addition, the effects of turbulent mixing and major ocean currents and eddies must be considered.

In addition, while phosphorus is generally accepted as the leading nutrient which controls phytoplankton biomass in the Great Lakes, nitrogen is considered the leading variable which controls phytoplankton biomass in marine waters. Therefore, information on phosphorus dynamics and concentrations are needed for the Great Lakes while information regarding the nitrogen cycle is of primary interest in the estuarine and coastal waters.

The lack of adequate synoptic data over relatively large areas precludes both the quantitative description of the various marine ecosystems and prediction of their essential characteristics. The spatial and temporal scales of these phenomena combined with the slow speed and sampling characteristics of research vessels, render traditional oceanographic sampling schemes inadequate to this task.

Measurement Required:

Parameter	Remote Sensing Capability	
	Present	Potential
Nutrients: Profile		Low
Chlorophyll: Surface	B	
Profile		Medium (for upper photic zone)
Temperature: Surface	A	
Profile		Limited
Salinity: Surface	A	
Profile		Low

Parameter	Remote Sensing Capability	
	Present	Potential
Dissolved Oxygen: Surface		None Identified
Profile		None Identified
Plankton: Biomass		High
Areal Extent	A,B	
Growth Rate		(Relate to Biomass)
Species Diversity	B	
Location	A	
Currents: Surface	A	
Profile		Medium (in photic zone)
Surface Wind: Speed	A	
Direction	B	
TSS: Surface	B	
Profile		High
Input Fluxes	B (Limited)	
Discharge Fluxes	B (Limited)	
Sediment Deposition Location	A (within limits)	
Land Use Classification	A,B	

Hazardous Substances

The environmental concerns of the early 1970s included a new emphasis on chemicals entering the Nation's waters, and this problem has more recently been termed hazardous substances. The Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500) required the identification of toxic substances and a determination of whether there were safe limits for their presence in effluent discharges. Additional amendments and controls for toxic substances were contained in the Clean Water Act of 1977 (P.L. 95-217) and these were further amended in the Clean Water Act Amendments of 1978 (P.L. 95-576). Even earlier legislation was amended to focus on new information about old substances; e.g., the 1972 amendments of the 1947 Federal Insecticide, Fungicide, and Rodenticide Act (P.L. 80-104) tried to balance on one side concern for higher farm production and economic benefits against the concern for health effects and long-term integrity of the environment. Even more widespread control was implemented through the Toxic Substances Control Act of 1976 (P.L. 94-469), amendments to the Federal Food, Drug, and Cosmetic Act of 1938 (P.L. 75-717), and the Occupational Safety and Health Act of 1970 (P.L. 91-595).

All of these concerns, of course, relate to the basic concern for the public health and well being. Numerous substances find their way to humans through the aquatic environment; however, our knowledge of the effects of many of these substances is most meager and new methods of research are required so that understanding and regulatory acts are well-founded and not simply "guilt by association."

It seems that each year in its annual report, the Council on Environmental Quality presents a new list of hazardous substances. Particularly complete is the documentation of the contamination and the human and environmental effects of kepone from Hopewell, Virginia, through the James River and its tributaries, to Hampton Roads and the lower Chesapeake Bay. Kepone is a chlorinated hydrocarbon pesticide related to the chemicals DDT, Aldrin, Dieldrin, and Mirex, other pesticides with familiar names because of similar histories. Additional hazardous substances include metals (mercury, lead, and others), asbestos, and other chemicals (chloroform, benzene, vinyl chloride, and others) found largely in the workplace and identified with occupational health hazards. In the Great Lakes, major concerns have been identified for pesticides, PCB's, asbestos, and the methylation products of mercury and lead. Concerns exist for many of these substances in the coastal estuaries and the offshore waters. In these waters, especially offshore, intentional as well as accidental inputs to the marine environment from petroleum products and other wastes have continued. International agreements, to which the U.S. is a part, call for the prohibition of the dumping of certain substances (e.g., organohalogen compounds, mercury, cadmium and associated compounds, petroleum and related petrochemical products, radioactive wastes, and materials produced for biological and chemical warfare). Also by these agreements any dumping must be carefully controlled through special permits following an assessment of the environmental impact and alternatives to ocean dumping. The U.S. has legislation implementing these concerns, viz., the Marine Protection, Research, and Sanctuaries Act of 1972 (P.L. 92-532) and the National Ocean Pollution Research and Development and Monitoring Planning Act of 1978 (P.L. 95-273).

The following are a few problems related to hazardous substances selected as representative for this study.

PROBLEM: Toxic Organic Compounds & Trace Elements

Toxic organic compounds such as the pesticides (DDT, Aldrin-Dieldrin, Chlordane), PCB's and Mirex can have harmful effects on Great Lakes biota.

PESTICIDES:

Recent studies have indicated that Great Lakes biota continue to show residual levels of DDT, Aldrin-Dieldrin and Chlordane. Pesticides have been used in the Great Lakes Basin for over 50 years. The earliest pesticides, no longer in use, were arsenic-based. These materials have become bound to soil particles in old orchards (where they were predominantly used) and can pose an environmental threat only if the soils of these orchards are disturbed during construction activities for housing or industrial developments and carried into surface waters.

Organochlorine pesticides (e.g., DDT) were first used in the Basin after World War II. These compounds were easy to apply to crops and were very effective in controlling insect pests. However, environmental problems associated with these materials are related to three features: 1) persistence, 2) widespread use, and 3) the ability to bioaccumulate in aquatic organisms. Extensive monitoring, begun in the early 1960's, is continuing.

Because of the current ban on the use of these particular pesticides in both the United States and Canada, levels of these chemicals in the Great Lakes are expected to decline. The role of pesticide enriched sediments as a possible long term source of pesticides is probably minimal due to their burial by fresh sediments with declining pesticides levels.

<u>PCB's (Polychlorinated Biphenyls)</u>:

PCB's are a major contaminant of the Great Lakes ecosystem. Diffuse sources including atmospheric inputs account for the major loading of PCB's into the lakes.

The class of compounds known as PCB's has been manufactured since the late 1920's and has been in use in the Great Lakes Basin for more than 40 years. They have been recognized as an environmental pollutant for the past 20 years. PCBs are extremely stable compounds that are usually only destroyed by high temperature incineration. These compounds are only sparingly soluble in water, but are quite soluble in fat. It is this latter property which makes PCBs an environmental hazard, since PCBs readily accumulate in the fatty tissues of fish, birds and human beings. Even when levels of PCBs may barely be detectable in the water, PCB levels in fish tissue can exceed established guideline concentrations for human consumption.

Environmental concern with PCBs centers in their ability to cause gross deformities in primates used as test animals and reproductive failure in fish-eating birds (herring gulls). These birds, over the past few years, have exhibited a sharp decline in egg hatching. Young birds are often grossly deformed, particularly their bills, rendering them incapable of eating. There is, as yet, no toxicological data on the effects of PCBs on human beings, although various studies are underway in both Canada and the United States to monitor levels of PCBs in human milk and fat tissue. PCB levels found in human fat tissue in Ontario residents have not declined between 1969 and 1974. It was found that the subjects with the highest PCB contents in their fat tissue were also large consumers of fish from the Great Lakes.

PCBs are barely detectable in the water component of the Great Lakes ecosystem and no data are presented here. High PCB levels in fish and sediments emphasize the fact that PCBs can readily bioaccumulate or can go into storage in the sediments. It is not yet known whether PCBs can be released from sediments to water or biota. Work is currently underway to investigate this question.

TRACE ELEMENTS (Heavy Metals)

Almost all the major elements in the earth's crust are detectable in Great Lakes' waters in at least trace amounts, derived mainly from natural sources.

With the coming of European settlements on a large scale in the mid 1800's, levels of metals entering the Great Lakes and ending up in sediments at the bottom of the lakes began to rise. This rise could be attributed to the clearing of the forests, resulting in increased erosion rates and increased inputs of geologically derived elements. In addition, the rapid growth of heavy industry in the Basin gave rise to elevated inputs of trace elements. Present inputs of two heavy metals of environmental concern, mercury and lead, can be traced to specific human activities (e.g., the chlor-alkali industry (mercury) and the advent of leaded fuels for automobiles).

Evaluation of the vertical distribution of trace elements in Great Lakes sediment cores has shown that modern surface sediment has been enriched in heavy metals.

Studies of trace element inputs to the lakes have determined that the following elements should be considered as present or potential pollutants requiring further close surveillance:

I mercury, lead

II arsenic, cadmium, selenium

III copper, zinc, chromium, vanadium

These elements have been ranked on the basis of their real or anticipated potential as an environmental hazard. Elements were included if they met either of the following criteria: (1) the potential for transformation of the element to a toxic methylated form; or (2) enrichment of sediments and organisms with the element. Mercury and lead are seen to be of greatest concern in the above ranking.

The impetus for the study of methylation of trace elements was the discovery that microorganisms in lake sediments were able to convert inorganic mercury in sediments into a very potent human nerve poison, methyl mercury. It has subsequently been shown that methylation is a common process in the aquatic environment.

Mercury

Sediments and fish, especially in Lakes Ontario, Erie and St. Clair, are presently contaminated with mercury. This mercury is derived from several sources, including past industrial discharges and present atmospheric deposition directly onto the Great Lakes and onto the land surface, with subsequent drainage to the lakes.

The major mercury loads to the lakes result from the redeposition of sediments contaminated by past industrial discharges, possibly from the continued use of small amounts of mercurial pesticides to combat bacterial and fungal infestations on turf and the current atmospheric deposition of mercury. Data on atmospheric and point source loads of mercury to the lakes are scarce.

Lead

At present, lead is not an environmental contaminant of concern in the Great Lakes, relative to current concentrations in fish. However, it has a potential for becoming a problem through chemical and biological methylation, if current loadings of lead to the lakes are not reduced. Major sources of lead are diffuse in nature. As with mercury, major source areas of lead may be inferred on the basis of sediment concentration patterns.

Measurements Required:

Parameter	Remote Sensing Capability	
	Present	Potential
Pesticide, Toxic Organic, Metals:		
Type		Low
In solution		None Identified
On sediment		None Identified
Total Suspended Solids:		
Surface	B	
Profile		High
Organic/Inorganic		Medium
Size Distribution		None Identified
Surface Wind:		
Speed	A	
Direction	B	
Currents:		
Surface	A	
Profile		Medium (in photic zone)
Bioaccumulation		None Identified

PROBLEM: Ocean Waste Disposal

The near-shore oceanic waters oftentime receive materials from sources other than riverine and estuarine discharges. Dredge spoil, associated with channel maintenance, is dumped offshore. Some municipalities discharge sewage effluents into coastal waters while others barge sewage sludge to designated dump sites. Some industrial waste products are permitted to be dumped in the ocean at present, although this regulated practice is being reduced each year. These activities due directly to man, represent additional pathways for the introduction of pollutants into the oceanic environment. Although legislation exists which call for the cessation or drastic reduction in ocean dumping, it seems reasonable that disposal alternatives will have to be shown as more acceptable before this source of pollution will be completely eliminated. The Marine Pollution, Research, and Sanctuaries Act of 1972 (P.L. 92-532) formally began the regulation of ocean dumping through its permit program. (The dumping into ocean waters of all materials is regulated by EPA permits except dredged materials, for which the U.S. Army Corps of Engineers issues permits.)

A. Sewage Outfalls

A number of municipalities are still permitted to use sewage outfalls draining into the offshore coastal waters. These permits require various amounts of treatment depending primarily on assessments of the impact, or potential impact, of the discharge on the affected ecosystem. Although outfalls do not represent large sources, their proximity to shore demands a concern that they not create problems for the ecosystem and thence to man.

Measurements Required:

Parameter	Remote Sensing Capability	
	Present	Potential
Discharge Plume Characteristics:		
Dispersion	A	
Persistence	A	
TSS: Surface	B	
TSS: Profile		High
Temperature: Surface	A	
Temperature: Profile		(Limited)
Nutrients: Profile		Low
Surface Films		High
Discharge Impact:		
Chlorophyll: Surface	B	
Chlorophyll: Profile		Medium (for upper photic zone)
Phytoplankton: Species		None Identified
Phytoplankton: Diversity	B	

B. Sewage Sludge

The dumping of sewage sludge is not a national issue. However, the near-shore Atlantic waters receive nearly 5 million tons per year, primarily from the New York-New Jersey area and Philadelphia. Although ocean dumping of all wastes has been decreasing since 1973, the dumping of sewage sludge has not, due, probably, to the continuing search for more environmentally acceptable alternate disposal means.

Measurements Required:

Parameter	Remote Sensing Capability	
	Present	Potential
Permit Compliance for Dump Site	A	
Dump Dispersion	A	

C. Industrial Waste

Probably the most significant impact of the P.L. 92-532 and the Resource Conservation and Recovery Act of 1976 (P.L. 94-580) has been the approximately 90 percent reduction in the dumping of industrial waste since 1973. These wastes were primarily chemical (liquid sulfuric and hydrochloric acids), slurry from ore production, pharmaceutical manufacturing waste, and aerobically treated biosolids. Numerous regulations have defined a considerable list of hazardous substances, and their control at present is such that intentional dumping via the permit process is highly improbable. Although both sewage sludge and industrial waste dumping is mandated to cease by December 31, 1981, it seems most probable that this goal will only be met for the industrial wastes.

Measurements Required:

Parameter	Remote Sensing Capability	
	Present	Potential
Permit Compliance for Dump Site	A	
Dump Dispersion	A	
Persistence	A	

D. Ecosystem Impact by Dumping

The impact, both near-term and long-term, of dumping on the marine ecosystems at and near the various sites remains a concern for science and research as well as for future beneficial applications of these areas. Programs such as the Marine Ecosystems Analysis (MESA) Program in NOAA began such studies in the New York Bight, where significant dumping on the East Coast takes place. This research has led to the development of a long-term monitoring plan for this area which is being evaluated through F.Y. 1981 and will be continued by NOAA in F.Y. 1982. The regional perspective of such a plan necessarily includes concerns for public health, economics, as well as ecosystem degradation and recovery. Ecosystem factors of primary concern are:

(1) Oxygen depletion and any attendant deaths of organisms.

(2) Pathogenic contamination of food resources (e.g., shellfish).

(3) Sediment quality.

(4) Nearshore water quality.

(5) Chemical contaminant levels in edible resources (fishes and shellfish).

(6) Modifications of fish distributions.

(7) Degradation of benthic communities.

Measurement Required:

Omitted from the list which follows are those parameters associated with detailed contaminants of sediments (e.g., heavy metals) and contaminants of fishes, shellfishes, and the benthic communities (e.g. heavy metals, pathogens, polychlorinated hydrocarbons, polynuclear aromatic hydrocarbons, PCB, etc.) which at present are determinable only by bioassay and laboratory methods.

Parameter	Remote Sensing Capability	
	Present	Potential
Temperature: Surface	A	
Profile		Limited
Salinity: Surface	A	
Profile		Low
TSS: Surface	B	
Profile		High
Dissolved Oxygen: Surface		None Identified
Profile		None Identified
Nutrients: Profile		Low
Plankton: Biomass		High
Diversity	B	

Parameter	Remote Sensing Capability	
	Present	Potential
Chlorophyll: Surface	B	
Profile		Medium (for upper photic zone)
Coliform	(See Note 1)	None Identified
Floatables		Low
Total Organic Carbon (TOC)		Medium

Note 1 - Automated in situ methods have been developed and their incorporation into a DCP (data collection platform) for remote retrieval demonstrated.

PROBLEM: Oil Spills

Oil spills represent environmental threats and promise to continue as problems until other sources of energy are developed. Reliable spill detection and monitoring, permitting early, effective cleanup, are key factors in avoiding or minimizing environmental damage. NASA has worked cooperatively with the United States Coast Guard, the National Oceanic and Atmospheric Administration (NOAA), and the Department of Defense/Naval Research Laboratory (NRL) in the research development, and evaluation of remote sensing techniques.

Large-scale spills, such as the Argo Merchant (1976) and the Ixtoc well blowout in the Bay of Campeche (1979), attract the most attention and do pose environmental problems. The larger problem, however, in terms of detrimental effects is due to the nearly sustained rate of flow of oil and oil wastes from natural seeps, refineries and industrial sites, and oil transportation (tank washings, bilge pumping, loading and unloading). Clearly, the subsurface distribution and movement of oil from major spills is a special problem which must be addressed.

Many Federal agencies become involved and are concerned with oil spills and have roles related to prevention, cleanup, and environmental effects. These agencies include DOT-U.S. Coast Guard, DOI-USGS, DOI-BLM, DOC-NOAA, EPA, DOD, State Department, and HEW. Although there is a wide variety of informational needs about oil spills, these might conveniently be divided into two categories: (1) those related to direct measurements of the oil in and on the water and its distribution and location, and (2) oceanographic and atmospheric parameters that constitute model inputs for predicting the trajectory (fate) of the oil and its potential threat to sensitive shore and marine resource areas.

Measurements Required:

Parameter	Remote Sensing Capability	
	Present	Potential
Areal Distribution	A	
Thickness	A	
Classifications (Type)		High
Surface Wind Speed	A	
Direction	B	
Currents: Surface	A	
Profile		Medium (in photic zone)
Waves: Signif. Wave Height	A	
Length	A	
Direction	A	
Temperature: Surface	A	
Profile		High
TSS: Surface	B	
Profile		High
Weather: Front Locations	A	
Precipitation	A	
Air Temp. (Surface)	A	

Other

This Section will include those activities which are best described outside the topical headings previously presented.

PROBLEM: Offshore Energy and Resources Activities

In this broad heading, there is included a number of activities for which concern of their environmental impacts has been recognized. Some of these activities are ocean thermal energy conversion (OTEC), offshore power plants (especially nuclear), offshore ports, oil and gas exploration, deepsea mining, and sand and gravel mining. Many of these concerns have been addressed by the Outer Continental Shelf (OCS) Environmental Studies Advisory Committee of the

DOI's Bureau of Land Management (BLM), NOAA's Office of Coastal Zone Management (OCZM), and the Department of Energy (DOE). Some of these developments are usually viewed as only having an impact on the marine ecosystem with the major consideration of whether or not there is any effect on productivity.

OCS petroleum developments have led to greater concern for nearshore impacts as well as onshore effects. The capability to predict oil spill dispersion, especially toward the shorelines, and the siting and management of pipeline corridors and their nearshore environmental effects are high priority items identified by many of the coastal states, especially along the East Coast of the U.S. The uniqueness of Alaska, however, has led to a special focus by BLM and NOAA on the impact of OCS petroleum developments there. This focus is the OCS Environmental Assessment Program (OCSEAP). The Alaskan Continental Shelf regions of concern are from the Northeast Gulf of Alaska and around through the Bering Sea and Chuckchi Sea to the Beaufort Sea, thus including all of the potential lease sites. Although the same words would be used in describing the concerns for monitoring, prediction models, etc., all of these concerns are complicated by the introduction of ice into these processes.

As noted earlier, it is the environmental impact that is of concern for the activities related to energy and resources. The following factors are representative of the concerns, although each activity may require a different level of detail: (1) contaminant definition, (2) determination of sources, (3) the transport processes, (4) the receptors, especially the food web, and (5) the effects. The magnitude of these tasks leads to a need for increased scientific understanding so that the operational and management functions required can evolve efficiently and effectively.

Measurements Required:

Parameter	Remote Sensing Capability	
	Present	Potential
Temperature: Surface	A	
Profile		Limited
TSS: Surface	B	
Profile		High
Chlorophyll: Surface	B	
Profile		Medium (for upper photic zone)
Phytoplankton: Species		None Identified
Diversity	B	
Nutrients: Profile		Low

Parameter	Remote Sensing Capability	
	Present	Potential
Oil: Surface Extent	A	
Thickness	A	
Type		High
In water Column		Low
Heavy Metals		None Identified
Hydrocarbon Fractions		None Identified
Dissolved Gases		None Identified
Currents: Surface	A	
Profile		Medium (in photic zone)
Surface Wind: Speed	A	
Direction	B	
Waves: Signif. Wave Height	A	
Length	A	
Direction	A	
Salinity: Surface	A	
Profile		Low
Toxicity Effects		None Identified
Ice: Presence	A	
Areal Extent	A	
Thickness	A	

B. DISCUSSION OF ASSESSMENTS

In the immediately preceding section, an assessment of the capability of remote sensing was made but without any comment or explanation. In this section, the capability assessment is explained in greater detail supported by references which are included as Appendix B. The assessment of the potential capability is necessarily more subjective since these are often extrapolations and rarely referenced. The potential noted herein is based on personal experience and the considered opinions of numerous researchers who are actively involved in work of this type and who are aware of the relevant research and technology development going on.

In the material immediately following, the remote-sensing technology has been divided into seven areas: visible and near visible radiometry, thermal infrared radiometry, laser-induced fluorescence, laser scattering, microwave radiometry, microwave scatterometry (radar), and microwave altimetry.

Present Remote-Sensing Capability

The assessment of the present capabilities of remote sensing is shown in more detail in Table I where the desired water property parameters (see Section III.A) are listed under that area of remote-sensing technology for which a capability for their measurement has been demonstrated. In addition, numbers are shown in parentheses which indicate the references in Appendix B which document the capability.

<u>Visible and Near Visible Radiometry</u> - Radiometric techniques in the near ultraviolet, visible, and near infrared portions of the spectrum have been employed because hues and color differences are often related to the water property of interest. Primary among the reasons for this ability is the increase in the number and types of scatterers, as illustrated by phytoplankton blooms, suspended sediment, and other materials in dumps or discharge plumes and in regions of concentrating mechanisms such as ocean fronts. Against a nominally very low background reflectance (less than 5 percent) of the basic water, the scatterers provide a significant increase in contrast which is detectable with radiometric methods. The scattering mechanism is augmented by the selective absorption of many of the substances involved, thus further altering the resultant upwelling radiation and, in some cases, leading to determinable spectral "signatures". In some cases, enough is understood about the chemistry to explain in considerable detail why the remote sensing is possible. For example, an acid-iron waste is dumped in the Atlantic Ocean off the coasts of New York and New Jersey. This waste is a solution of hydrochloric acid with large quantities of iron chloride salts which, when buffered by sea water, results in a suspended solid aggregate containing ferric hydroxide. This acid-iron waste has a spectral signature different from pharmaceutical or petrochemical wastes which have been dumped off Puerto Rico and in the Gulf of Mexico. Therefore, multispectral scanning techniques in the visible and near infrared exist to permit remote sensing to discriminate between some of the dumped materials, and in the case of acid-iron waste, to quantitatively infer the particulate iron concentration in the dispersing plume.

Considerable success has also been realized in providing quantitative estimates of chlorophyll, total suspended solids, and water clarity (Secchi depth) through multiple regression techniques wherein extremely high correlations have been established between measured color spectral radiances and in situ water property measurements. In this case the data reduction algorithms are site specific, giving excellent results throughout the waters of that particular region but becoming inadequate for application in other regions. Since most of the aircraft and spacecraft multispectral instruments are scanners, these techniques can lead to complete scene and regional maps of the distributions of near-surface chlorophyll, sediment, and Secchi depth. Research is currently underway (e.g., Upwelled Spectral Signature Laboratory tests at the Langley Research Center and Nimbus 7 Coastal Zone Color Scanner (CZCS) Experiment Team and Lewis Research Center activities) to make these techniques less site-dependent.

Some measurements, however, remain fairly qualitative. For example, the detection of oil spills is not a routine capability; apparently some factors still are not well understood. The multispectral scanner (MSS) on Landsat has shown that oil detection from satellite altitudes is feasible under certain conditions. The most favorable seem to be those where the solar elevation angle exceeds 55 degrees with surface winds less than 5 meters per second, and, of course, cloud free. Recent enhancement analysis techniques are expected to aid in providing the contrast required to detect oil on the sea consistently. Landsat has been successful in detecting the transport of oil along the western Gulf of Mexico following the well blowout on June 3, 1979, in the Bay of Campeche. Near ultraviolet reflectance of oil in thin layers is usually greater than the surrounding waters and thus affords a contrast for oil detection. In 1973, NASA demonstrated the effectiveness of an aircraft-mounted television (TV) system with appropriate color (near ultraviolet and visible) and polarization filters for detecting spills with greater clarity than with the unaided eye. Research also demonstrated the usefulness of real-time, false color TV images. Operational systems based on this research are now a part of the U.S. Coast Guard's Airborne Oil Surveillance System (AOSS).

It must be emphasized that optical and near optical techniques are based primarily on solar radiation inputs. Hence, these techniques are dependent on cloud-free conditions. These techniques are not all weather, day-night possibilities.

Thermal Infrared Radiometry - Surface water temperature measurements are possible through radiometric measurements in the thermal infrared wavelength region (5-14 μm) provided the spectral region is chosen at an atmospheric window and appropriate corrections made for atmospheric effects if the accuracy required demands it. Cloud-free conditions are required for this technique. It has been used from aircraft and spacecraft for quite some time for the detection and mapping of thermal plumes, current boundaries (e.g., the Gulf Stream), eddies, and ocean fronts.

Laser-Induced Fluorescence - The detection and identification of substances through their fluorescing properties is an accepted laboratory analytical technique. Recent advances in laser powers and frequency tunability have afforded the development of techniques where more efficient selection of excitation wavelengths can be made for enhancing fluorescent detection in the field. For example, laser-induced fluorescence of chlorophyll a has led to chlorophyll concentration measurements. Diversity information in the form of the distribution among the four major algae color groups (blue-green, green, golden brown, and red) has been demonstrated using a four-color tunable dye laser operated sequentially at each wavelength and a radiometer to measure the chlorophyll a fluorescence due to each excitation. This technique provides not only an estimate of total chlorophyll a concentration but also enough detail to assess the density, or concentration, of each algal color group in the waters being investigated.

Oil is also known to fluoresce and some success has also been demonstrated in its detection and in an application to map the areal extent of the surface oil. Laboratory and limited field experiments have also shown that the detection of the presence of dissolved organics is also feasible using laser-induced fluorescence techniques. The detection of fluorescent dye tagged water and resolution of the integrated dye concentration in the upper five meters of the water column from an airborne laser have been demonstrated. The use of this technique for following currents or establishing residence times of water masses is feasible.

Laser Scattering - Laser light scattering is a demonstrated technique for measuring surface characteristics and, as such, has been used in characterizing waves, including spectral data and in detecting water-ice boundaries. Coastal bathymetry has also been demonstrated by measuring the time difference from receiving the initial surface reflection of the laser light to that from the bottom reflection. The applicability of this technique is, of course, dependent on the turbidity of the water and on the resultant signal strength in relation to input signal power. The depth capability already demonstrated is useful for many coastal applications of interest (e.g., inlet formation during severe storms and hurricanes).

A Raman scattering technique has been used in the measurement of the thickness of thin, surface films on water. This is accomplished by measuring the attenuation of the water Raman line due to the film. Oil film thickness has successfully been measured using this technique.

Microwave Radiometry - Passive microwave techniques are highly developed. In the frequency range of interest (from about 1 to 40 GHz) and for typical terrestrial temperatures, the Rayleigh-Jeans approximation to the Planck blackbody radiation law works extremely well, the thermal radiation intensity being proportional to the absolute temperature of the emitter. This intensity is characterized as a brightness temperature, which is the thermodynamic temperature required for a blackbody to emit the given intensity of radiation. The brightness temperature measured is a function of the surface emissivity and its thermodynamic temperature and corrections for atmospheric effects. The known influences of desired parameters on the surface properties (and hence the surface emissivity) permits an analysis of measured brightness temperatures to determine the desired parameters.

Simultaneous passive measurements at L- and S-bands (1.43 and 2.65 GHz) have been used in nadir viewing airborne tests to provide sea surface temperature and salinity (to within 1^{o} C and to within 1 ppt for salinity greater than 5 ppt).

Differences in dielectric constants of ice and water permit their discrimination. Differences in surface roughness between oil-suppressed capillaries and the surrounding waters leads to oil spill detection. The relation between oil thickness and wavelength also provides a limited capability for measuring oil thickness and, hence, with areal extent spill volume.

Microwave radiometers have also demonstrated the capability for detecting rain and inferring grossly whether the rainfall rate is heavy or light. Discrimination between water in liquid and ice forms in clouds also permits rain and snow to be differentiated.

Microwave Scatterometry - A scatterometer is a special purpose radar which permits a quantitative measurement of the backscattered power from a target surface. This measured radar cross section or reflectivity is a function of the electromagnetic wave frequency, polarization, and incidence angle as well as of the surface roughness and its complex dielectric constant. (Microwave altimetry is a separate scatterometry technique and is discussed in the following section).

It has long been recognized that the roughness of the water surface (or sea state) is a function of the surface winds. It is this strong correlation between capillary waves and surface winds that leads to the usefulness of a scatterometer for inferring wind vectors over the ocean. This capability has been demonstrated through many aircraft experiments and the Seasat 1; a system with improved algorithms is planned for the NOSS scatterometer.

Active microwave techniques have probably been the most attractive remote-sensing technique for oil spill detection because of their day-night and all weather capabilities. The oil suppression of the capillary waves provides a detectable change in the backscatter received from which oil spill characteristics can be derived. However, varying oil thicknesses cause different interactions as radar frequencies, polarizations, and look angles are used, and unequivocable detection of oil and optimum system characterization have not been realized as yet. Real and synthetic apertures have both been used in aircraft-borne systems for oil detection. The U.S. Coast Guard's AOSS has a real aperture, side looking airborne radar (SLAR) operating at X-band and having both horizontal and vertical polarization. Additional research and tests at both L- and X-bands, two polarizations, and varying look angles in coordination with surface truth measurements are currently underway.

Radar detection of ice is also an accomplishment, even though determination of many key ice features using this technology cannot be made at this time.

Another radar system for the remote (though not airborne or spaceborne) detection of currents and waves in coastal waters is the high-frequency (HF) doppler radar. In this system, two radars are spatially separated on shore and are operated simultaneously but independently. The frequency shift of the received echo to that of the transmitted signal, the doppler shift, is related to radial velocity effects with other details of the signal return being due to Bragg scattering effects from the illuminated wave train. The two station analysis provides the resolution of the velocity measurements to current velocities. The NOAA system (called CODAR, Coastal Ocean Dynamics Radar) is mobile and has successfully mapped the surface current field over an area of 2500 km^2. Wave characteristics, including spectra, have also been determined using this technique.

Microwave Altimetry - Precision radar altimetry has been successfully demonstrated from orbital platforms (GEOS-3 and Seasat 1) for the observation of global topographic features, measurement of significant wave height and dominant wavelength, and determination of ocean currents, tides, and storm surges. Transit time from transmission of the RF pulse to reception of the return pulse along with return pulse shape and amplitude are the key measurements (with orbital and geoid elements) used to derive the surface characteristics. This technique is highly developed and is being improved in accuracy for applications to NOSS.

Special Note - Another remote-sensing technique, but used from shipboard rather than in aircraft or spacecraft, is acoustic sounding, ranging from simple sonar to acoustic tomography. This technique has been used for sediment settling studies, e.g., in the vertical dispersion of materials dumped in the ocean.

Potential Remote Sensing Capability

The assessment of the potential capabilities is shown in more detail in Table II where the desired water property parameters (see Section III.A) are listed under that area of remote-sensing technology for which a potential for the measurement is believed to exist. It is emphasized again that the assessment of potential remote-sensing capability is quite subjective and was determined primarily from personal communications with researchers who are doing some of this work and are cognizant of ongoing research activities.

Visible and Near Visible Radiometry - It is known that pesticides, toxic organics, and heavy metals are often adsorbed onto particulates and that their impact on ecosystems of concern may be primarily due to suspended particulate transport. Since particulates in water are detectable with visible radiometric methods, clues to the presence of hazardous substances with them are possible only if their presence alters the scattering and absorption sufficiently so as to have some spectral "signature" effect. Similarly, the ability to separate or distinguish between organic and inorganic suspended solids would also require some characteristic change in the spectral upwelling radiances. Since laser fluorescence techniques have been shown capable of detecting dissolved organics, it may well be that a combination of these two techniques would prove of value. Since concerns are with truly trace amounts of the hazardous substances and probably very small differences in spectra for organic/inorganic discrimination, the probability for this task is considered low, but not zero, and therefore worthy of further consideration.

Some images of oil spills have shown varying reflectivities throughout the spill area. There has been speculation that this may be due to variations in thickness. Little research has been done on such a possibility and the probability assessed for this is low also, since other effects (e.g., surface roughness at angles causing glint) may be equally probable explanations.

Laser-Induced Fluorescence - The success at measuring near-surface chlorophyll a concentrations with laser excitation leads to the high probability for determining chlorophyll profiles with depth using range gating techniques. Unfortunately the chlorophyll response is in the red portion of the spectrum; thus the recovery of depth resolved concentration seems constrained to the upper portion of the photic zone. The electronic techniques, although advanced, are well understood and by separating the returns timewise, the returns from various depths can be examined.

Controlled laboratory experiments have been encouraging enough to say a medium probability exists for laser-induced fluorosensing methods to provide some classification or typing of oil. This method, however, has a low probability for detecting oil in the water column.

An inference of total organic carbon (TOC) is considered feasible since in some instances, researchers have indications that a correlation exists between TOC and the fluorescence from dissolved organics. This probability is rated medium with additional research required.

The question of using laser-induced fluorescence to detect nutrients (phosphates and nitrates) has been raised, but the opinion now is that the probability of success should be considered as low.

The use of laser stimulated fluorescence to detect and quantify subsurface dye concentrations through the time gated recovery of a particular fluorescent return wavelength appears feasible for the near future.

Laser Scattering - Investigations using Raman scattering by the water molecule where detailed characteristics of the Raman return are considered have shown some success at determining the water temperature at depth. Experiments are continuing to reduce the limitations of this technique.

Similar investigations involving the sulfate ion as a measure of salinity have been less successful because of the weakness of this return. It is believed now that for salinity, as well as nutrient profiles, that the probability must be low.

The use of range gating for sensing the particulate distribution in the water column has a high probability of success. Continuing experiments are underway to advance this potential.

Microwave Scatterometry - The use of radar for ice monitoring has been quite successful (e.g., Great Lakes coverage using side looking airborne radar-SLAR); however, there seems to be general agreement that more research and development is required (and indeed is in progress) before many of the desired detailed ice parameters, including thickness, can be measured. Measurements at multipolarization and incidence angles may afford some of the additional information required, and some feel that a combination of radar and multi-frequency microwave radiometry may be a better approach for getting major ice parameters, such as roughness (ridging, rafting), age (first year vs. multi-year), and thickness. The potential for such accomplishment is at least medium and may be high.

No Remote-Sensing Capability

For the sake of completeness, this section is concluded with this listing of those water property parameters (from Section III.A.) which were assessed as beyond the capability of remote sensing, at least for the foreseeable future.

Phytoplankton - Species, Growth rates

Conductivity

Currents - Profile

Pycnocline Topography

Fish Catch, Species, Location, Quantity

Pesticides, Toxic Organics, Heavy Metals -

Type, In solution, Chemical reaction rates

TSS - Size Distribution, Settling Rate

Bioaccumulation

Oil - Hydrocarbon Fractions

Waste Dumps - Floatables

Dissolved Gases

Toxicity Effects

Particulate Organic Carbon (POC)

TABLE I

SUMMARY OF PRESENT REMOTE SENSING CAPABILITIES
(Numbers in parentheses are references in Appendix B.)

Visible and Near Visible Radiometry

Chlorophyll - Surface (1,2)
Phytoplankton - Areal Extent (3,4)
Light Attenuation (5,6)
Wetlands (7,8,9)
TSS - Surface (10,11)
Oil - Areal Extent (12,13)
Meteorological - Front Locations
Discharge Plumes - Sewage Outfalls: Dispersion, Persistence
Waste Dumps - Compliance, Dispersion, Persistence (14,15,16)
Ocean Fronts - Location by Color (17)
Extent by Color
Surface Gradients - Color, Reflectance, Roughness, TSS, Chlorophyll (18)
Land/Water Interface (19)
Eddies - Location, Size, Duration (20)
Ice - Presence, Areal Extent (21)

Thermal Infrared Radiometry

Temperature - Surface (22)
Eddies - Location, Size, Duration (23)
Discharge Plumes - Sewage Outfalls: Dispersion, Persistence
Ocean Fronts - Location, Extent, Surface Gradient: Temperature (22,24)

Laser-Induced Fluorescence

Chlorophyll - Surface (25,26)
Phytoplankton - Diversity, Areal Extent (25)
Oil - Areal Extent, Thickness (27,28)
Dissolved Organics (29)
Ocean Fronts - Surface Gradients: Chlorophyll (29)
Dry Tracer Concentration (30)

Laser Scattering

Light Attenuation (29)
Waves - Significant Height, Dominant Wavelength, Direction, Spectra (31,32)
Ice - Presence, Areal Extent (33)
Bathymetry (34)
Oil - Thickness (35)
Surface Films (35)

Microwave Radiometry

Temperature - Surface (36)
Salinity - Surface (36)
Ice - Presence, Extent, Thickness (37)
Precipitation - Type, Rate (38,39)
Sewage Outfall - Dispersion, Persistence
Ocean Fronts - Location, Motion, Surface Gradients:
Temperature, Salinity
Oil - Areal Extent, Thickness (40,41)

Microwave Scatterometry

Surface Winds - Speed, Direction (42,43)
Currents - Surface (44)
Oil - Areal Extent (13,37,45)
Waves - Significant Height, Dominant Wavelength, Direction,
Spectra (46,47)
Ice - Presence, Areal Extent (48, 49, 50)

Microwave Altimetry

Currents - Surface (51, 52)
Waves - Significant Height, Dominant Wavelength, Spectra (53)
Ocean Fronts - Surface Gradients: Roughness (52)

TABLE II

SUMMARY OF POTENTIAL REMOTE SENSING CAPABILITIES
(Assessment of potential given in parentheses.)

Visible and Near Visible Radiometry

Pesticides, Toxic Organics, Metals - On sediment (Low)
TSS - Organic/Inorganic (Low)
Oil - Thickness (Low)

Laser-Induced Fluorescence

Chlorophyll - Profile (Medium)
Nutrients - Profile (Low)
Oil - Classification (High)
In water column (Low)
Dissolved Oxygen - Profile (Low)
TOC - (Medium)
DOC - (Medium)
Tracer Dyes, subsurface (High)

Laser Scattering

Temperature - Profile (Limited)
Nutrients - Profile (Low)
Salinity - Profile (Low)
TSS - Profile (High)

Microwave Scatterometry

Ice - Thickness (Medium)

IV. TECHNOLOGY THRUSTS

In this section, the assessments of the capabilities of remote sensing (previously presented) are viewed with the intent of identifying needed technology advancements for remote-sensing applications to problems in coastal and inland waters. A rationale for the direction of this thrust is presented first, followed by the particular broad and specific recommendations.

Rationale for Suggestions

A review of the measurements required to address the problems which exist in the inland, coastal, and shelf waters reveals the basic need for the determination of in-the-water parameters. The dynamic nature of and the interrelationships between the broad topical areas of interest into which those problems can be divided (such as productivity, sedimentation, hazardous substances, etc.) emphasizes that near-surface characterizations only will seldom suffice in supplying all of the data needed. This is simply another way of saying that the concern is three-dimensional and, of course, time dependent. The demonstrated capabilities of remote sensing that NASA has provided, especially from its spacecraft and aircraft platforms, is recognized as giving the areal coverage demanded by the regional scale of most of these problems. So, even though remote sensing may never be able to address fully the variety of quantities desired, there is the requirement that the capabilities of remote sensing be advanced to infer as many in-the-water properties as possible and that the limitations of the interpretation of the remotely sensed data be thoroughly understood.

Recommended Thrusts

<u>Basic Thrust</u> - A prerequisite for technology advancement in the remote sensing of in-the-water properties is an increased understanding of the fundamental properties of materials in the water and their interactions with light. By light, here, is meant the visible and near visible portion of the electromagnetic spectrum where penetration of the radiation into the water to some depth is possible. Although a foundation exists for analytically describing the in-the-water optical processes of absorption and scattering of light, much remains to be done. More certainly needs to be accomplished before we can predict adequately the upwelled radiance field due to the various substances of interest in the water environment. The ability to invert upwelled radiance spectra into unique inherent optical properties is quite limited, as is the ability to provide substance identification and quantification. Further research is required in such areas as these if the interpretation of remotely sensed data is to be non-site specific.

The initial work in remote sensing of water quality parameters was with radiometry techniques where the primary radiation source was solar illumination. More recent investigations involving laser illumination have opened new possibilities for the determination of in-the-water volumetric properties. This approach, using the techniques of fluorescence and Raman spectroscopy, has already afforded specificity and uniqueness for some parameters of interest. Similarly, however, it must be emphasized that our understanding of some of these fundamental interactions is insufficient for predicting whether or not a substance can or cannot be detected or the system parameters required for detection, discrimination, and quantification. The promise for these methods, however, is of such a magnitude as to demand continued research, even though such a technique may not be applicable from space for many years, if ever.

Visible and Near-Visible Radiometry Thrust - A primary thrust in the advancement of radiometric techniques must be in the development of data interpretation algorithms. This thrust should encompass theoretical, laboratory, and field investigations. The following questions are valid here:

(1) What does the theory permit in the way of unique inversions of spectral radiance to inherent or apparent optical characteristics? From optical characteristics to substance identification and quantification (e.g., chlorophyll, total suspended solids, nutrients, etc.).

(2) How well do the theoretical inversions work with controlled laboratory situations? Do laboratory spectra suggest data analysis algorithms? Do we understand why they might work? Is site specific information required for this interpretation? Can techniques for separating multiple effects or defining mixtures be derived?

(3) Does the analysis of the "real world" spectra or multispectral scanner results from field investigations using the techniques from (1) and (2) yield acceptable results? Are there unaccounted for characteristics (or noise) that, with surface truth measurements, suggests additional laboratory tests?

In answering these questions, there must be identified those other factors related to the sensor or instrument technology, such as spectral bandwidths, minimum radiance detectability, minimum change in radiance desired, and dynamic range. These factors along with measurement requirements which are defined by the experiment itself (e.g., spatial resolution, swath coverage, etc.) will then permit a rough instrument design approach to be stated which will show where specific technology advancements (sensors, filters, scanners, data handling, etc.) are required. At this present time, it is believed that existing technology will not be the limiting factor in advancing the capabilities of visible and near-visible radiometry for investigations of inland and coastal waters. Technology developments for other program areas, such as those represented by the thematic mapper for Landsat D and linear array and mosaic sensor technology, are directly applicable to our area as well.

It is well to emphasize again that visible and near-visible radiometry will require atmospheric corrections, especially when measurements are made from high altitude aircraft and spacecraft platforms. The next generation of radiometers should probably include features integral to their design for simultaneous measurements of those atmospheric parameters needed to provide the required corrections. The specifications for such features will, of course, be based on present methods, CZCS experience, and new concepts.

Laser-Induced Fluorescence and Scattering Thrusts - In an earlier section (III.B.), the potential of laser techniques was noted for the measurement of several parameters, and especially for some as a function of depth below the water surface. Continued investigations should be encouraged, even toward some of the parameters for which a low probability of success was the assessment. This research should be accompanied by theoretical studies to verify our present understanding and confirm our ability to predict the phenomena. It is uncertain as to whether technology advances beyond the present state of the art will be required; however, the techniques for range gating which are a part of the lidar mode of operation in providing depth discrimination, may be difficult. Even if no significant, new technology is required, it will be necessary to upgrade some of the existing systems, particularly with more powerful lasers and more adequate data handling and processing equipment.

Microwave Techniques - The applicability of microwave imaging and non-imaging techniques for the detection of surface phenomena continues to develop rapidly; however, there is little probability that measurements of in-the-water volumetric properties can be realized. Fortunately, though, these techniques provide significant capabilities for determining details of water dynamics which have already been shown to be so very important. Continued development of active and passibe microwave techniques is encouraged for providing driving function data (such as wind stress and other meteorological factors), dynamic water response information (such as wave climate and current fields), and all weather, day-night detection of critical surface (such as oil spills) and subsurface (bottom topography) features.

V. PROGRAM RECOMMENDATIONS

Introduction

The sampling of problems contained in previous sections of this document, as well as those in the documents of Appendix A, emphasize the need for increased understanding of coastal processes. Such an understanding is important because the Great Lakes, the estuaries, and coastal shelf waters provide livelihoods for a quarter of a million persons. These waters are major transportation throughways. They provide recreation for more than half of our population and they are the source for 1.3 billion kg (2.9 billion pounds) of food annually.

While these waters have tolerated remarkably well man's assaults on them, they have not been immune to the uses and misuses we have required of them. The environmental movement in the U.S.A. received a great impetus from the terrible condition that many of these water areas were in from such things as excess nutrients, pesticide residues, poor development practices, and a general laissez-faire attitude towards proper management. The reaction of the environmentalists has produced, in many cases, severe regulations that have caused significantly increased costs to individuals and companies using the waters. This has produced still another reaction for abolishing the regulations. Indeed, some of these rules have been arbitrary, but they have often been established because too little is known about the processes affecting these water bodies. These increasing economic pressures, plus the ecological consequences of inadequate management decisions, demand a more complete understanding of these water bodies.

The approach of this document has been to identify representative problems and to determine those measurements essential to providing understanding and possible solutions to those problems. An assessment was made of the present and potential capabilities of remote sensing to measure each identified water property. Then some suggestions for thrusts for the advancement of this technology were made. It is the intent of this section to present recommendations for a program which addresses significant problem areas in our inland, estuarine, and coastal waters. Before the detailed recommendations are given, a discussion of the criteria used in formulating these specifics is included. The section is then completed with a few suggested activities beyond the effort represented by this document.

Criteria for Program Recommendations

In formulating the recommendations for a program for inland, estuarine, and continental shelf waters, two questions were addressed to provide criteria for selecting and oedering the program elements. These questions were:

(1) What are the priority problem areas in the inland and coastal waters?

(2) Why NASA?

In the remainder of this section, the answers to these questions are presented to show the considerations deemed important in making the program recommendations which follow.

Priority Problem Areas - The numerous studies, symposia, workshops, and legislation reveal that there is no lack of priority problems in the inland, estuarine, and continental shelf waters. Few of the relevant documents, however, even attempt to venture a concensus as to prioritization. Certainly, it is agreed that the inland and coastal waters are those most biologically productive. As one example, it has been estimated that the coastal waters to the edge of the continental shelf constitute 10 percent of the area of the world's oceans. But 99 percent of the world's fish catch originates from these coastal waters and from the relatively small (0.1 percent) upwelling areas. The natural interactions between the water and land in the coastal zone provide those basic ingredients which support the food chain. These waters, too, are the ones impacted most heavily by man's many activities. Therefore, productivity is considered the problem area of highest priority for this program emphasis.

The problem area selected for second highest priority for these waters is sedimentation. Coastal sedimentation, like productivity, occurs naturally but is also strongly influenced by man's activities. Since particulate matter can affect the quality of the coastal environment in so many ways, the ability to understand and predict its behavior is of the greatest scientific and practical importance. The complex coastal geometry influences the dynamics of the sedimentation processes. Man's use of land and water in this zone, such as near-shore construction and channel maintenance, leads to near-continual disruptions of the natural processes. Another factor demanding an understanding of the sedimentation processes is the increasing realization of its role in the transport of pollutants and hazardous substances throughout the aquatic environment.

Although two problem areas have been listed as top priorities, it must be remembered that they are not mutually exclusive; indeed, few problems in the coastal zones are not multidisciplinary. Sediment influences productivity through its transport of nutrients as well as its influence on the penetration of light into the water column. These influences are only two of many, yet they serve to focus on another aspect of the problem areas which requires understanding. The problems of the coastal waters, including productivity and sedimentation, are dynamic ones. Consequently, it is imperative that the driving factors and the circulation and transport response of the waters be an integral part of the priority problem considerations.

As noted earlier herein, it is upon this movement of the water that the other physical, biological, and chemical processes are superimposed. From the point of view of problem areas in the inland and coastal waters, water dynamics may be considered as a fundamental part of all other areas or as a separate problem area all its own.

In summary, then, the priority items from a problem point of view are productivity dynamics and sedimentation dynamics, where the word "dynamics" has been included to emphasize the role of water dynamics in each area.

Why NASA? - This question arises quite naturally because of the limited expertise within NASA to address all of the scientific and application aspects of the problems of the inland and coastal waters. The effective application, however, of the NASA technology and, in particular, the remote-sensing technology, to priority problems is, of course, the primary reason for NASA involvement. It is reasonable, therefore, to look toward problem areas where there is in-house expertise for advancing their understanding and solution and where the remote-sensing technology has put NASA in the lead to do it or for which it would make a large or significant contribution.

The status of current remote-sensing technology and the near-term potential is such that these techniques will complement rather than replace other methods. Present capabilities (and much of the identified potential) especially in the determinations of in-the-water properties provide primarily surface or near-surface characterizations. Yet, the value of the perspective of remote sensing is still generally acknowledged to be beneficial, especially the synoptic and regional view provided by its use from aircraft and spacecraft platforms. And this benefit is realizable to some extent even with some of our current methods which are dependent on limited surface truth measurements and are, therefore, site specific. The status of remote sensing, along with the limited scientific expertise in the problem areas, argues for a joining of forces with other agencies in attacking specific problems in our selected areas of emphasis. Fortunately, NASA has successfully molded together such diverse groups into programs before (e.g. Skylab, Seasat, Nimbus). This cooperative approach would further assist in assuring a transfer of the NASA-developed technology to viable users.

Finally, NASA should be particularly sensitive to those specific program elements which would be supported by its ongoing and planned missions. The planned National Oceanographic Satellite System (NOSS) is a specific case in point. There should be continued availability of water color data from, for example, the NOSS Coastal Zone Color Scanner (CZCS) for investigations beyond those of the Nimbus 7 CZCS for inland and coastal water research and applications. The fact that the same satellite will provide data relevant to water dynamics makes such considerations more attractive. Yet, it is acknowledged that the large spatial resolution of the "footprints" of the sensors involved will require special planning for their data use in order that their scale will not negate but will contribute to experiment objectives. In this same view, NASA has utilized aircraft remote sensing very effectively in its research and development. Since some of the newer capabilities will not be on orbital missions for some time to come, their use onboard aircraft and even ships should be planned.

In summary, then, the answer to the question, "Why NASA?", says that criteria for selecting program specifics should include NASA scientific and technical expertise, those remote-sensing techniques that are most advanced and the most promising, consideration of where the remote sensing could provide the most relevant complementary data, and finally, a consideration of "filters" related to contributions from space and aircraft missions in NASA's program.

Recommendations

Before making the recommendations which follow in this section, it is emphasized again that the interactions between problem areas in the coastal zone are very significant. As noted earlier, for example, sedimentation processes do impact productivity. And, while the previous section or priority problem areas did not emphasize hazardous substances, any reasonable program in inland and coastal waters which includes productivity and sedimentation processes must sometime be concerned about hazardous substances. Consequently, in the detailed recommendations, there will be several activities which will be listed under two program areas. It is recognized that the implementation of these and all program elements would never be so narrow as to exclude contributions when appropriate to related areas of emphasis and would include multidisciplinary participation.

In these sections, specific program elements will be recommended. They will be recommended in a priority order, meaning that those recommended first satisfy more of our criteria than those recommended later. In addition, the prioritization, though still subjective, considered impact on understanding the problem, probable success of the project with remote sensing included, and technology availability and potential in NASA to attack the problem. While elements within each program area will be prioritized, a priority relationship between elements of productivity and of sedimentation has not been made, although productivity has been ranked above sedimentation. When program elements are presented, some will be problems which have been discussed herein, but there may be additional ones noted. The intent here is to indicate specific program elements which will, in every case, require additional definition of their specific scope before implementation planning could begin.

Supporting Research - There is little disagreement that the remote-sensing techniques and their utilization in solving important problems should be on the soundest possible scientific base. Even as present capabilities are extended, there will be elements of basic research which necessarily must accompany the applications tasks. Some of these research aspects have been addressed in the previous section as a basis for Technology Thrusts, and it is recommended that the NASA program for inland and coastal waters include basic research focused primarily on increasing our understanding of the fundamental properties of materials in the water and their interactions with light. Continued basic research in optical physics is required and is justifiable not only for this program but for its science and application uses as well. It is required for the acceptance and the advancement of remote-sensing capabilities, and in this program especially for the measurement of those volumetric properties required for coastal zone problems.

The primary area of research involves radiative transfer processes, including fluorescence, Raman spectroscopy, and polarization as well as the more standard properties of absorption and scattering. The ability to predict the upwelled radiance spectra due to solar or laser illumination is imperative. The methodology for the opposite problem, the inversion of these spectra, to deduce inherent optical properties and substance identification and quantification is now quite limited. This research should attempt to decide the limits to which unambiguous measurements can be made by remote sensing and to provide a greater understanding of those supplemental measurements which would contribute most to specificity and uniqueness in data interpretation when site-specific considerations are required. Analytical, laboratory, and field measurements, therefore, are necessary elements in such research. There is a very limited amount of such work in the NASA Office of Space and Terrestrial Applications (OSTA) on-going programs.

Productivity Dynamics - It is recommended that the highest priority in the NASA Program for inland and coastal waters be in the area of productivity. This should include those properties of water dynamics which influence productivity and its subsequent distribution.

The list which follows presents the priority elements recommended for the productivity part of the program: (Note, again, that the priorization includes understanding the problem, probable success, and technology in NASA to attack the problem.)

(1) Large Scale (Regional and Ocean Basin Scale) Productivity Mapping,

(2) Productivity and Eutrophication in the Great Lakes,

(3) Location and Characterization of Coastal and Estuarine Fronts,

(4) Regional Scale Dynamics of Phytoplankton Patchiness,

(5) Wetlands Interactions with Estuarine and Coastal Productivity,

(6) Relationships of Estuarine Plume Dynamics with Coastal Productivity,

(7) Quantitative Linkage Between Primary Productivity and Upper Trophic Levels,

(8) Productivity Impacts of Episodic Events (For example, unusually high freshwater runoff, accidental or deliberate discharge of petrochemicals, industrial wastes/effluents, and toxic materials; unusual temperature stresses).

At this point, it is well to emphasize that NASA OSTA already supports research and applications in this program area of productivity dynamics which represent significant and substantial contributions. Some of these activities are: investigations of the CZCS Nimbus Experiment Team, applications of CZCS in the Great Lakes, dynamics of phytoplankton patches on Nantucket Shoals and in the California Bight, Chesapeake Bay plume measurements (with NOAA NMFS support), the relationship of ocean fronts to Atlantic Bluefin Tuna management, development and application of laser technology, optimization of acoustic backscatter techniques for measuring current profiles and laboratory studies and field remote measurements for detection of pollutants, ocean wastes, and oil spills.

Sedimentation Process - It is recommended that the second priority in the NASA program for inland and coastal waters be in the area of sedimentation processes.

The list which follows presents the priority elements recommended for the sedimentation part of the program:

(1) Estuarine Plume Dynamics,

(2) Sediment Flux, Transport, and Fate in the Great Lakes,

(3) Estuarine Sediment Flux, Transport, and Fate,

(4) Impact of Episodic Events on Estuarine Sediment Dynamics,

(5) Particulate Transport in a Thermally Stratified Water Body,

(6) Sedimentation Transport Due to Dredging and Dredge Disposal,

(7) Non-point Source Sediment Loadings in the Great Lakes, Estuaries, and Nearshore Marine Waters, and

(8) Utilization of Sediment Transport to Indicate Pollutant Fluxes.

Activities related to sedimentation processes already being supported by NASA OSTA are: investigations by the CZCS Nimbus Experiment Team, Chesapeake Bay plume measurements (with NOAA NMFS support), applications of CZCS in the Great Lakes, development and applications of laser technology, and laboratory spectral signatures of various sediments and mixtures.

Other Recommendations - It is recommended that pertinent remote-sensing capabilities which have been successfully demonstrated by prepared for technology transfer to users. Potential items here include

(1) New Techniques for Monitoring Oil Spills, and

(2) Monitoring of Ocean Dumping Activities.

In any implementation of this program two thrusts require continued attention. The first is a technology development portion of the program required to perform the necessary research for creating and verifying new techniques. This is the familiar proof of concept. The status of these concepts and techniques will influence the scope of the contributions which remote sensing can make and the rapidity with which the program elements can be pursued. The second thrust recognizes that additional work is almost certainly required to go from proof of concept to acceptable quasi-operational techniques. This part of the program is necessary because new techniques and even refinements of existing techniques are often developed with less than optimum instrumentation; often both the sensor and data analysis require modification and improvement. Because this is such an important portion of the program, the mechanism for supporting this thrust within the Divisions of OSTA must be clear to everyone involved in the program. It is recommended that OSTA document its guidelines concerning this issue.

Concluding Remarks

This assessment concludes that remote sensing can play a significant role in providing many of the measurements required in addressing problems of the inland and coastal waters. Combining the needed research and development together with priority scientific and applications program elements can contribute to increasing our understanding of this important area of environmental concern. It is understood that the recommendations presented can only be considered a beginning for the planning and development for a program within NASA concerned with the study of inland and coastal waters. It is hoped that this effort may provide a structure or framework upon which a program can be built and within which existing activities may be put into perspective. It is our belief that a program already exists in this area and that the framework presented could provide for more sharply focusing and justifying the current tasks and future efforts. The complexities of the problems in these waters and the status of remote-sensing technology provide a worthy challenge for this undertaking.

APPENDIX A

Source Documents for Problems

Anon.: Reports of the Subcommittees on: National Needs and Problems; Data Collection, Storage, and Distribution; Monitoring; Research and Development. Interagency Committee on Ocean Pollution Research, Development, and Monitoring/Federal Coordinating Council for Science, Engineering and Technology, Working Papers 2-5, August, 1979.

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P.L. 94-580: Resource Conservation and Recovery Act of 1976.

P.L. 95-273: National Ocean Pollution Research and Development and Monitoring Planning Act of 1978.

APPENDIX B

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15. Supplementary Notes

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16. Abstract

Several, previously described, problems within Great Lakes, coastal, and continental shelf waters were selected and organized under the topical headings of Productivity, Sedimentation, Water Dynamics, Eutrophication, and Hazardous Substances. The measurements required in the study of each of the problems were identified. An assessment was made of the present capability and the potential of remote sensing to make these measurements. The relevant remote-sensing technology for each of these classifications was discussed and needed advancements indicated. Finally, prioritized recommendations were made to address science and applications needs with a view toward providing a framework for a stronger program focus related to inland and coastal waters.

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