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Practical Applications of Space Systems

Supporting Paper 5

Inland Water Resources

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A Panel Report Prepared for the

Space Applications Board

Assembly of Engineering

National Research Council

PREFACE

In November 1973, the National Aeronautics and Space Administration (NASA) asked the National Academy of Engineering* to conduct a summer study of future applications of space systems, with particular emphasis on practical approaches, taking into consideration socioeconomic benefits. NASA asked that the study also consider how these applications would influence or be influenced by the Space Shuttle System, the principal space transportation system of the 1980's. In December 1973, the Academy agreed to perform the study and assigned the task to the Space Applications Board (SAB).

In the summers of 1967 and 1968, the National Academy of Sciences had convened a group of eminent scientists and engineers to determine what research and development was necessary to permit the exploitation of useful applications of earth-oriented satellites. The SAB concluded that since the NAS study, operational weather and communications satellites and the successful first year of use of the experimental Earth Resources Technology Satellite had demonstrated conclusively a technological capability that could form a foundation for expanding the useful applications of space-derived information and services, and that it was now necessary to obtain, from a broad cross-section of potential users, new ideas and needs that might guide the development of future space systems for practical applications.

After discussions with NASA and other interested federal agencies, it was agreed that a major aim of the "summer study" should be to involve, and to attempt to understand the needs of, resource managers and other decision-makers who had as yet only considered space systems as experimental rather than as useful elements of major day-to-day operational information and service systems. Under the general direction of the SAB, then, a representative group of users and potential users conducted an intensive two-week study to define user needs that might be met by information or services derived from earth-orbiting satellites. This work was done in July 1974 at Snowmass, Colorado.

For the study, nine user-oriented panels were formed, comprised of present or potential public and private users, including businessmen, state and local government officials, resource managers, and other decision-makers. A number

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*Effective July 1, 1974, the National Academy of Sciences and the National Academy of Engineering reorganized the National Research Council into eight assemblies and commissions. All National Academy of Engineering program units, including the SAB, became the Assembly of Engineering.

of scientists and technologists also participated, functioning essentially as expert consultants. The assignment made to the panels included reviewing progress in space applications since the NAS study of 1968* and defining user needs potentially capable of being met by space-system applications. User specialists, drawn from federal, state, and local governments and from business and industry, were impaneled in the following fields:

Panel 1: Weather and Climate
Panel 2: Uses of Communications
Panel 3: Land Use Planning
Panel 4: Agriculture, Forest, and Range
Panel 5: Inland Water Resources
Panel 6: Extractable Resources
Panel 7: Environmental Quality
Panel 8: Marine and Maritime Uses
Panel 9: Materials Processing in Space

In addition, to study the socioeconomic benefits, the influence of technology, and the interface with space transportation systems, the following panels (termed interactive panels) were convened:

Panel 10: Institutional Arrangements
Panel 11: Costs and Benefits
Panel 12: Space Transportation
Panel 13: Information Services and Information Processing
Panel 14: Technology

As a basis for their deliberations, the latter groups used needs expressed by the user panels. A substantial amount of interaction with the user panels was designed into the study plan and was found to be both desirable and necessary.

The major part of the study was accomplished by the panels. The function of the SAB was to review the work of the panels, to evaluate their findings, and to derive from their work an integrated set of major conclusions and recommendations. The Board's findings, which include certain significant recommendations from the panel reports, as well as more general ones arrived at by considering the work of the study as a whole, are contained in a report prepared by the Board.**

It should be emphasized that the study was not designed to make detailed assessments of all of the factors which should be considered in establishing priorities. In some cases, for example, options other than space systems for accomplishing the same objectives may need to be assessed; requirements for

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*National Research Council. *Useful Applications of Earth-Oriented Satellites, Report of the Central Review Committee.* National Academy of Sciences, Washington, D.C., 1969.

**Space Applications Board, National Research Council. *Practical Applications of Space Systems.* National Academy of Sciences, Washington, D.C., 1975.

institutional or organizational support may need to be appraised; multiple uses of systems may need to be evaluated to achieve the most efficient and economic returns. In some cases, analyses of costs and benefits will be needed. In this connection, specific cost-benefit studies were not conducted as a part of the two-week study. Recommendations for certain such analyses, however, appear in the Board's report, together with recommendations designed to provide an improved basis upon which to make cost-benefit assessments.

In sum, the study was designed to provide an opportunity for knowledgeable and experienced users, expert in their fields, to express their needs for information or services which might (or might not) be met by space systems, and to relate the present and potential capabilities of space systems to their needs. The study did not attempt to examine in detail the scientific, technical, or economic bases for the needs expressed by the users.

The SAB was impressed by the quality of the panels' work and has asked that their reports be made available as supporting documents for the Board's report. While the Board is in general accord with the panel reports, it does not necessarily endorse them in every detail.

The conclusions and recommendations of this panel report should be considered within the context of the report prepared by the Space Applications Board. The views presented in the panel report represent the general consensus of the panel. Some individual members of the panel may not agree with every conclusion or recommendation contained in the report.

PANEL ON INLAND WATER RESOURCES

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INTRODUCTION AND SCOPE

OBJECTIVES OF PANEL ON INLAND WATER RESOURCES

The stated purpose of the 1974 Summer Study on Space Applications held at Snowmass, Colorado, was as follows:

> "The objective is to conduct a comprehensive study of applications of space systems for the 1980's, including practical approaches, assessment of socio-economic benefits, planning for implementation, and influences on or by the principal space transportation system of the era."

The primary objective of the Panel on Inland Water Resources was established by the Panel as determining how and to what extent space technology can be used in the timely development and improved management of the nation's inland water resources.

The term "space technology," as used herein, refers to a system or systems which may include satellites, high-altitude aircraft, and ground installations with attendant sensors that remotely measure various parameters and collect ground-based data and relay them via satellite to processing centers. Data so obtained may be applied to four main areas in the management of water resources:

Inventory
Basic research on hydrologic balance
Planning
Operation

Emphasis has been placed on user applications which the Panel believes will arise within the next decade. Primary users are seen as federal, state, and local governmental agencies and firms and individuals in the private sector. Less attention is given to the needs of individual research scientists or engineers in universities or in government agencies, although parts of the program may be highly beneficial to them. No attempt has been made to treat "spin-off" applications of space technology although many are used, particularly in new sensors. It is believed that a large body of space related technology exists which could profitably be applied to problems related to inland water resources

but which, for various reasons, has had little application to date. The Panel believes this calls for placing a high priority on practicable applications of space technology.

SCOPE OF THE TERM "INLAND WATERS"

The Panel applies the term "inland waters" to those waters bounded by land within the various states and possessions of the United States. In addition, the Panel includes coastal waters, as is customary, because of their inseparable interrelationships with riverine systems. Also included are the Great Lakes and contiguous waters. It should be recognized that much of the content of the present report also applies generally to similar inland waters throughout the world.

PROGRESS SINCE 1967-68 STUDY

During the summers of 1967 and 1968 technical panels were convened at Woods Hole, Massachusetts, to assess future useful and practical applications of earth-oriented satellites. From these efforts a series of reports were published which treated the potential role of satellites in various disciplines. Hydrology was one of the disciplines.*

In the perspective of 1974, a little over one-half decade since the completion of the 1967-68 study, the appropriateness and insight provided by the Panel on Hydrology is noteworthy. This is particularly true when the work is considered in light of economic, political, technological, and other changes that have occurred. Major findings and recommendations of the 1967-68 Panel on Hydrology are reviewed briefly in order to assess the progress made between then and now in applying space technology to a better understanding and management of water resources. In general, one can see that these findings and recommendations have provided an excellent stimulus to and framework for program development.

It could very easily be concluded that these findings are even more valid in 1974 than they were in 1967-68. The successful progress that has been made supports these findings in every case and suggests that the implied and explicit goals set forth in the 1967-68 study should be pursued even more vigorously.

1967-68 FINDINGS AND RECOMMENDATIONS

The Panel on Hydrology summarized its findings as follows:

"1. The application of space technology to hydrologic problems promises significant benefits in scientific understanding of hydrologic systems and in planning and management of water-resources projects.

"2. Four hydrologic objectives amenable to current space technology and promising substantial immediate and long-term benefits have been identified: basic studies of hydrologic cycle and large-scale

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*National Academy of Sciences. *Useful Applications of Earth-Oriented Satellites, Report of the Panel on Hydrology* (Panel 3). Washington, D.C., 1969.

hydrologic systems; snow and ice mapping; surveys of coastal hydrologic features and large inland lakes; and real-time communications of ground-based hydrologic data.

"3. The proposed hydrologic-satellite program consists of a communications satellite (HCS), a sensing satellite now considered feasible (HSS-1), and a sensing satellite embracing greater capabilities after further research and development. To achieve maximum net benefits, these proposed satellite programs may be integrated with other proposed earth-resources satellite programs.

"4. Solid economic evaluation of these applications is not possible at this time.

"5. In spite of this lack of economic evaluation, the prospects of success warrant a substantial satellite program in hydrology.

"6. Extended research and development are necessary to develop much-needed spaceborne sensor capabilities such as: snow depth and its water content, and ice thickness; precipitation rate at the ground surface; identification of chemical and biological character of water and pollutants; streamflow velocities and discharge; groundwater elevation and discharge; and vertical and horizontal movement of atmospheric water vapor.

"7. Major benefits to hydrology expected from interdisciplinary programs of space technology include: improved weather forecasts; improved land-use mapping and classification; improved topographic and geologic mapping; precipitation reporting on a real-time basis; and areal estimates of soil temperature.

"8. Space technology applied to hydrology should be evaluated and exploited in the interest of the users, taking into consideration the following: the transfer of data from ground stations or sensors finally to the users; the impact of economic, social, and political factors on water-resources development and the needs for hydrologic data; and the administrative structures to coordinate and integrate all space programs regarding applications in hydrology.

"9. No particular hardware can be recommended by this Panel at this time pending studies of alternates, including the sharing of space and communications hardware."

The Panel on Hydrology made the following recommendations:

"a. NASA with other appropriate agencies should continue the steps needed for developing a capability for acquiring data in an operational hydrologic-satellite program in or before 1975.

"b. Appropriate agencies should institute long-range comprehensive research programs to upgrade hydrologic theories and methodologies to exploit new capabilities of space technology.

"c. Prompt dissemination should be made of available space photographs and imagery to the hydrologic community."*

UPDATING FINDINGS

Several reviews that detail the advances made in applying space technology to hydrologic and water resources monitoring and management objectives are available and show that noteworthy progress has been made since 1968. Some of the most recent are those by Bock (1973), Molloy and Salomonson (1973), Freden et al. (1973), Salomonson and Greaves (1974), Salomonson (1974), and Rango et al. (1974). (See Bibliography, Appendix A.) In addition, the National Academy of Sciences (NAS) Committee on Remote Sensing Programs for Earth Resource Surveys (CORSPERS) has made available its 1974 draft conclusions on the status of remote sensing in hydrology for review by the Panel on Inland Water Resources.

It seems fair to indicate that probably the most significant spacecraft technology advance made in the 1968-74 period was the launching of the first Earth Resources Technology Satellite (ERTS-1) on July 23, 1972. This satellite provided relatively high-resolution (80 m) multispectral (0.5 to 0.6 μm, 0.6 to 0.7 μm, 0.7 to 0.8 μm, and 0.8 to 1.1 μm) observations over the earth with a nominal 18-day periodicity. Observations over areas of 186 km by 186 km were produced in photographs and computer-compatible tapes. The photographs and tapes were and are still being analyzed by approximately 300 investigators including some 40 who deal primarily with water resources. The ERTS-1 was the culmination of several years of sensor development and data analysis effort that was accomplished in NASA earth-resources aircraft program, the Mercury, Gemini, and Apollo flights, satellite research and operational meteorological programs by the National Oceanic and Atmospheric Administration (NOAA) and NASA, and other programs undertaken by personnel in universities, private industry, and federal agencies. Technological developments of considerable significance to hydrology and other water resources disciplines have been provided by recent launches of the NOAA-2 satellite with its Very High Resolution Radiometer (VHRR), the completion of a series of observations in the Skylab Earth Resources Experiment Package (EREP), and the flight on NIMBUS-5 of several improved sensors including, in particular, the Electrically Scanned Microwave Spectrometer (ESMR) and the NIMBUS-E Microwave Spectrometer (NEMS). Economic studies completed since 1968 (see, for example, Dynatrend, 1973; ECON, Inc., 1974) fully support finding number 5 of the 1967-68 Panel on Hydrology.

**Report of the Panel on Hydrology*, (1969), pp. 1-2.
**ERTS has since been renamed LANDSAT.

Monitoring and Mapping Surface Water Bodies

The 0.8 to 1.1 μm spectral band included in the Multispectral Scanner Subsystem (MSS) on ERTS-1 has been shown to be quite effective in locating and mapping surface water bodies only a few hectares in area. A program is now in progress, sponsored by the U.S. Army Corps of Engineers, which utilizes this capability for mapping water impoundments (McKim et al., 1972). Other investigators have documented this capability with relationship to wetlands monitoring, playa lakes studies, etc. (See, for example, Freden et al., 1973.)

Monitoring Snow and Ice

Early in the 1968-74 period it was shown that the regional extent of snow and ice can be repetitively observed (Barnes and Bowley, 1970). The ERTS-1 and the NOAA-2 VHRR observations have improved upon this capability (Rango et al., 1974). ERTS-1 observations have been shown to be capable of monitoring the areal extent of snow and to agree to ± 60 m with surveys and estimations of snowline elevations made from operational aircraft. These observations can serve to calibrate the more frequent 1-km NOAA-2 VHRR observations. ERTS-1 observations are quite useful for observing glaciers, including surging glaciers, and attendant features such as snowlines and medial and terminal moraines. Several detailed observations of ice cover on the Great Lakes have been obtained from ERTS-1 and from NOAA-2 VHRR. Analyses of microwave data also indicate that there is substantial promise in this spectral region for obtaining quantitative observations of snowpack parameters (Meier and Edgerton, 1971). Furthermore, results from the NIMBUS-5 ESMR as applied to the monitoring of sea ice, along with airborne microwave observations, indicate that this spectral region has very substantial utility for monitoring ice cover. Low-altitude surveys of water equivalent in snow have also been successful using an ability to measure background gamma radiation emission (Peck et al., 1971; Jones et al., 1974).

Mapping Flooded Areas

One of the most interesting capabilities of the ERTS-1 MSS is its ability to observe the extent of flooded areas as much as 1 to 2 weeks after the actual occurrence of the flood. Flood inundated areas can be mapped on scales of 1:250,000 and smaller and positive results have been reported at the 1:100,000 scale. (See reports by Rango and Salomonson, 1973, and Deutsch et. al., 1973, as well as others already cited concerning ERTS-1.)

Detecting and Surveying Turbidity and Pollution

Several intriguing observations of turbidity variation in reservoirs, coastal regions, and at the mouths of rivers have been reported. These have been related to pollution plumes, algal activity, and waste dumping. The dynamics of circulation have been inferred in various water bodies including Utah Lake, the Great Lakes, and the Chesapeake Bay, for example, and in the

interaction of rivers emptying into large water bodies. Some empirically established estimates of sediment load can be derived for near-surface layers of reservoirs and lakes (Freden et al., 1973). The 18-day repeat cycle has limited the operational applicability of these data, but some considerable potential seems indicated in improved systems with greater observational frequency.

Determining Soil Moisture

The most significant advances in the determination of soil moisture have been associated with the utilization of the microwave portion of the spectrum and the monitoring of background gamma radiation. Airborne microwave radiation measurements up to depths of 21 cm show that soil moisture and brightness temperature are linearly related over smooth, bare soil surfaces (Schmugge et al., 1974; Ulaby, 1974). Positive results using background gamma radiation for soil moisture determinations are reported by Wiesnet and Peck, 1974.

Monitoring Watershed Land Cover

The multispectral character of ERTS-1 observations has provided an ability to monitor the extent of various ground-cover types, such as the amount of bare soil, vegetation, open water, and impervious area, on scales of 1:250,000 and smaller. This capability permits the timely updating of maps on these scales so as to reflect hydrologically significant changes that may have occurred since the issuance of the map itself. In many cases a capability to provide information commensurate with larger scales such as 1:24,000 is desirable and this would come with higher instrument spatial resolution.

Locating Groundwater Supplies

The ERTS-1 MSS has provided enough spectral and spatial resolution to be quite useful in delineating geological features including, for example, unmapped lineaments and major trends in karst terrain. These features offer guidance or clues that can facilitate drilling for groundwater.

Monitoring Parameters by Use of Data Relay

Parameters such as river stage or discharge and various water quality parameters are difficult to observe via remote sensing. The ability of the ERTS-1 data collection system (DCS) to collect data on parameters such as these over large and remote regions has been conclusively demonstrated. Over 100 ERTS-1 data collection platforms (DCP) are now in operation in areas stretching from Iceland to Hawaii and from northern Canada to Central America (Cooper and Ryan, 1974). This kind of capability will be continued on polar-orbiting spacecraft such as ERTS and NIMBUS and on the Geostationary Operational Environmental Satellite (GOES) series.

Observing Hydrometeorological Parameters

The NOAA VHRR and the Applications Technology Satellites, ATS-1 and ATS-3, have shown that cloud-top temperatures and cloud features can be observed from space and are useful in forecasting severe storms. These observations are subsequently important in terms of providing input relative to dangerous or anomalous river runoff. The SMS-1 and ATS-6 spacecraft, which were launched recently, provide atmospheric "window" observations in the 10 to 12 μm spectral region and thus produce significantly improved capabilities from geostationary altitude.

Relative humidity in the lower troposphere can be estimated with errors less than 30 percent (Smith and Howell, 1971).

Precipitable water above 1000 millibars can be estimated to within 20 percent using the NIMBUS-4 Satellite Infrared Spectrometer (SIRS-B) in a cloud-free atmosphere. Early results from the NIMBUS-5 ESMR indicate that precipitable water can be estimated to within 10 percent and the liquid water content of clouds to within 25 percent (private communication from NASA).

An excellent review of methods used for rainfall estimation from satellites is given by Martin and Scherer, 1973. Over oceans, the recent results from the NIMBUS-5 ESMR indicate that the areal extent of rainfall can be delineated well and the rainfall rate directly estimated to within a factor of 2. No results demonstrating direct measurement from spacecraft of precipitation over land appear to be available and this remains a goal for the future.

UPDATING RECOMMENDATIONS

Examination of the 1967-68 recommendations listed earlier indicates that some progress of substance has been made, but considerable work remains in order to achieve the goals indicated in those recommendations.

Recommendation 3 has been partially met in that the Department of the Interior (USDI) Earth Resources Observation System (EROS) Data Center has been established in Sioux Falls, South Dakota. This Center serves as a source from which anyone can obtain image data such as from ERTS-1 and the NASA Earth Resources Aircraft Program. Delivery of these data, however, is still not rapid enough for operational application to inland water resources. The delivery process needs to be substantially improved.

With reference to Recommendation 2, some 40 hydrologic investigators have been funded in association with the ERTS-1 program, and several significant and productive programs exploring the utility of remotely sensed data for monitoring hydrologic parameters exist in federal agencies other than NASA. These include NOAA, the USDI, the U.S. Army Corps of Engineers (USCE) and the Environmental Protection Agency (EPA). However, these efforts generally have not been implemented in such a way as to improve theories and understanding of the hydrologic cycle on various time and distance scales.

Recommendation 1 involving the establishment of an operational hydrologic satellite program by 1975 will not be met. As already indicated, some progress has been made, such as with ERTS-1, but the time when an operational earth resources satellite program will be established is unclear. One important element of an operational hydrologic system, a data collection system, is being

implemented in conjunction with the NOAA-GOES program. There is substantial interest in obtaining this capability on an operational polar-orbiting satellite. This goal, however, remains to be accomplished.

DATA NEEDED FOR MANAGEMENT OF INLAND WATER RESOURCES

Most current needs for data on inland water resources can be met using existing technology. Measurements are obtained from point-sampling locations, field surveys, aerial photographs, etc. Current data collection methods, however, often are expensive, and are labor-intensive, and thus data collection programs are limited by budgetary constraints. In addition, current data collection technology does not readily facilitate synoptic studies of water resources nor does it allow an overview so that individual sampling points may be optimally selected. The use of earth satellites may alleviate some of these limitations. As direct sensing from space becomes more readily available and as spacecraft are used more extensively for data relays, the Panel anticipates that needed hydrologic data will be supplied more systematically. Space technology will be used when it provides better or cheaper data than conventional means of data collection.

Tables I and II show the more common water balance and environmental parameters for which data are needed in the management of inland water resources and for which space technology may be used to acquire the data. Measurement capabilities that are required for obtaining acceptable data on these parameters and the needed range anticipated for each type of measurement are included. Numerical values are given for geographic scale, spatial resolution, accuracy, speed of data delivery, frequency of coverage, and relative benefit. Relative benefit is based on the priority the parameter should receive according to its importance in management and is rated H (high), M (medium), or L (low). The list of parameters is far from complete but should furnish insight into possible applications of space technology. The parameters included and the range of values presented are as comprehensive and accurate as the Panel could make them within the working time available. The Panel believes that Tables I and II may be used as working documents even while they are subject to refinement and extension. Individual values encompass and are expressed in the range that is required to take care of specific intended uses. For example, the measurement of background surface temperature of natural water bodies often requires different resolution, accuracy, and possibly other variances from those required in the measurement of thermal wastewater discharge. Therefore, no one set of requirements for measurement of water surface temperature can be specified to suffice for all possible uses. For nearly all of the parameters presented in Tables I and II, exact measurement requirements depend upon the specific intended use of the data.

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It should be understood that the requirements expressed in Tables I and II are based solely on needs related to inland water resources and are not influenced by present or prospective capabilities of remote or *in situ* sensors. Thus, these requirements in effect represent recommended goals for sensor development.

From the information in Tables I and II, one may compile some general requirements for data, as follows:

Geographic scale

Range from local to global
For most uses, local to regional

Spatial resolution

1. Surface
   Range from 1 m to 10 km
   Mode from 10 m to 50 m

2. Depth
   Range from 0.3 m to 100 m

Frequency of coverage

Varies greatly
Hourly in some cases
Daily to weekly in many cases
Annually or longer in some cases

Speed of data delivery

Varies greatly
Real-time delivery optimal for certain uses
From hours to 2 to 7 days in many cases
From 1 to 2 months for many areal measurements and mapping purposes

Parameter	Data Range	Geographic Scale	Spatial Resolution (in meters)	Accuracy	Speed of Data Delivery	Periodicity Of Coverage	Relative Benefit
			ATMOSPHERIC WATER				
Liquid water	0 - 20 g/m^3	Mesoscale to global	100 - 10,000	± 10%	1 hour to 1 month	1 hour to 1 week	L, M
Crystalline water	0 - 1 g/m^3	Mesoscale to global	100 - 10,000	± 10%	1 hour to 1 month	1 hour to 1 week	L, M
Water vapor							
Vertical distribution	0 - 20 g/kg	Mesoscale to global	1,000 - 60,000	± 20-30%	1 hour to 1 week	1 - 24 hours	L, M
Precipitable water	0 - 5 g/cm^2	Mesoscale to global	1,000 - 60,000	± 20%	1 hour to 1 week	1 - 24 hours	L, M
			SURFACE WATER				
Lakes, reservoirs							
Area	0.4 hectares to 13,000 km^2	Small to Great Lakes	10 - 300	90-95%	1 - 60 days	1 - 30 days	L, M
Depth	0 - 150 m	Small to Great Lakes	0.3 - 1.0	90-95%	1 - 60 days	1 - 30 days	L, M
Temperature	0 - 45° C	Small to Great Lakes	10 - 300	90%	3 - 4 weeks	1 day	M

(continued)

TABLE I WATER BALANCE DATA REQUIRED FOR MANAGEMENT OF INLAND WATER RESOURCES

Parameter	Data Range	Geographic Scale	Spatial Resolution (in meters)	Accuracy	Speed of Data Delivery	Periodicity Of Coverage	Relative Benefit
Rivers							
Area		Small streams to major rivers	5 - 20	90-95%	1 - 60 days	1 day to 1 month	L, M
Depth	0 - 15 m	Small streams to major rivers	0.3 - 1.0	90-95%	1 - 60 days	1 day to 1 month	L, M
Temperature	0 - 45° C	Small streams to major rivers	5 - 10	90%	10 - 14 days	1 - 2 days	M
Snow							
Area	1 sq. km or more	Local to regional to hemispheric	80 - 300	95%	2 - 4 days	1 day to 1 week	M, H
Water equivalent	1 - 100 cm	Local to regional to hemispheric	80 - 300	95%	2 - 4 days	1 day to 1 week	M, H
Temperature	-30 - 0° C	Local to regional	80 - 300		1 day	1 day	H
Lake ice							
Cover	0 - 100%	Lakes, rivers, impoundments, harbors	80 - 600	± 15%	3 days to 1 month	2 - 14 days	L, H
Thickness	0 - 10 m	Lakes, rivers impoundments, harbors	0.1 - 1.0	± 0.3 m	3 days to 1 month	1 week	L, H
Type		Lakes, rivers, impoundments, harbors	80 - 600		3 days to 1 month	2 - 14 days	L, H

River ice							
Cover	0 - 100%	Rivers	5 - 10	± 15%	1 day to 1 week	1 day to 1 week	M
Thickness	0 - 2 m	Rivers	0.1 - 1.0	± 0.3 m	1 day to 1 week	1 day to 1 week	M
Type		Rivers			1 day to 1 week	1 day to 1 week	M
Glacial ice							
Area		Local to areawide, particularly in western U.S. and Alaska	20 - 100	± 15-20%	1 week to 1 month	1 - 4 times per year	M
Thickness	3 - 150 m	Local to areawide, particularly in western U.S. and Alaska	1 - 10	± 1 - 5 m	1 week to 1 month	1 - 4 times per year	M
Surface details	Classifications	Local to areawide, particularly in western U.S. and Alaska	20 - 100		1 week to 1 month	1 - 4 times per year	L, M
Estuaries							
Area	4 to 2,000 km^2	Areawide, regional and global	30 - 100	± 10-20%	1 week to 2 months	1 - 2 times per year	M
Depth	0 - 10 m	Areawide and regional	1 - 10	± 5-15%	1 week to 1 month	1 - 4 times per year	M

(continued)

TABLE I WATER BALANCE DATA REQUIRED FOR MANAGEMENT OF INLAND WATER RESOURCES

Parameter	Data Range	Geographic Scale	Spatial Resolution (in meters)	Accuracy	Speed of Data Delivery	Periodicity Of Coverage	Relative Benefit
Wetlands							
Water area	Average of small to large surfaces	Local, areawide to regional	1 - 100	± 10-20%	1 - 2 months	1 year	L, M
Vegetation types and coverage	Type classifications	Local, areawide to regional	10 - 100	± 10-20%	1 - 2 months	1 year	M, H
			SUBSURFACE WATER				
Soil moisture	0 - 100%	Local and regional	80 - 300	± 5%	2 - 60 days	1 day to 1 week to 1 month	H
Groundwater							
Depth of water table	0 - 100 m	Local and regional	1 - 10	± 0.3 m	2 - 30 days	1 week to 1 month to 1 year	H
Aquifer dimensions							
Area	0 - 0.1 m	Local and regional	50 - 100	90%	10 - 14 days	1 month to 1 year	M, H
Depth	0 - 100 m	Local and regional	0.1 - 10	0.3 m	20 - 30 days	1 week to 1 year	M, H

Porosity		Local and regional					
Transmissibility		Local and regional					
Recharge zones	0.04 to 40 km^2	Local and regional	50 - 100	100 m	10 - 30 days	1 month to 1 year	M
Area of salt-water intrusion	0.4 to 40 km^2	Local and regional	50 - 100	100 m	10 - 14 days	1 month	M
Potential locations	0.02 to 40 km^2	Local and regional	50 - 100	100 m	10 - 14 days	1 month	H
Impervious zone (subsurface)		Local and regional	10 - 50	50 m	10 - 14 days	On demand	H
			FLUXES				
Precipitation	0 - 15 cm/hr	Mesoscale to global	1,000 - 25,000	± 5-10%	Real time to 7 days	1 minute to 1 day	H
Evaporation	0 - 2 cm/day	Mesoscale to global	10 - 1,000	± 5-20%	1 - 14 days	1 hour to 1 day	L, M, H
Transpiration	0 - 2 cm/day	Mesoscale to global	10 - 1,000	± 5-20%	1 - 30 days	1 hour to 1 day	M

(continued)

TABLE I WATER BALANCE DATA REQUIRED FOR MANAGEMENT OF INLAND WATER RESOURCES

Parameter	Data Range	Geographic Scale	Spatial Resolution (in meters)	Accuracy	Speed of Data Delivery	Periodicity Of Coverage	Relative Benefit
River discharge	0.03 to 8,500 m^3/sec	Small watersheds to large basins	1 - 20	± 5-10%	1 - 30 days	1 hour to 1 week	M, H
Groundwater discharge	0 - 0.03 m^3/sec		1 - 20	± 10-30%	2 - 180 days	1 day to 1 year	M, H
Seepage		Canals, reservoirs and levees	10 - 100	± 10%	10 - 14 days	1 month	M, H
Tidal dynamics and storm surges							
Stage	0.02 - 3 m	Small estuaries to large coastal areas	100 to 1,000	± 20%	1 month or more	5 to 60 minutes	M, H
Flow	2.8 to 14,160 m^3/sec	Small estuaries to large coastal areas	100 to 1,000	± 20%	1 month or more	5 to 60 minutes	M, H

TABLE I WATER BALANCE DATA REQUIRED FOR MANAGEMENT OF INLAND WATER RESOURCES

Parameter	Data Range	Geographic Scale	Spatial Resolution (in meters)	Accuracy	Speed of Data Delivery	Periodicity Of Coverage	Relative Benefit
			WATERSHED PHYSIOGRAPHY				
Area	0.08 to 500,000 km^2	Small watersheds to major basins	10 - 500	± 5-10%	7 - 30 days	1 time or 1 year	L, M
Stream characteristics							
Length	1.6 to 1,600 km	Small streams to major rivers	10 - 100	± 5%	10 - 90 days	1 time or 1 year	L
Width	3 to 1,500 m	All size streams	1 - 20	± 5%	7 - 90 days	1 time or 1 year	L
Topography (slope)	0.02 to 9.5 m/km	Small streams to major rivers and segments thereof	1 - 10	± 5-10%	7 - 60 days	1 time or 2 years	L
Channel characteristics	Various classes	Small streams to major rivers	10 - 20	± 10-20%	10 - 90 days	1 year	M
			LAND CHARACTERISTICS				
Soil							
Type	Soil classifications	Local, areawide	10 - 30	± 10-20%	10 - 90 days	1 time	M, H
Infiltration	0.2 to 10 cm/hr	Local, areawide	10 - 30	± 10-25%	10 - 90 days	1 time or 1 - 2 years	M

(continued)

TABLE II ENVIRONMENTAL DATA REQUIRED FOR MANAGEMENT OF INLAND WATER RESOURCES

Parameter	Data Range	Geographic Scale	Spatial Resolution (in meters)	Accuracy	Speed of Data Delivery	Periodicity Of Coverage	Relative Benefit
Soil (continued)							
Areal extent and location	0.002 to 1.2 km^2	Local, areawide	10 - 30	0.004 to 0.04 km^2	10 - 90 days	1 time	M, H
Salinity	ppm	Local, areawide	10 - 100	± 15-25%	10 - 90 days	1 year	M
Vegetation							
Type	Classifications	Local and regional	10 - 100	± 5-15%	10 - 90 days	1 month to 1 year	M
Moisture stress			10 - 100	± 20%	1 - 30 days	1 day to 1 year	M
Areal extent	0.002 to 1.2 km^2	Local and regional	10 - 100	± 5-15%	10 - 90 days	1 month	M
Flood plain delineation	2 to 2,000 km^2	Local and regional	1 - 100	± 15-20%	10 - 90 days	1 - 5 years	M, H
Storm damage area	0.4 to 2,000 km^2	Local and regional	10 - 100	± 10-20%	1 - 3 days	On demand	M
Waterworks	0.4 to 2,000 km^2	Reservoirs, canals, etc.	1 - 100	± 10-15%	10 - 90 days	1 - 5 years	L
Impervious areas	10 to 1,000 km^2	Local, areawide	10 - 100	± 15-25%	10 - 180 days	1 time or 1 - 2 years	L, M
Irrigation practices	0.08 to 2 km^2	Local and regional	10 - 100	± 10-20%	10 - 90 days	1 month	M, H

			WATER QUALITY				
Temperature	0 - 45° C	Local, areawide in various waters	10 - 1,000	0.1 to 1.0° C	1 - 60 days	1 hour to 1 month	M, H
Total dissolved solids	0 - 31 kg/m^3	Local, areawide in various waters	100 - 30,000	5-15%	2 - 60 days	1 hour to 1 week	M
Salinity	0 - 22 kg/m^3	Local, areawide in various waters	200 - 1,000	5-15%	2 - 60 days	1 hour to 1 week	M
Nutrients	for NH_3 and NO_3: 0 - 2 g/m^3 for PO_4: 0 - 0.5 g/m^3	Local, areawide in various waters	100 - 500	5-15%	14 - 60 days	1 month	M, H
Heavy metals (Pb, Ca, Zn, etc.)	Varies	Local, areawide in various waters	500	40%	2 - 60 days	1 week to 3 months	M
Biological Oxygen Demand	0 - 50+ g/m^3	Local, areawide in various waters	25 - 500	5-50%	2 - 60 days	1 hour to 1 month	M, H
Chlorophyll-a	0 - 5 g/m^3	Local, areawide in various waters	100 - 1,000	100%	2 - 60 days	1 day to 1 month	H
Dissolved oxygen	0 - 12 g/m^3	Local, areawide in various waters	10 - 500	1 g/m^3	2 - 60 days	1 hour to 1 month	H

(continued)

TABLE II ENVIRONMENTAL DATA REQUIRED FOR MANAGEMENT OF INLAND WATER RESOURCES

Parameter	Data Range	Geographic Scale	Spatial Resolution (in meters)	Accuracy	Speed of Data Delivery	Periodicity Of Coverage	Relative Benefit
Oil and grease	0 - 5+ g/m^2	Local, areawide in various waters	50 - 1,000	100%	2 hours to 7 days	1 hour to 1 week	M
Pesticides	Varies	Local, areawide in various waters	500	100%	60 days	1 hour, to 1 week to 1 month	M
Suspended solids							
Surface	0 - 5 kg/m^3	Local, areawide in various waters	50 - 250	25%	14 - 60 days	1 hour to 1 week	M
Subsurface		Local, areawide in various waters			14 - 60 days	1 hour to 1 week	M
Aquatic plants							
Type	Classifications	Local, areawide in various waters	1 m or more	5	2 - 180 days	1 week	H
Density		Local, areawide in various waters	1 m or more	5	2 - 180 days	1 week	H
Depth	0 - 2.5 m	Local, areawide in various waters	1 m or more	5	2 - 180 days	1 week	H

			SHORELINE INFORMATION				
Bluff line recession or accretion	1.5 to 30 m/year	Great Lakes, large lakes	0.1 - 15	0.2 to 1.5 m	30 - 60 days	1 month to 1 year	H
Amount of materials carried in littoral drift	750 to 750,000 m^3/year	Great Lakes	10 - 100	± 25%	1 - 3 month	1 week to 1 month	M
Illegal shoreline fills	0.001 to 0.4 km^2	Great Lakes, lakes	10 - 40	± 20%	1 week to 1 month	1 month to 1 year	M
Shoreline waves, direction and intensity	0 to 100 km/hour	Great Lakes large lakes		± 20%	1 week to 2 months	1 hour on demand	M
Shoreline							
Area	0.001 to 0.25 km^2	Lakes	10 - 100	± 10%	2 months	1 time or 1 year	M
Flooded area	0.004 to 2.5 km^2	Lakes	10 - 100	± 10%	1 week to 2 months	1 hour during storm period	M
			ATMOSPHERIC ENVIRONMENTAL				
Near-surface temperature	-70 to 50°C	Local to continents	10 - 1,000	0.1 to 1.0° C	1 hour to 1 week	1 hour to 1 month	M

(continued)

TABLE II ENVIRONMENTAL DATA REQUIRED FOR MANAGEMENT OF INLAND WATER RESOURCES

Parameter	Data Range	Geographic Scale	Spatial Resolution (in meters)	Accuracy	Speed of Data Delivery	Periodicity Of Coverage	Relative Benefit
Wind	0 to 100 m/sec	Mesoscale to global	100 - 5,000	± 1 - 3 m/sec	0.5 to 6 hours	5 minutes to 1 day	M, H
Forecasts							
Short-term (severe weather)	1 - 72 hours	Mesoscale	100 - 1,000	90% confidence	1 hour	5 minutes to 1 hour	H
Climatic	1 week to 10 years	Regional, global		Greater than 70% confidence	1 month	1 month to 1 year	M, H
			SURFACE RADIATION				
Albedo (0.2 - 4.0 μm)	0 - 100%	1 - 1,000 km^2	100 - 10,000	1-20%	1 - 7 days	1 - 7 days	
Incoming radiation							
Far infrared (4.0 - 30.0 μm)			50 - 500		10 - 14 days	1 day	L
Solar (0.2 - 4.0 μm)	8.1 $J/cm^2/min$		50 - 500			1 day	L
Outgoing radiation			50 - 500		10 - 14 days	1 day	L

TABLE II ENVIRONMENTAL DATA REQUIRED FOR MANAGEMENT OF INLAND WATER RESOURCES

POTENTIAL BENEFITS
FROM BETTER MANAGEMENT OF INLAND WATER RESOURCES

ANALYSIS OF CONCEPTS

The Panel has concluded that estimation of nationwide tangible benefits for operational applications of space technology in the field of inland water resources is wholly impracticable in view of the limited time and the limited information available to the Panel during the study. The Panel recognizes that incremental costs and benefits should be used in evaluating space applications. Comprehensive estimates of benefits and costs for the several demonstration projects suggested (see "Proposed Demonstration Projects") are also considered to be impracticable for the same reasons. Partial estimates of costs and benefits have been made to the extent possible for the projects which seem to have greatest potential for applications of space technology.

Benefits from the use of space systems to acquire data will result from: (1) reductions in the cost of data acquisition, (2) improvements in the data acquired, and (3) reductions in management costs. Benefit estimates are made on a "with space-acquired data and without" type of analysis. In some cases, intangible secondary benefits are realized. Potential benefits from acquisition of new types of information which can be obtained only with the use of space systems appear in some cases to be very substantial. In cases where additional costs are required to adapt to new uses or to modified techniques for the handling of data by user agencies, the potential benefits cited are the net of these costs and benefits.

The Panel is aware that there is a need to examine the relative benefits and costs between use of satellites and use of aircraft. While recognizing the general advantages and disadvantages of each method, the Panel has not attempted to decide which technique should be used. The use of satellites is usually advantageous in applications where data are required over large areas or where repetitive acquisition of data is needed.

On the demonstration projects, the Panel has attempted to work closely with the Panel on Costs and Benefits. Identification of benefits is complicated by the fact that precise costs are not available on present data-gathering activities and by the fact that remote sensing frequently provides useful information which previously had not been acquired because of prohibitive costs or difficulties of acquisition.

The Panel has not attempted to evaluate existing economic analyses of space applications. Its analyses of the proposed demonstration projects are preliminary and the Panel considers that careful economic analysis should be made in

depth and at an early date for each of the demonstration projects. These analyses should project savings which can be realized from extending the applications throughout the United States.

Another complicating factor in attempting to apply economic analysis is the need to relate an information requirement to an end product rather than to a rigid definition of the data elements. When a user describes information requirements, there is a tendency to demand the same data elements that are currently used. Improvements then relate to increased accuracy or resolution and/or decreased costs in acquiring these data elements. Since the use of these data frequently has developed because of the structure and limitations of present acquisition methods, remote sensing techniques frequently are not competitive. The accuracy required for point sampling may be higher than that necessary for synoptic sampling. When information about an area is developed with use of conventional sampling techniques, the accuracy and resolution must be high because of the inherent degradation which results from interpolation between the sample points. Since remote sensing provides synoptic coverage, no interpolation is required and therefore the accuracy and resolution required for sampling may be less. It may be that data sensed from space should be of an entirely different form or character, and that such alternative approaches should be examined.

DEVELOPMENTS NECESSARY FOR ACHIEVEMENT OF BENEFITS

The potential benefits of using space technology in many facets of managing inland water resources have been recognized and affirmed by the Panel. To realize these potential benefits certain deficiencies must be overcome. These deficiencies can be categorized as follows: (1) inadequate sensors, (2) inadequate data processing programs, (3) need for improved mathematical models, and (4) the absence of fully effective institutional arrangements. Throughout the ensuing discussion the transport of sensors into space, space packaging systems, and other aspects of space transport are not considered to be constraints on any potential program.

Sensors

It is readily apparent that the primitive state of present sensor technology is a primary constraint on the application of space technology to the management of inland water resources. Many of the parameters included in Tables I and II cannot now be monitored from space, and many cannot be sensed automatically from ground stations. The Panel therefore places an extremely high priority on sensor development and believes that a lack of adequate sensors probably will impede other developments for some time to come.

The use of aircraft -- both high-flying, such as the U-2 and B-57, and low level -- has provided remotely sensed water data that have relevance and reliability. Multi-lens cameras with high-resolution broad band films are able to *detect* a combination of water quality factors although more work needs to be done to *quantify* those parameters.

Data collection platforms (DCP) and low-level aircraft have shown great capability for sensing many of the wanted parameters. These include measurements

of the water content of ice and snow, crop-canopy emittance and other parameters related to subsurface water, the dynamics of surface water flux, and many of the water quality and environmental constituents. Present sampling, monitoring, and laboratory techniques are available and, in most cases, standardized to obtain these measurements. In order to utilize space technology, accurate automated stations which can operate service free over long periods of time need to be developed. Their data output can be relayed by satellite or aircraft without the need for human intervention and thus coverage can be provided for many locations, some of which may be remote and difficult to service.

There are two key areas in which substantial breakthroughs are needed to develop ground sensors compatible with the capabilities of satellite-borne data collection systems. First, present equipment is not rugged enough to survive the severities of weather, vandalism, and environmental contamination for periods of 6 months to 1 year. The improvement required is largely an engineering problem and should be attainable. Secondly, present sensors either cannot duplicate the laboratory analysis required for detection of many parameters or they require in-place equipment which impedes navigation or other uses of inland waters.

For some of the basic water resources parameters, direct measurement from space may be impossible and it is doubtful that complete independence from ground stations will ever be desirable. Many parameters can be sensed directly, however, and others can be inferred. The Panel believes that the development of airborne and spaceborne sensors shows great promise and should be pursued vigorously. Areal coverage offered by direct space measurement is quite valuable and, where technically feasible, probably will prove more cost effective than ground stations.

Finally, a plea is made for use of imagination in sensor development. Tables I and II are based on well-defined descriptions which have been developed and used by engineers and scientists for many years, but they are not sacred. It is essential that sensor technology be sensitive to user needs, but it is also important that new capabilities inherent in space-based systems not be forced uselessly into old patterns. Since developers of sensors and water resources experts usually are not expert in each other's field, a continuing dialogue between the two is required. The result can be beneficial to both and may produce new approaches in the management of inland water resources.

Data-Handling Systems

The Panel believes that data handling is a major unsolved problem in the practical use of space data by the water resources community. The satellite with its subsystems is an effective means of data collection whereas the means for data reduction, processing, dissemination, and feedback from users are neither adequate nor effective.

Data-handling systems have traditionally fallen short of the expectations of users concerned with inland water resources. Operational systems now exist within EPA, NOAA, U.S. Bureau of Reclamation (USBR), U.S. Geological Survey (USGS), and several states, but none is entirely suitable for space-relayed data. The USDI facility at Sioux Falls was created specifically for this purpose and, if developed properly, may become the best vehicle for dissemination of space data.

User feedback, from federal, state, and local agencies and from the private sector, is absolutely essential both in the design and operation of an acceptable information system. The lack of user feedback has contributed greatly to the shortcomings of existing systems. The user must have *effective* access to the system, that is, he must be able to get the data he wants in a timely and efficient manner.

Timeliness is an important element in data on inland water resources. Many uses are concerned with hazardous events such as flooding or ice jams. Emphasis in these cases is on rapid perception of what is happening so that warnings can be issued and corrective measures taken. This requirement is akin to a real-time response. For certain pollution problems, such instant reporting is not needed but a response time of a few hours will be beneficial. Frequency and area of coverage, as well as resolution, relate directly to the data-processing system. In many cases, data that are not efficiently handled bewilder the user and discourage practical application. Many problems require frequent coverage, and some users will be served best by continuous monitoring from ground stations or from a geosynchronous satellite. Also there should be added a capability for selectivity, either at the time of collection (through pointable sensors) or during the processing cycle.

Many levels of sophistication are found among potential users. Some want raw data or data which have been only radiometrically or geometrically corrected. Others desire fully interpreted or analyzed data. Data systems which evolve for use in the management of inland water resources should reflect these varying user needs. Graphic displays, photographic imagery, and digital-data forms all are of interest.

Mathematical Models

Much of the work in the field of inland water resources has been descriptive in nature, and space technology is viewed by many as an extension of the descriptive process. However, a mature program of space technology must be adaptable to predictive as well as to descriptive techniques. In order for this to be done, the data obtained from space technology must be applicable to mathematical modeling of systems of inland water resources.

The usage for modeling can take several forms. At the first level, the capability for synoptic coverage of large geographic areas at frequent intervals provides input to models much like the present ones, but these must be more dependable, and more accurate to be widely accepted and used by professionals in the field of inland water resources. The use of real-time modeling for water management is currently arousing wide interest and data from the space program can help to make it a reality.

Space systems can provide not only data similar to those which can currently be collected but also those that are not currently available, for example, reflectivity measurements at various wavelengths that can be categorized by varying intensities. This can and should lead to totally new concepts in water resources models. As the parameters obtained from space systems are confirmed in relation to the behavior of water resource systems, considerable reliance will be placed on the new parameters. It is believed that such an approach is warranted for numerous models, including but not limited to the following:

Estuaries and tidal rivers
River basins, including streamflow and groundwater and their interrelationships
Lakes and reservoirs
The Great Lakes
Urban runoff
Snow depletion and snowmelt.

Institutional Arrangements

Attainment of benefits through the use of space systems is not only a matter of hardware and data processing. It is also essential to have the proper data delivered at the appropriate time to meet the demands and requirements of specific users. In water resources this is particularly important since the data in many cases may be "perishable" for some users but need to be classified and stored for others. In order to create acceptable links between data acquisition and intermediate and ultimate users, careful consideration must be given to institutional arrangements.

The Panel concludes that, to develop operational programs utilizing space systems for water resources management, some federal agency or agencies must take the lead, since it is considered unlikely that the states will be able to do so. The Panel also stresses the importance of integrating inputs and requirements, not only from federal and state agencies, but also from local agencies, universities, private individuals, and corporations. The Panel notes that acceptable institutional arrangements must take into account the legal responsibilities of federal agencies for certain functions. The Panel believes that legal, moral, and ethical responsibilities must be continuously exercised and publicly reviewed. Views of the Panel concerning institutional arrangements have been furnished to the Panel on Institutional Arrangements.

POSSIBLE APPLICATIONS OF SPACE TECHNOLOGY TO MANAGEMENT OF INLAND WATER RESOURCES

INVENTORY

Management of inland water resources begins with inventories or assessments of the resources. There is a continuing need for inventories of the quantity and quality of the water resources of the U.S., of all the states, of regions of interest to other levels of government, and of specific hydrologic basins. Hydrologic, water quality, and water use data, all time-related and fixed, are collected throughout the nation by many agencies and at many levels of detail. Data are needed, for example, in the understanding of river mechanics and shore processes. Requirements for inventories also stem from legal considerations embodied in laws, treaties, compacts, water rights, and lawsuits. Most of the basic parameters that are needed for inventory are included in Tables I and II.

The degree of detail needed varies over a wide range. Where general reconnaissance studies are being made, general characteristics may be satisfactory. On the other hand, if a detailed program in water quality monitoring is being carried out, it will be necessary for a remote sensing system to have the accuracy of detail and measurement provided by *in situ* sampling and laboratory analysis. Too much detail where not needed can be just as detrimental as insufficient accuracy for more precise programs.

The Water Resources Planning Act of 1965 stipulates that a national inventory be made biannually. To date only one inventory has been made and it was less than satisfactory because basic data were lacking on both the supply and the use of water and because, at that time, there was an almost complete lack of data on the quality of the nation's water. Currently another national inventory is underway at an appropriated cost of $605 million. The total cost will probably be double this amount. Other inventories for specific purposes are frequently being undertaken on a national scale. For example, the recent National Estuaries, Shoreline and Streambank Erosion, Native Ocean Survey, National Lakes and Wetlands inventories are a few that come to mind. Space technology might have had significant and favorable impact on most of these studies if the necessary R&D on space systems had been completed and if the studies had been designed to use space technology. Since these studies, except for the lakes and possibly the ocean surveys, are complete or are too advanced to benefit from space technology, the Panel has not attempted the sterile exercise of estimating benefits for these activities. It can be expected, however, that future inventories will be required and that appropriate space systems should be available and should be used.

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In the past 10 years the U.S. has expended in excess of $150 million on framework studies to inventory in more detail the conditions, problems, and needs of its inland waters. State agencies have spent about $30 million for similar purposes. The expenditure for collection and evaluation of basic data on inland water resources in one state (California) is approximately $26 million annually. This expenditure is broken down by sources of funds as follows: federal, $5.3 million; state, $5 million; local, $14 million; private sector, $1.7 million. Further details on the expenditures for water resources data in California are shown in Table III.

	Expenditure in Millions of Dollars		
Type of Data	Collection	Evaluation	Total
Surface water quantity	4.12	0.83	4.95
Groundwater measure	1.57	0.31	1.88
Flood forecasting	3.12	0.63	3.75
Climate and snow*	1.21	0.24	1.45
Surface water quality	5.38**	1.07	6.45
Groundwater quality	3.54**	0.71	4.25
Sediment	1.09	0.21	1.30
Land use survey	1.67	0.33	2.00
TOTAL	21.70	4.33	26.03

*Includes precipitation, temperature, and snow surveys.
**Includes laboratory analysis.

TABLE III CURRENT EXPENDITURES FOR WATER RESOURCES DATA IN CALIFORNIA

BASIC RESEARCH ON HYDROLOGIC BALANCE

The hydrologist must forecast basin water balance, but determination of the complete hydrologic balance for a river basin is currently limited by the state of the art. Understanding of the exchange between subsurface and atmospheric regions can be enhanced by use of satellite-acquired data. Some features not now available may be determined with such data.

PLANNING

Planning for management of inland water resources must consider the full cycle of water occurrence, water use, and waste water disposal. The objectives are to meet, at minimum cost, public needs for the beneficial use of water and to protect life and property from the damaging effects of water. Water quality planning should not be separated from water quantity planning since quality affects various beneficial uses. Management planning must provide for collecting the basic data needed (see Tables I and II) and preparing for decision and implementation. A successful management program must insure adequate water supply, improve its quality, and develop facilities for the sanitary disposal of waste.

Most urban and industrial uses require long-range planning, particularly where surface water developments may be necessary (for example, agricultural irrigation uses over 85 percent of the water consumed in the southwestern U.S.). To plan these developments, data are needed on the character, occurrence, and quality of potential surface water supplies. The planning process may be of a reconnaissance nature, exploring the feasibility of a basin-wide scope, or of a more specific project nature. This should be recognized and considered in applying space systems to provide the basic data, since the capabilities required for area, resolution, and accuracy vary with the level of planning.

Groundwater is an important source of supply in many areas. Planning for management of this resource requires that its limits, character, and potential for replenishment be known. Many coastal groundwater basins are being intruded with salt water. Other groundwater basins are now being overdrawn, so that their future use is limited. Locating and assessing additional groundwater supplies are necessary, and space systems may be able to assist in making a general inventory.

Protection of life and property from floods and wave damage entails the use of both structural and nonstructural methods. Flood runoff is affected by meteorological and hydrological phenomena and watershed characteristics. Potential damage is a function of many factors including the extent and type of development in the flood plain. Long-term hydrological records are needed for effective planning but real-time data are not necessary at this stage of management. Planning of shoreline structures such as groins, breakwaters, and jetties is a part of the protection function. Adequate mapping measurements of wave and tidal spectra are needed.

OPERATION

Operation and control of water resource systems require data that space systems can provide, particularly through real-time observations. Floods and other storm hazards need rapid assessment for dissemination of warnings. Real-time information on rate of precipitation, snow cover, including water content and rate of melt, and soil moisture are essential to operate flood-control systems and to provide hazard warnings.

Reservoir operations require forecasts of storms and seasonal runoff to control water storage space (for flood control), for generation of hydroelectric power, and for conservation of water supplies. Long-range (3 month), medium-range (1 week), and short-range (2 day) forecasts of runoff would all contribute to better reservoir operation. Meteorological and hydrological data are essential since both disciplines must be applied interactively for effective operation of reservoirs.

Real-time data are also needed in water pollution monitoring and control. Knowledge of the water quality parameters shown in Tables I and II is essential to implement many programs related to water quality and pollution control. For broad-scale surveillance, lower resolution and accuracy may be adequate. For precise monitoring, it is necessary that measurements be comparable to those now obtained from laboratory analysis.

SPECIFIC EXAMPLES BY CATEGORIES

Appendix B lists a number of feasible uses of space systems which the Panel has not been able to examine in the limited time available. Included are specific examples of activities in which remote-sensing techniques can be applied to problems related to inland water resources. These activities are grouped into categories that cover large areas of concern in the management of these resources. The Panel believes that with further thought the list can be greatly expanded.

PROPOSED DEMONSTRATION PROJECTS

The Panel on Inland Water Resources has stated its objectives in the introduction of this report. In discussing these objectives and how they may best be achieved, it was concluded that certain basic parameters should be given priority for sensing by space systems. These parameters are essential to adequate performance of certain types of activities which are demonstrated in a series of specific projects or programs set forth and given high priority by the Panel. Selection is based on filling gaps in current knowledge and on opportunities for demonstrating economic advantage.

The Panel attempted to establish priorities for 16 demonstration projects. It soon became evident that adequate information was not available at the Summer Study for an objective and rational priority ranking of these projects. In the discussion it was brought out that many of these projects have economic benefits which are difficult to define since they are scale sensitive. Questions of interagency responsibilities also arise, and it is difficult in some cases to establish the state of the art in existing technology. For these reasons the projects, whose tasks are as follows, are not ranked in this report:

Improved forecasting of runoff from mountain snowpacks

Mapping areal extent and depth of groundwater

Mapping areal extent and location of seepage from reservoirs, canals, and levees

Surveillance of river channel and beach migration

Delineation and assessment of shoreline processes

Mapping of water-related land areas

Relating urban development to changes in runoff

Nationwide inventory of thermal conditions

Detection and measurement of suspended solids

Detection and measurement of salinity in water and soil

Assessment of lake eutrophication

Assessment of tidal regimes in estuaries

Surveillance of ice conditions

Assessment of flood damage

Survey of rooted and attached aquatic vegetation

Detection and early warning of pollution violations.

Some of these projects are described in considerably more detail than others. Whenever possible, costs and economic benefits are estimated. The projects are derived from an examination of data problems considered to be of high priority by federal, state, and private users. It appears that space systems would be highly beneficial in accomplishing the tasks but demonstrations in an operational mode are needed. Research and development are required as a part of certain projects, since the needed technology is not available. When the projects are developed, consideration should be given to trade-offs among the detail desired by the user, the cost and the technology attainable. Data from remote sensing with less detail than normally preferred may be acceptable if other benefits to the user outweigh the loss in detail.

The Panel believes that space systems may have heretofore unexploited capabilities which could achieve large economies in the management of inland water resources if the whole subject of space applications could be thoroughly investigated by technological and user teams working together.

IMPROVED FORECASTING OF RUNOFF FROM MOUNTAIN SNOWPACKS

A need exists to use space-acquired and space-related data to improve the monitoring of winter snowpack accumulation and melt rate. Operation of downstream reservoirs for hydroelectric power production, irrigation, flood control, and water supply can be optimized with a better knowledge of the total amount and the rate of water availability on a near real-time basis. Present space systems such as ERTS and NIMBUS should be utilized to full advantage and new spacecraft sensors, such as active and passive microwave systems and thermal scanner systems, should be developed to provide wide-area, repetitive, all-weather observation and measurement of ice and snow.

All systems capabilities should be demonstrated and tested in a pilot study conducted on a major western river system, for example, the Rio Grande, San Juan, Gunnison, Upper Colorado, or Green River. The pilot study should be a long-term one, lasting 5 to 10 years to permit establishing the relationship between measured parameters and actual runoff conditions. The demonstration should lead to establishment of techniques for rapid (near real-time) data retrieval, interpretation, processing, and analysis in order to provide information of immediate utility to managers of inland water systems.

Operation of water reservoirs in the western U.S. is based largely on estimates of the amount of water contained in the mountain snowpacks. Storage

space for the anticipated runoff must be adequate and should include an allowance for error to prevent floods. If improved methods for monitoring snowpack accumulation and melt rate throughout the season can be coupled with knowledge of soil conditions, short-range weather forecasts, and climatic conditions during the melt cycle, a maximum amount of power production can be realized, irrigation interests will be better served by more available water, and all but the most severe flood situations will be eliminated.

Hydroelectric power is a clean form of energy, already extensively developed in the western U.S. Power is produced most efficiently when waters are at high levels in the reservoirs. If present runoff prediction methods are used, a trade-off must be made between power production (energy storage) and flood control. Estimates of expected runoff are based at present on a limited number of ground observations in remote areas. These estimates involve much uncertainty, which makes it impossible to use the water with maximum efficiency. There is clearly a need to reduce this uncertainty and to apply more reliable information to the management of hydroelectric power systems. Two additional parameters of value in runoff forecasting, snow evaporation losses and ground storage, should be measured. Under certain conditions these are believed to represent a significant amount of the total available water.

The U.S. Bureau of Reclamation and the U.S. Army Corps of Engineers presently produce hydroelectric power with an annual value estimated at $164 million. These two federal agencies produce about 25 percent of the total hydroelectric power in the U.S. With improved runoff forecasts that would permit reservoir operation at maximum head, a 15 percent increase in revenue could be realized, an annual benefit of nearly $25 million. Improved techniques should be applied to state and privately owned utilities, which also use the present uncertain runoff forecasts, so that potential benefits can be further and significantly increased.

A project in which cloud-seeding techniques are used to augment the snowpack (presently being tested by the USBR in the San Juan Mountains of Colorado) can be better managed with reliable runoff predictions. The data can be used to avoid cloud seeding in areas where snow accumulations are above normal usable amounts or otherwise excessive. Operational use of weather modification is conceivable for the Upper Colorado River system in the near future.

MAPPING AREAL EXTENT AND DEPTH OF GROUNDWATER

A definite need exists for the development of sensor capability to measure from aircraft or space platforms the depth below the earth's surface of groundwater. Such a sensor should have a spatial resolution of approximately 4000 m^2 and a vertical resolution equal to approximately 15 percent of the total ground penetration. These sensors should be able to measure directly the depth of groundwater regardless of surface conditions. The Panel recognizes that development of the required sensors may be extremely difficult, but considers that the importance of finding and managing groundwater justifies the required research and development.

In the initial investigation of an area to be developed as an irrigation project, depth to water barrier, groundwater depth, and soil permeability are some of the parameters that must be determined to evaluate the drainage characteristics of the area. Irrigated lands having inadequate natural and/or manmade

groundwater drainage can become unusable for agriculture. The development of drainage problems on irrigated lands has been noted throughout the world.

Irrigation of agricultural lands alters the groundwater regimen and usually produces a rising water table. If groundwater invades the root zone, crop growth is adversely affected by the presence of excessive moisture. In arid climates, soluble salts that are detrimental to crop growth tend to concentrate at the soil surface and in the root zone. The net results are waterlogged and salinized soils which pose serious threats to continuance of productive agriculture within these areas. As a result, drainage studies have been and are being conducted in areas affected by rising water tables. These studies are quite costly and entail a considerable expenditure of time.

The only practical solution to a subsurface drainage problem, if land is to be retained for agricultural use, is the removal of excessive groundwater and salinity by deep drains or wells. Effective and permanent drainage facilities require extensive and time-consuming field investigations, precise design requirements, and careful construction. Drainage investigations are presently performed by drilling an extensive network of holes in the specific area to be investigated to measure water depths and to sample soils. Because the areas involved are large, numbers of personnel are limited and, in some cases, access is limited during the growing season, much of the groundwater data for drainage investigations must be extrapolated.

The potential savings in both time and money which would result from the successful use of remote-sensing techniques to detect the location, nature, and extent of drainage-problem areas, has led the USBR, through the USDI EROS Program, to initiate studies aimed at the utilization of data required from ERTS and from aircraft. A recent USBR and EROS study (under contract with South Dakota State University) in which aircraft data were used to relate crop-canopy emittance and reflectance to variations in water depth has found significant correlation. Initial phases of this study show that multi-feature analysis of thermal imagery has good potential for detection of near-surface groundwater. While the study thus far is showing success, it is limited to regions of irrigated agriculture and the results are affected by the wide variation of environmental conditions on the surface such as weather conditions, types of crop cover, and individual farming practices.

The development of sensor technology to detect water table depths from 1 meter down to 5 meters would result in far-reaching worldwide consequences. It would, to say the least, revolutionize groundwater hydrology. It has been estimated by the USBR that if techniques can be developed to detect groundwater at depths of 2.5 meters to 3 meters, a savings of 40 to 50 percent may be realized in investigations of irrigation drainage alone. This represents a savings of $3000 per square kilometer, based on an average cost of $5000 to $6000 per square kilometer investigated. This amounts to an annual benefit of $180,000 from irrigation drainage investigation alone since in 1973 the USBR investigated 60 square kilometers for irrigation drainage.

In addition to sensing shallow groundwater that is important to the planning and management of irrigated agriculture, there is a need for sensing of groundwater aquifers at depths of the order of 100 meters. Much of the nation's water supply is produced from groundwater at these depths. The areal extent of aquifers as well as their depths and characteristics are important factors in their study and utilization. The understanding of groundwater basins is complicated by certain phenomema, including the frequent occurrence of several

aquifers at varying depths, separated by aquicludes or other geologic formations of low permeability. Subsurface drilling, logging, and testing are among the procedures normally used to locate and measure aquifers in such cases.

Remote sensing that could penetrate to a depth of approximately 100 meters and give an indication of areal extent would be useful in locating potential groundwater basins, particularly in desert areas where little subsurface information is available. The development of sensor technology to detect water-table depths from 1 meter to 100 meters would have far-reaching worldwide consequences.

MAPPING AREAL EXTENT AND LOCATION OF SEEPAGE FROM RESERVOIRS, CANALS, AND LEVEES

A high resolution space-borne sensor is needed to provide annual observation of effects of seepage from water reservoirs, canals, and levees at selected sites throughout the U.S. and in foreign countries. The sensors should provide multispectral imagery in the visible, near-infrared (IR), and thermal IR portions of the electromagnetic spectrum with a spatial resolution of 10 meters and covering an area of approximately 130 square kilometers per scene.

Facilities for water storage, water distribution, and flood protection require surveillance of their operation and surrounding environment in order to detect seepage, which may be observed from surface or near-surface groundwater levels. Seepage results in loss of valuable water, and if continued, may weaken or erode dams and embankments to the extent that failure occurs.

Because in most cases the features related to seepage losses are too small to be detectable within the spatial resolution of the ERTS imaging systems, it is recommended that a satellite high resolution imaging system be provided. An alternative approach is to use aircraft remote sensing for this purpose. The cost of doing this on a wide scale is prohibitive; data has been acquired by this method only in special cases where the need was urgent.

The satellite high resolution imaging system described herein will have a wide variety of valuable uses in every area of earth resources as well as in the field of inland water resources. Initially, the system would be experimental. The technology is available to provide a large quantity of data. User needs for data are not yet fully understood and until they are matched to the available technology, care must be exercised to supply the amounts and kinds of data that the user community is ready to assimilate.

The current cost of using aircraft systems to acquire pictorial coverage of water resource facilities can be conservatively estimated at well over $1 million per year for one-time coverage. It may be possible to "piggy back" water resource observation systems with other spacecraft on space shuttle missions and thus share the launch costs and make the water resource observation concept cost-effective. It is possible, however, that the wide range of benefits envisioned from ultimate use of the data for water resource management may justify a separate satellite placed in orbit.

SURVEILLANCE OF RIVER CHANNEL AND BEACH MIGRATION

Over periods of time the flow of water in a river channel or in littoral currents along a coastal area tends to erode banks and beaches, move the loosened

material to new locations, and redeposit it. This process causes the river channel to migrate, with continuously changing bend locations and radii, stage-discharge characteristics, and buildup and dissipation of shoal areas. If the stream is navigable, it is desirable to stabilize the channel to prevent costly dredging operations, possible vessel groundings, and accidents. Sometimes river channels are straightened as a flood reduction measure, to change the flow characteristics, and as an aid to navigation. It is then necessary that the straightened channel be maintained. Early detection of changes in channels which may endanger preventative works or require remedial work will reduce preventative and maintenance costs.

In response to a requirement established in Section 120 of the Rivers and Harbors Act of 1968, the U.S. Army Corps of Engineers has presented estimates of the extent of streambank erosion in the U.S. In August 1969, the Corps estimated that 1 million kilometers of banks were experiencing some degree of damage. This is about 8 percent of the total 13 million kilometers of streambanks in the U.S. Damages estimated at $90 million annually were occurring on 275,000 kilometers of banks and were sufficiently serious to require remedial measures. Approximately one-half of the damage was due to sedimentation, one-third was due to land losses, and the remainder was due to miscellaneous effects. Now, 7400 kilometers of bank protective works have been completed at a cost of $1.8 million and another 3700 kilometers are under construction.

In coastal areas, wave action and littoral currents cause beach erosion which results in loss of high-value beachfront property and in many cases requires the establishment of costly beach nourishment programs. If littoral drift is occurring near a coastal inlet, material is frequently deposited at the inlet, which may eventually be closed unless costly maintenance programs such as dredging are performed.

In order to gain an understanding of the magnitude of the erosion problem, it is helpful to examine some estimates of its extent. In the *National Shoreline Study* (U.S. House of Representatives Document 93-121), it is noted that of the 156,000 kilometers of U.S. shoreline, 38,000 kilometers are experiencing critical erosion problems. It is estimated that it would cost $1.8 billion in 1974 dollars to halt this erosion.

It is necessary to detect incipient changes in channel and beach configuration and location so that measures to control erosion can be initiated where justified. Data are required to describe lateral movements of channels, widening or narrowing of channels, formation or destruction of channel bars, narrowing of inlets, and erosion of beaches. The topography of the channel or beach area must be mapped to water depths up to 30 meters. The water is usually sediment-laden. Resolution is required that permits mapping at a scale of 1:24,000 with accuracy of 1 to 2 meters in the horizontal dimension, and 0.1 meter in the vertical. The areal extent of such measurements ranges from 10 square kilometers upward. Since channel migration is relatively slow, measurement and comparison to detect changes need to be repeated annually and following major floods or storms. The data should be made available to the user within 10 days of the measurements to allow prompt initiation of corrective actions. Coverage should include all coastal areas, the Great Lakes, and all major rivers and waterways of the U.S.

In order to demonstrate the utility of such a capability, it is proposed that a pilot project be established for monitoring the rate of migration and

shoaling of a portion of a major river, such as a segment of the Arkansas-White-Red River system, the Missouri River, or the Willamette River, and of a major inlet which has been experiencing serious shoaling problems, such as the southwest pass of the Mississippi River or the Masonboro Inlet, South Carolina. Methods available for such monitoring involve land, aerial, and hydrographic surveying. The benefits of obtaining the data rapidly and more frequently than is presently possible include savings in the determination of dredging requirements, in prompt planning of programs for bank and channel stabilization, and in their maintenance in advance of failure, and allow evaluation of the effectiveness of engineering works. These benefits are highly site-specific and average values are meaningless. The test program can be initiated in areas of very high return and proceed to areas with fewer benefits.

The potential for savings may be estimated by examining the latest costs of related programs of the U.S. Army Corps of Engineers. Approximately $4 million was expended in fiscal year 1973 for beach erosion control. Costs for stream channel stabilization are included in the general category of "Channel and Harbor Operation and Maintenance," which required $170 million during the same period. It is estimated that approximately $75 million was used for bank protection and channelization, while the remainder was required for dredging operations.

DELINEATION AND ASSESSMENT OF SHORELINE PROCESSES

Many facets of shoreline processes along the Great Lakes are poorly understood. Shoreline processes have a significant bearing on a number of serious problems in the Great Lakes region, including shoreline erosion and flooding, design of structures and shoreline protective works, power plant siting and thermal discharge restrictions, dredging to maintain navigation, associated dredge-spoil disposal, and sediment and other pollutant inputs from tributaries. A further complication is introduced by the fluctuation of levels of the Great Lakes. Additional problems during low-water periods include reductions in navigation capacity and interference with recreational boating facilities.

Research programs employing remote sensing techniques offer a potential avenue for advancing the present understanding of shoreline processes in the Great Lakes. This advancement will assist various federal and state agencies in carrying out regulatory and management programs. Data desired include wind directions, durations, and forces; wave heights, periods, directions, and patterns; surface and subsurface current patterns; littoral-drift transport quantities, patterns, and dynamics; near-shore bathymetry and dynamics of offshore sand bars; impact of navigation structures on littoral drift and shoreline erosion; upwelling phenomena; and dispersal of sediment and other tributary inputs.

It is recommended that a research project be undertaken to assess how space systems can be applied to assist in the further understanding of shoreline erosion processes along the Great Lakes. This effort can benefit from work ongoing in the NOAA Marine Resources and Ocean Survey Program. Additionally, concurrent efforts can be devoted to the development of models to explore and to utilize fully the data collected. This research program can be correlated with present meteorological data collection programs, with the activities of

the NOAA Great Lakes Center, with the Littoral Environment Observation (LEO) program of the USCE Coastal Engineering Research Center, and with state coastal-zone management programs. Collection by conventional means of research data of this type is very expensive and difficult. Effective application of remote sensing programs offers an attractive and cost-effective alternative.

MAPPING OF WATER-RELATED LAND AREAS

Management of inland water resources is concerned with and influenced by the location, extent, type, use, and management of various land areas which exhibit varying degrees of interrelationship with water quantity and quality. A partial list includes wetlands, both coastal and inland, of various types; lakeshores, shorelines, and stream corridors which through their use, development, and management impact the use and quality of adjacent waters; developed urban areas which often substantially modify natural hydrologic conditions; lands used for waste disposal as in an increasing number of waste-water treatment systems; irrigated agricultural areas; and lands associated with water-based recreation, commerce and industry, and various other water projects.

Accurate data on general and specific land uses and characteristics are vital ingredients in the planning and, to a lesser degree, in the operations related to water resources. Such data are also necessary in waterfowl and other wildlife management programs, in wetlands and other environmental preservation and management programs, and in numerous related activities. In general, the data required include location, extent, classification by use or character, and possibly other attributes. The level of detail needed varies according to the user and the intended use. In some cases, 80 meter resolution is satisfactory; other cases may need 10 meter resolution.

A land-use mapping program specifically for water resources management is probably not warranted. Instead the data needed can be acquired by a space system designed to serve a variety of uses, all part of a community concerned with land use. It is recommended that priority be given to the development of a system with the capability to supply land use data to users at federal, state, and local levels. Specific steps required are improvements in ground resolution to perhaps 20 meters; increased sensitivity and accuracy in sensors to delineate land use classes so that a minimum of satellite data will be acquired thus minimizing costs; and a user-servicing organizational framework which parallels the present role of NOAA in providing satellite meteorological data.

A general land-use mapping program will significantly assist water-resource programs. At present, data on inland water resources are collected by expensive and time-consuming techniques including field surveys, aerial-photographic interpretation, and questionnaires. Securing up-to-date data is a major problem. Some useful information cannot be collected in the desired detail because the cost of using current methods would be too high. Water resources and other land planning and management programs have many data needs in common, and this can contribute to a cost-effective approach. It should be recognized, however, that some water managers may need highly specialized land use data which will require individual collection and analysis.

RELATING URBAN DEVELOPMENT TO CHANGES IN RUNOFF

The existing data-base on quantity and quality of urban runoff is very small, and no comprehensive attempt has been made to relate urban growth to changes in runoff. A pilot project is needed to establish how urbanization and associated changes in physiography are related to modifications of runoff and runoff quality.

Typically, the most harmful effects of storms in urban areas occur during and following thunderstorms when short periods of intense rainfall produce high flow rates. The result is local flooding, often severe, combined with very high concentrations of pollutants. Maximum flooding and maximum pollution frequently occur at about the same time.

In large watersheds, the results of urbanization upstream can be very serious and, although many studies have noted the general nature and magnitude of changes, much is still unknown about specific cause-effect relationships. A particularly obvious shortcoming in previous investigations is the spotty characterization of runoff data with little, if any, attempt to collect data on a synoptic basis.

The recommended project seeks to compensate previous shortcoming by making maximum use of space data, both directly sensed and transmitted from ground sensors, to trace the basic changes in watershed physiography through a period of urbanization and to relate these changes to changes in flow and quality. Specifically, it is recommended that one or more rapidly developing areas be selected and monitored over a period of 10 years. The Panel has no particular area in mind, but the areas selected should resemble the Santa Ana Valley area in California or Fairfax County in northern Virginia as they existed 10 or so years ago.

Complete records of land use should be compiled at regular intervals, say annually, during the study period. In addition to the traditional measures of land use, such items as permeability, ground cover, channel modification, installation of sewers, and changes in topography should be noted. Flow and quality should be monitored, both from space when possible and from a series of 10 to 25 ground locations. The quality parameters to be measured include biological oxygen demand (BOD), suspended and total solids, nutrients, and temperature. At least three major storms would be sampled annually and more, if possible.

Data sensed directly from space require a resolution of approximately one-half hectare (one acre) for land use characteristics and perhaps 25 meters for stream related variables. Flow and quality should be accurate to $\pm$ 25 percent or better.

Several good mathematical models of urban systems exist, but their use is severely hampered by lack of data. It is proposed that this study use existing models. As the study proceeds it may point the way toward new and improved ones. The resulting tools will be invaluable to urban planners and engineers and not only will have a direct benefit to planning for flood control and pollution abatement but also will permit more deliberate and rational planning of urban development and resources conservation.

The cost of the program described here is very hard to estimate, but an estimate of $300,000 per year can be postulated. A study on the scale proposed has never been attempted, but it is clear that to attempt it with conventional data gathering methods would be prohibitively expensive, and the information obtained would be incomplete.

NATIONWIDE INVENTORY OF THERMAL CONDITIONS

The Panel recommends the establishment of a thermal baseline for all major surface waters in the U.S. The natural temperature of these waters is increasingly subject to modification, either through the direct action of man as when the water is used for cooling in industry or through indirect action as in urban development or in the destruction of forests. Water temperature is a vital factor in the aquatic ecosystem, and it is now widely recognized that changes in the thermal regime may alter the entire food web, causing the rise of certain species and the loss of others. Unfortunately, there is not a good thermal baseline, and investigators today are not able to make valid comparisons with conditions of a decade ago. The purpose of the recommended study is to provide such information for the future. Data on responses of surface waters to thermal loadings will also permit a check on important theoretical calculations. The electric utility industry has a need for large volumes of water for cooling of thermal electric power plants. Once-through cooling with ocean water, and to a limited extent, inland surface water, has in the past provided the means for dissipating the waste heat. Because of limitations for ambient temperature rise being established by regulatory environmental agencies, increased attention is being given to evaporative cooling systems. Large additional quantities of water for consumptive use are not available in many parts of the country. To examine the trade-offs with once-through cooling, there is a need for careful and well-documented measurement of the thermal characteristics of inland and coastal waters.

An ideal study would measure average monthly temperatures for all major surface waters, but the Panel believes that valid data for any year, by month, will be valuable even though that year may not be average or even typical. The important factor is to obtain a "snapshot" of present conditions. What are major surface waters? This classification includes as many bodies of water as possible, but the Panel recognizes that every creek and pond cannot be covered. Basically, all navigable streams should be included, all lakes in excess of about four hectares (ten acres), and all streams with flow in excess of 2.8 m^3/sec. All situations should be covered for which a satellite-borne thermal sensor having a resolution of about 25 meters can take a good reading. *In situ* sensors are desirable to furnish vertical thermal distributions in deep lakes. Data should be collected at least seasonally; weekly intervals would be optimal. Space data should be supplemented by ground data at a number of locations sufficient to provide indications of daily fluctuations. The finished inventory should provide records of average monthly surface water temperatures in both digital and map forms. For large lakes and rivers, a significant amount of sampling is implied; for small water bodies, a single-point value may be adequate.

The Panel considers this inventory of thermal conditions impractical by any known means other than satellite and remote sensing. Using a space system can give the wide coverage desired and the added advantage of a uniform approach. The benefits of this project are based largely on health and social values in much the same way as is the current massive pollution control program, a program which involves a commitment of as much as $100 billion over a 15-year period, and which has been decided upon without any serious attempt to make a cost-benefit assessment. The cost of preparing the inventory of thermal conditions

by conventional means, if it is possible, would be immense. The Panel estimates that the use of space systems may result in savings in excess of 50 percent of this cost.

DETECTION AND MEASUREMENT OF SUSPENDED SOLIDS

Many reservoirs in the arid western U.S. lose storage space because suspended solids are carried in both from tributaries and from the watershed itself. Additional volume to compensate for silting must be provided when the reservoir is constructed. Often high maintenance costs are incurred because of siltation of outlets and other operational facilities. Silt deposited in waterways and bays becomes an impediment to navigation and requires continual dredging. Where flood-control dams have been built on sediment-carrying streams, reductions of flows below the dams may allow sediment deposition. This deposition can detrimentally affect fish spawning areas and habitats to a significant degree. Starvation of coastal beaches can occur when suspended solids, which would normally nourish the beaches are instead trapped in reservoirs. Without such nourishment vegetation does not grow and the erosion of coastal features often takes place.

It is recommended that a demonstration program be designed to determine how satellite and aircraft remote sensing capabilities can be applied to the problems of siltation in reservoirs and waterways. A study model can be based on an existing reservoir where sedimentation is a problem. An additional study can be undertaken to measure the shoaling in a U.S. harbor. Remote sensing should be capable of measuring suspended solids along a stream in concentrations from 0 to 5 kg/m^3 with an accuracy of $\pm$ 10 percent. In a bay or harbor various scouring and shoaling patterns should be observable.

The benefits of such a demonstration program will be extensive. For streams and reservoirs, more effective project designs and reduced operating costs will result. The danger of environmental damage to fish can be defined and corrected or mitigated. Dredging in a navigational waterway or harbor can be done in a more timely manner and with greater efficiency.

DETECTION AND MEASUREMENT OF SALINITY IN WATER AND SOIL

Remote sensing of salinity, including electrical conductivity and chlorine content, will be of major assistance in the management of inland water resources. While the occurrence and extent of salinity varies widely throughout the U.S., the problem affects many aspects of the beneficial use of water.

1. Salt water intrusion into estuaries can affect both plant and animal life. The shape and extent of the salt water wedge must be taken into consideration in the diversion of water for irrigation, municipal, and industrial purposes.

2. The salinity of inland lakes is important in determining the extent of usable water supplies and in locating sumps for the disposition of brines and other waste waters.

3. The salinity of soils affects the suitability of land for many uses, such as installation of pipelines and structures subject to corrosion. Salinity is an important factor in considering whether land is potentially useful, if irrigated, for agriculture.

4. Concentrations of salts in the root zones of plants are a factor in determining the most efficient irrigation practices and the amount of water to be applied. They also are a factor in the drainage of waterlogged lands whose productivity is decreased by salt buildup.

5. Salinity of surface streams is affected by both point-source and nonpoint-source degradation. Natural runoff from surface areas carries dissolved salts into stream systems, particularly in arid southwestern U.S. Salt-laden springs frequently contribute significant quantities to the system. The return flow or drainage from irrigated lands must return to streams salt in quantity equal to that brought in by the water used for irrigation, or else the salt balance of the irrigated soil will not be maintained. Effluents from municipal sewage disposal and from many industrial processes increase the salt loading of surface streams.

A demonstration program should be designed to provide for the research and development of a remote-sensing capability for salinity measurement. This should be done on a basin-wide basis and should include as many kinds of salt occurrence as possible. The Colorado River is one example of an overcommitted stream system and displays most of the salt problems previously discussed. Salinity of the river occurs naturally because of leaching of soils in the basin draining into the stream and because highly mineralized springs and geysers help feed the stream. Saline return flows from irrigated lands and high reservoir evaporation result in a continuing downstream degradation. Oil-shale processing, coal gasification and liquefaction, and other energy-related processes have an effect on the river salinity but the extent is unknown. It is desirable to establish baseline conditions along the entire Colorado River and its major tributaries. Continued monitoring will determine changes, assist in control of waste-discharge activities, and help in the enforcement of existing regulations.

In order to conduct the demonstration program, additional ground truth will be needed. A remote sensing system should have the capability of 20 meter resolution for water surfaces and a larger area of measurement for soils. The desired measurement will range from 0 to 32 kg/m^3 with an accuracy of $\pm$ 5 percent.

The U.S. Bureau of Reclamation is authorized by Public Law 93-320 to undertake a salinity-improvement program on the Colorado River System at a cost of $284 million. While a remote-sensing program that proves effective on the Colorado River will have long-range benefits along that river, its major benefit will be in reducing the cost of future instrumentation and data-gathering activities for other river basins and estuaries. For a basin comparable to the Colorado River that cost saving might be in the order of $600,000 annually.

ASSESSMENT OF LAKE EUTROPHICATION

Considerable interest has developed nationally in the eutrophication of natural and man-made lakes. The National Water Pollution Control Act of 1972 specifically requires determination of the trophic status of all publicly owned inland lakes and authorizes funding for lake restoration programs. The Environmental Protection Agency currently has underway a National Lake Eutrophication Survey based on conventional water sampling techniques. Data collection for the determination of lake trophic status by using conventional techniques is costly and labor intensive and requires considerable logistical and laboratory support. Adequate evaluation often requires repetitive sampling at different seasons of the year. These factors, combined with the fact that many thousands of lakes require evaluation, lend support to the need for developing an economical method of assessing the trophic conditions of lakes. Therefore, EPA has looked into the applicability of satellite remote sensing techniques and preliminary results show substantial potential benefits.

Remotely sensed data may be useful in lake eutrophication assessment in two general ways:

1. By eliminating or reducing the frequency and extent of conventional water sampling

2. By augmenting conventional data, which are generally point samples and limited in number, to provide a broader assessment of lakewide conditions.

The parameters suggested for evaluation include: lake-surface area, bathymetry, temperature regimes, Secchi disk transparency, chlorophyll-a concentration, and plankton levels. There may possibly be additional parameters.

It is recommended that high-priority efforts be undertaken jointly by NASA and EPA to research, develop, and make operational an effective space-borne sensing system for assessing the trophic status of inland lakes. Specific objectives of this demonstration project include: (1) improvement in areal ground resolution to 40 meters, (2) further investigation of the potential which active laser systems have for differentiating classes of algae, and (3) improvement in sensitivity of other sensors to detect spectral manifestations that can be related to eutrophication. In addition, efforts should be directed toward the development of models that can relate spectral values to such indicators of trophic status as chlorophyll-a and Secchi disk transparency. One approach to this project can include detailed surveys on selected lakes throughout the nation in concert with remote sensing from both spacecraft and aircraft. There is a possibility that ongoing detailed lake studies by various agencies can be incorporated into this effort.

ASSESSMENT OF TIDAL REGIMES IN ESTUARIES

Estuaries, the mixing zones of fresh and salt waters, are usually shallow and relatively sheltered. Here the copious quantities of nutrients contributed by the rivers and the mineral salts supplied by the sea are synthesized by

sunlight into a basic substance of life, the protoplasm of the phytoplankton. The estuaries, providing abundant phytoplankton, support vast populations of mollusks, crustaceans, and other invertebrates which feed directly on unicellular plants and in turn become the source of energy for higher forms of life.

Estuaries have also become other things: avenues of commerce, sites of intensive commercial and sports fisheries, loci of residential and industrial development, convenient receptacles for enormous quantities of industrial and domestic wastes, and in recent years heat sinks for producers of electrical energy. Despite characteristically enormous capacities for assimilation of wastes and dispersion of heat, many estuaries are becoming degraded. Government agencies are confronted with the very difficult problem of preventing further degradation while accommodating continued residential and industrial growth in the estuarine areas. Central to resolution of that problem is increased knowledge of the dynamics of estuaries and particularly of the tidal regimes.

In some estuaries the tidal regime has become, in general, rather well understood and documented, through many years of painstaking research that has employed conventional methods of data collection, storage, and retrieval. Seldom, however, is that knowledge sufficiently detailed, complete, and current to provide sure guidance in such critical management decisions as the following: where to locate power-generating stations, how many such stations to permit, and what restrictions to impose on their operation; where to permit the discharge of domestic and industrial effluents and in what quantities; whether to permit major morphological alterations; how to dispose of dredging spoil; how to manage fishery resources.

It is believed that with data from satellite-borne sensors there is promise of acquiring definitive knowledge of the tidal regimes of estuaries, certainly with timeliness and possibly with cost effectiveness. The critical data needs are numerous. Accurate measurements of surface and subsurface temperature, salinity, current velocity, and surface elevations must be obtained synoptically on a precise schedule. If such data needs are to be met by remote sensing, resolutions of 100 meters in open waters and 10 meters in more confined waters must be obtainable. Required accuracies are temperature, 0.1°C; salinity, 0.1 part per thousand; current velocity, 0.5 cm/sec; current direction, 0.1 degree; and surface elevation, 5 cm. If the required data at hourly intervals cannot be obtained by remote sensing, the employment of *in situ* sensors reporting through a geosynchronous satellite may well be a viable alternative. Necessary modifications of conventionally employed sensors appear technically and economically feasible. The Chesapeake Bay appears to offer significant advantages as a site for a demonstration project. The Bay is large, complex, highly productive, rather well researched, and deserves early attention. Construction by the U.S. Corps of Engineers of a hydraulic model centered on the Bay is nearing completion. Over the next several years, when the model is in process of verification, opportunities will exist for comparison of data obtained by various methods.

The Panel is not prepared to quantify the benefits and costs of the proposed demonstration project. It is believed that if the required data are obtainable by remote sensing, the ratio will be very favorable. If the same data must be obtained by *in situ* sensing and relayed through a space platform, it is somewhat less likely that the costs will be lower than with conventional methods. In both cases, the probability of a reduction in the time required to achieve the objective is a factor that cannot be ignored.

SURVEILLANCE OF ICE CONDITIONS

Increased knowledge of ice conditions in lakes and streams is important for research needs and for operational purposes. Navigation operations under winter conditions are drastically affected by such factors as ice formation, types, thickness, and areal extent. In addition, particularly in northern streams, ice jamming causes serious flooding which can be avoided only if anticipated and alleviated during early stages. The spatial resolution required for operational purposes is about 20 meters with a required accuracy of $\pm$ 15 percent. Vertical accuracy should be within 10 centimeters. Data must be delivered within 1 day and preferably within 1 to 2 hours following observation. The geographical area covered may extend for 500 kilometers.

The Panel believes that a demonstration project can be accomplished with currently available spacecraft and aircraft sensors and ground-truth information. For research purposes additional sensors including *in situ* sensors may be required. The project will study the type and distribution of ice in a number of critical portions of the Great Lakes, the Illinois waterway, and the navigable portion of the upper Mississippi River. Areas of interest will be monitored during conditions of ice freezeup, growth, and breakup and during drastic weather changes throughout the winter. Data collected will include ERTS-type imagery and ground truth on ice thickness and types at selected locations at the time of satellite passes and aircraft overflights. Data on air and water temperature will be collected continuously. Estimates of ice thickness will be attempted through interpretation of surface temperatures. The dielectric constant of surface materials will be utilized to assist in determination of snow moisture content, snow temperature, impurities, and open water conditions. The project should establish the types of ice, ice thickness, ice movement, and ice location, should predict the onset of ice formation and breakup, and should permit correlation of this information with the difficulties of navigation through ice fields.

The benefits from this project will include a reduction in the cost of collecting data, in comparison with current means. Collection of ground-truth information about ice for operational purposes is very hazardous and the risk of loss of life is always very real. Loss of life has occurred from floods following the breaking of ice jams. Applications of remotely sensed data will help eliminate such hazards.

Benefits to the waterborne shipping industry also occur through an extension of the navigation season. Experience during the winter of 1973-74 from a joint project involving NASA, NOAA, the USCE, and the U.S. Coast Guard gives an indication of these benefits. A test was conducted on the Great Lakes. It involved providing ice-condition information to 30 vessels, or about 10 percent of the total fleet. The information was obtained by using radar remote sensing with surface observations on ice thickness. With this information the vessels were able to extend their operation beyond December 15, 1973 to February 7, 1974. This resulted in an estimated 5 million tons of additional shipping being moved after December 15 and resulted in revenue to the shippers of $5 million. This amount does not include the savings in inventory costs of the commodity and in the cost of providing additional storage at the terminals. If it is assumed that similar extended periods can be obtained annually and if benefit can be extended to the entire Great Lakes fleet, an estimated additional revenue to shippers of $50 million can be realized. To this can be added additional value received by the inland-waterway industry.

ASSESSMENT OF FLOOD DAMAGE

During and following floods along rivers and in coastal areas, federal and state agencies must assess the extent of the flood damage. The information is used to support requests for emergency assistance, to determine recovery efforts required, to determine what flood damage was prevented by existing protection measures, and to evaluate the need for new or additional flood protection. The rapid availability from remote sensing of information about the extent of flooding can be most helpful, particularly when the flooding involves extensive areas. Visual imagery, before and after the flood, together with surveillance of developments in the flood plain, may also be useful in damage estimation. Presently, damage assessments are conducted by expensive and complete *in situ* surveys. Finally, rapidly available data on water surface elevation and river width during the progress of the flood together with topographic information throughout the region can be used to predict flooding downstream. This is very important since channel characteristics change during high flows, as may be noted particularly in changes that have occurred in the lower Mississippi River.

Parameters required for assessing flood damage are the width across the stream, both within and without the bank area, and the elevation of the water surface. The width of the water surface has been previously measured successfully with ERTS-1 imagery. Remote sensing has proven to be useful in providing quick estimates of the extent of regional flooding. To be most useful, the data should permit mapping the flooded area to a standard scale of 1:24,000 (a scale not available from ERTS-1) and with an accuracy of 5 percent. The regional area to be covered may range from 250 to 2500 square kilometers. All river basins within the U.S. must be included in this coverage. Areas subject to flooding should be covered at least twice daily during the flooding period, preferably every 4 hours.

As the required capability has been demonstrated previously, the main effort in the proposed project should be directed toward introducing the program into the operational procedures of appropriate agencies. Primarily involved are the U.S. Army Corps of Engineers and state and local agencies. Estimates of costs and benefits are difficult to obtain. As one measure, the USCE expended $8.5 million for flood and coastal emergencies during fiscal year 1973. It is difficult to determine the amount expended in the assessment of flood damage because of differing accounting procedures. The figure given does include costs of remedial measures taken during emergencies, for example, levee repairs.

SURVEY OF ROOTED AND ATTACHED AQUATIC VEGETATION

Abundance and distribution of rooted and attached aquatic plants are of significant interest in the management of inland water resources and related fields of fisheries and waterfowl management. Both rooted and attached aquatics can be and frequently are detrimental where they occur in excessive abundance and interfere with navigation or impede water flow directly or by trapping sediments and accelerating shoaling, clog intakes of water withdrawal systems, shade out more valuable species, and interfere with recreational activities such as swimming and fishing. Many species of rooted aquatics are more or less beneficial and some are extremely valuable as cover and forage for many animals, including

crustaceans and other invertebrates, fish, and waterfowl. In estuaries and large lakes, rooted aquatics provide relative stability where they occur in shoal water and thus make possible the existence of communities of lower animal species of great importance in the food chain.

Surveys of aquatic vegetation are routinely conducted by management agencies as a means of obtaining early warning of need for control measures; for evaluation of the effectiveness of control measures; or, conversely, for evaluation of the effectiveness of efforts to establish desirable species, extend their range, or accelerate their growth. Such surveys usually combine air and ground observations. The effectiveness of observations from the air is limited by turbidity and by the fact that many rooted aquatics are submersed rather than emergent or floating. However, when most of the submersed species are at or near full growth, their terminal leaves extend to or very near the air-water interface and are easily observed, particularly at low water levels.

It is believed that multispectral sensing in the visible and near-infrared range from a polar-orbiting satellite or high-altitude aircraft can be advantageously employed in surveys of rooted and attached aquatics. Resolution of 10 meters should be should be adequate except in a very few areas, and 100-meter resolution probably will suffice for some purposes. Species differentiation is desirable, but less accurate identification can be useful. The matters of plant type and density of population can be resolved at the R&D level by coordinated space-sensing and ground surveys. Logical sites for demonstration projects appear to be (1) one or more states in the southeastern U.S. where problems have long occurred with "pest" species of aquatics in waterways and where control programs are ongoing and (2) one or more states which have important wintering grounds for waterfowl, especially where there is an ongoing effort to promote growth of one or more species of aquatics.

Quantification of benefits and costs is not possible with the information at hand. The Panel believes the benefits could be very substantial. A measure of potential benefits may be obtained by noting the expenditure of one federal agency. During fiscal year 1973 the U.S. Army Corps of Engineers required $1 million for detection and $1.5 million for control of aquatic vegetation. It is estimated that a 30 percent reduction in the cost of detection and a 15 percent reduction in the cost of removal (due to early detection) would result in a savings of $450,000 annually for one agency. The resulting savings in manpower which can be used for other purposes is also a substantial benefit.

DETECTION AND EARLY WARNING OF POLLUTION VIOLATIONS

During the past decade, the federal and various state governments have enacted or promulgated an unprecedented number of stringent laws and regulations against water pollution and have issued great numbers of discharge permits specifying the level at which permittees are authorized to "pollute." The specified levels are those at which, in the judgment of the regulatory agency issuing the permit, water quality standards are not violated and the environment is not degraded. Laws, regulations, standards, and permit specifications are meaningless, however, without effective enforcement, but enforcement has been exceedingly difficult to achieve.

The inherent difficulty in the enforcement process lies in the nature of most of the violations. They often are inadvertent, usually are transient, and

almost always are detected only hours or days after they occur and then only through observation of secondary effects. A "slug" of acid mine drainage or an ephemeral discharge of a toxic chemical from a paint factory, which causes no visible change in the receiving water, may kill thousands or millions of fish, generate hundreds of telephone calls to the enforcement agency, and leave no substantial clue to the origin or even the nature of the discharge. The frustrating experiences of a number of years of enforcement effort force the conclusion that agencies responsible for prevention of pollution must have timely warning that pollution has occurred if they are to be effective. To be maximally effective, those agencies need to know that pollution *is* occurring and, to minimize effects and fix responsibility, they need to know exactly *when* it begins and precisely *where* it is occurring. Supplying that information appears to be within the capability of current technology.

Under the provisions of extant statutes, every discharger of a significant volume of effluent must obtain a permit. The regulatory agency is advised by the applicant of the quantities and compositions of effluents proposed to be discharged and the permit, if issued, specifies rates of discharge which may not be exceeded. The regulatory agency, in every case apprised of the nature of the discharge, is often in a position to arrange for the design of sensors that can be installed at or near the point of discharge, are capable of detecting and reporting violations of permit specifications, and can identify the location of the violation. The Panel suggests that a communications system be provided through a geosynchronous satellite, with violations reported directly to enforcement agencies. With full implementation of this proposal, an enforcement agency, probably at the state level, will be able to dispatch investigators to the scene of a violation within minutes after occurrence rather than hours or days later. The Panel believes that the proposed system will provide substantial assistance, not only in fixing responsibility for violations but also in discouraging chronic or intentional violators and in encouraging occasional or inadvertent violators to be more careful.

The Panel suggests that a research program be initiated now to design appropriate sensors and communications systems and that a demonstration project be launched as soon as practicable in a region where pollution violations are frequent. The advantages of using the Chesapeake Bay for a demonstration project have been discussed earlier. The Baltimore harbor area seems particularly suitable for the project.

Potential benefits of an operational program of the kind recommended include (1) saving of many man-hours of investigative effort now expended too late to be effective and (2) the value of biotic resources that would not be destroyed if damaging discharges were detected and terminated promptly.

CONCLUSIONS AND RECOMMENDATIONS

INFLUENCE OF THE PROPOSED SPACE TRANSPORTATION SYSTEM

The space transportation system for the 1980's in the form of space shuttle, Spacelab and the associated upper stages (tugs) can have significant impact on needs related to inland water resources in four areas. The Panel offers conclusions and recommendations in these four areas as follows:

1. The development of multispectral sensors is pertinent for water quality studies. The Panel on Inland Water Resources has pointed out several situations in which the quality of inland waters should be inventoried and monitored. The needs for quality characteristics apply not only to layers of water near the surface, where spaceborne sensors have already been shown to have some potential, but also to water well below the surface. Furthermore, many water quality parameters need very precise spectrometric observations if they are to be identified by remote sensing. Spacelab offers a possibility of permitting the development of sensors which may achieve these results. A payload technician on board the Spacelab would be able, ideally, to coordinate observations with ground-based experiment teams. These teams would collect ground truth and coordinate and refine the results of preliminary analyses performed by the payload technician. There is a very significant challenge in this area of endeavor, and the potential benefits are quite large.

2. The development of microwave sensors with high spatial resolution can contribute to quantitative measurements of soil moisture, ice cover and thickness, snow water equivalent, and precipitation. Observations from space in the microwave portion of the electromagnetic spectrum offer considerable promise of obtaining quantitative measurements of these parameters. As described earlier, promising results have already been obtained with use of sensors on NIMBUS, Skylab, and high-altitude aircraft. However, instruments should be developed with capabilities for high vertical and horizontal resolution and for multispectral active or passive microwave measurements involving the use of large antennas or synthetic aperture antennas. These systems could involve relatively large amounts of power, include complex on-board data-processing systems, and produce large amounts of data. Before such a microwave system can become operational and thus be applied to problems related to inland water resources, including the specific ones mentioned here, considerable research and development are needed. This R&D very appropriately can be accomplished in Spacelab.

The presence of a payload technician should markedly increase the probability of obtaining successful results during the 7- to 30-day missions.

3. The space shuttle can serve as a platform from which to launch unmanned spacecraft. Data required for management of inland water resources generally involve long-term repetitive observations from unmanned spacecraft. It is conceivable that large numbers of such satellites will be needed to implement proposed projects. The satellites may be launched, repaired in space, or retrieved by means of the space shuttle and the procedure may offer considerable savings to users of the data so obtained.

4. Observations and interpretations provided by a human in space may make a valuable contribution toward realizing the objectives of water resources management. Although it is difficult to describe specific situations in space other than those already indicated where more human involvement will be required, it nevertheless intuitively seems to the members of the Panel very probable that a trained hydrologist or water resources specialist on board Spacelab can obtain valuable insight from visual observation. For instance, a hydrologist on board Spacelab may be able to survey and direct assessment of damage due to large floods in a way which will expedite ground-based operations associated with insurance claims and rescue operations. A hydrologist should be included on at least one Spacelab mission in order to evaluate this possibility.

GENERAL CONCLUSIONS

In reviewing the 1969 report of the Panel on Hydrology, the Panel on Inland Water Resources concludes that the findings of the 1967-68 study generally remain valid. The hydrologic applications that were within the state of the art in 1968 have been partially realized. Further development and refinement of these applications will produce significant benefits. The Panel on Inland Water Resources further concludes that:

1. The operational hydrologic program recommended in the 1967-68 study will not be realized in the time frame suggested by the Panel on Hydrology.

2. Programs based on applications of space technology can generally be grouped into four main areas related to the management of inland water resources:

   a. Inventory
   b. Basic research on hydrologic balance
   c. Planning
   d. Operation

3. While considerable *basic* research has been carried out that indicates a great potential for remote sensing, limited *applied* research has been conducted to develop the kinds of fully operational systems that are needed in the broad spectrum of inland water resources for application now by the nonresearch user.

4. In order for applied research to be successful it must have the direct involvement of potential users.

5. There is a need for all public agencies, federal and state, and the private sector to take advantage of potential capabilities of space technology to meet user requirements.

6. Because aircraft, especially the U-2 and RB-57, offer needed flexibility in operations, are useful in testing and developing equipment, and offer the advantage of increased resolution at lower elevations, the Panel has concluded that they will continue to be useful for remote sensing.

7. ERTS-1 with its 80-meter resolution has demonstrated a limited but useful capability to map snow and ice cover, large lakes, and flooded areas and to relay directly sensed data through DCS.

8. Current practices for dissemination to users of available space data on inland water resources are not satisfactory. Prompt dissemination of data is required for many operational programs because of the transient nature of the data.

9. The Panel discussed a potential combination of data services now located at Suitland, Maryland (National Environmental Satellite Service), Sioux Falls, South Dakota (EROS Data Center) and Salt Lake City, Utah (Agriculture Information Center). It was noted that the National Cartographic Information Center (NCIC) is currently being established as a joint venture of the Departments of Commerce and the Interior to provide data location services. This new venture combined with the existing structure appears to meet current user needs (provided NCIC moves rapidly). This, combined with the fact that each of the three centers has specialized missions, leads the Panel to conclude that no merging of center functions should be considered at this time.

10. The practical application of space systems, while it offers potential benefits to users, is being inhibited and may continue to be limited because of a lack of knowledge of how to use space technology in the user community.

11. There is a need for professional and technical societies to promote a greater awareness of progress in the practical application of space technology and to encourage its development through their publications and committees.

12. Advances in basic understanding of hydrologic phenomena and in capabilities for water resources management can be facilitated provided a vigorous, sustained, and coordinated effort is mounted similar to that which occurred in the field of meteorology.

13. To achieve maximum net benefits any proposed satellite water resources program should be integrated with other satellite earth resources programs, for example, land use, agriculture, and environmental quality.

14. There is a need to develop both *in situ* and remote sensors to measure adequately many of the water resources parameters required in an operational satellite program.

15. Essential components in the effective application of space technology to water resources problems are data processing, modeling techniques, and information-display procedures.

GENERAL RECOMMENDATIONS

The Panel on Inland Water Resources recommends the following:

1. *An operational satellite water resources program should be developed within the next 5 years. To achieve maximum benefits this program should be integrated with other satellite earth resources and weather programs. A data collection system must be one element of such a program. The use of aircraft, including the U-2 and the RB-57, should continue in the development of remote sensing programs.*

2. *Federal agencies with responsibilities in the development and management of the nation's inland water resources should take a lead role in the development of operational systems using space technology. This role must include programs for data and technology transfer to all users. To obtain maximum benefits these federal agencies must maintain, in the development process, a partnership approach with state and local agencies and close coordination with industry, private consultants, and universities. These agencies must develop a strong user interface with space technologists in order to implement successfully such operational systems. Federal agencies should begin immediately to exploit demonstrated capabilities of space technology and should incorporate them, where appropriate, into operating procedures for fulfilling their missions.*

3. *The EROS facility at Sioux Falls, South Dakota, should be expanded to meet user needs more adequately, including more rapid data dissemination, and increased technical assistance, education, and training.*

4. *Provisions should be made for the user community to be assured timely access to the full range of data obtained from a satellite water-resources program.*

5. *An R&D program should be carried out to develop and improve in situ and remote sensors that can supply data for use in water resources management including, in particular, water quality parameters, soil and snow moisture content, groundwater levels, river and near-shore hydrography, water velocity, precipitation, and ice cover and thickness. For these and other parameters, the capability to make measurements below the surface is essential.*

6. *At the earliest practicable date NASA should develop space hardware, sensors, and necessary programs for accomplishing, in cooperation with appropriate user agencies, the following high-priority demonstration projects related to inland water resources:*

   a. *Improved forecasting of runoff from mountain snowpacks*
   b. *Mapping areal extent and depth of groundwater*

c. *Mapping areal extent and location of seepage from reservoirs, canals, and levees*
d. *Surveillance of river channel and beach migration*
e. *Delineation and assessment of shoreline processes*
f. *Mapping of water-related land areas*
g. *Relating urban development to changes in runoff*
h. *Nationwide inventory of thermal conditions*
i. *Detection and measurement of suspended solids*
j. *Detection and measurement of salinity in water and soil*
k. *Assessment of lake eutrophication*
l. *Assessment of tidal regimes in estuaries*
m. *Surveillance of ice conditions*
n. *Assessment of flood damage*
o. *Survey of rooted and attached aquatic vegetation*
p. *Detection and early warning of pollution violations*

7. NASA, either singly or in combination with related programs of other agencies, should make available to the maximum extent practicable, earth resources measurements obtained through ongoing programs. In the field of inland water resources, this availability is considered particularly important so that the professional community who administer, manage or plan water resources may be provided with opportunities to apply this data for the continual improvement of their decision making.

8. Professional and technical societies with interests in inland water resources should develop programs to make the user community increasingly aware of developments in the application of space technology to water resources problems.

9. In order to facilitate applications of space technology, a periodical should be published, devoted to providing information on existing and developing techniques and methodologies for applying space technology to user requirements.

APPENDIX A

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APPENDIX B

POSSIBLE APPLICATIONS OF REMOTE SENSING TECHNIQUES RELATED TO INLAND WATER RESOURCES

Water Resources Data

1. Delineation of sediment plumes and measurement of sediment loads
2. Definition of mud-water interface for various tidal conditions
3. Evaluation of effluent discharge patterns
4. Monitoring of flow patterns by use of dye injections
5. Detection of algal blooms
6. Oil pollution
7. Temperature distribution in reservoirs
8. Water velocity
9. Flooded areas
10. Seepage and drainage areas, including canals, reservoirs, and levees
11. Levee and dam surveillance
12. Irrigation return flows
13. Reservoir evaporation losses
14. Noxious groundwater seeps
15. Seiches and lake setup
16. River migration
17. Tidal monitoring
18. Soil moisture measurements
19. Saline intrusions
20. Surface water mapping
21. Precipitation monitoring
22. Runoff forecasting

Agricultural Lands for Water Use Studies

1. Extrapolation of land use conditions based on real-time surveys

    a. Acreage change detection
    b. Delineation of irrigated and non-irrigated areas
    c. Delineation of dry-farmed and native vegetation

d. Determining change of fallow lands throughout the year
e. Determining extent of multiple cropping
f. Determining planting and harvesting dates

2. Identification of major crop groups (for example, tree and vine, forage, and row) and some individual crops
3. Evaluation of rate of expansion of irrigated cropland and ground cover
4. Anticipated marginal applications

a. Identification of individual crops not falling under item (2)
b. Delineation of sprinkler irrigated fields
c. Detection of winter time uses of water for frost protection
d. Detection of frost damage
e. Cold-air drainage patterns for frost damage potential
f. Detection of soil moisture changes
g. Detection of salinity and drainage problem areas

5. Consumption of water by agriculture
6. Monitoring of aquatic vegetation (emergent and submersed)
7. Monitoring embankment vegetation (weeds and phreatophytes)
8. Irrigated land drainage investigations

Ecology

1. Major ecological system interfaces
2. Ecological equilibrium and dynamics
3. River and harbor pollution
4. Water quality parameters

Snow and Ice

1. Runoff forecasting

a. Mapping areal extent of snowpack
b. Temperature of snowpack
c. Water content of snowpack
d. Short-term weather forecasting
e. *In situ* monitoring of hydrometeorological parameters in real-time
f. Soil moisture measurement

2. Ice jams
3. River, sea, and lake ice cover
4. Glacial movement and melt rate
5. Glacial fissures

Native Lands

1. Acreage change detection, vegetation, cultural uses, etc.
2. Definition of broad vegetative types and other dominant characteristics
3. Evaluation of geologic features

    a. Landforms
    b. Fault lines
    c. Contact zones
    d. Beach morphology
    e. Alluvial processes

Urban Lands for Water Use Studies

1. Acreage change detection (land use, impervious areas, etc.)
2. Urban flood hydrology
3. Delineation of urban land use patterns
4. Determining location and extent of recreational subdivisions

Climate

1. Forecasts of regional climatic trends

Water Resources Engineering

1. Design and management of inland waterways for navigation
2. Engineering geologic investigations
3. Site selections of reservoirs, canals, conduits, and levees

Hazards

1. Conditions for snow avalanches
2. Flood alerts
3. Bank and beach erosion

Disaster Assessment

1. Floods
2. Coastal storms

APPENDIX C

STATEMENTS OF INFORMATION NEEDS PROVIDED BY FEDERAL AGENCY CONSULTANTS TO THE PANEL

U.S. Department of the Interior

Water Management in Pacific Northwest (Bonneville Power Administration)

Better information, which would in turn permit improved water management in the Pacific Northwest, could bring benefits including savings of tens of millions of dollars. Present limitations are in:

Frequency of observations;

Ability to estimate total water content of snow; and

Models to predict runoff from space-derived data.

Use of meteorological satellites for acquiring frequent low-resolution data and use of ERTS for acquiring less frequent high-resolution data are promising. There is still the major problem of estimating water content. Water content may be determined by development of adequate sensors to use with a data collection system and/or through the use of microwave methods from aircraft and/or spacecraft. These capabilities are essential for realizing the full benefit of space technology for reservoir management in this region.

Sports, Fish, and Wildlife

Prediction of wildlife productivity requires monitoring surface water and the extent of shore lands. This type of monitoring probably requires a combination of spacecraft and aircraft capabilities. Improved models to predict wildlife productivity are also needed. Many of the benefits are social but modest econo[illegible] benefits can also be attained once the reliability of prediction is estab[illegible]shed.

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U.S. Geological Survey

Background

The Water Resources Division of the U.S. Geological Survey is the largest single water data collection agency in the U.S. Data are collected for multiple purposes and made available to many agencies as raw data and as comprehensive studies related to water availability and quality. Surface-water and groundwater data and interpretations are included. The programs are funded through direct federal appropriations, state and federal cooperative programs, and interagency transfer of funds. In the cooperative programs, state funds generally exceed those available from the USGS.

Space Experiments

Experiments with data from satellites have been conducted during the 2 years since the launch of ERTS-1 and have been highly successful in the following major areas:

Experiments using the data collection system (DCS) to collect information from *in situ* sensors;

Experiments using imagery for wetland evaluation (coastal, swamp, and flood); and

Experiments using DCS and imagery to improve inventory of impounded water.

Experiments using DCS indicate a high level of operational readiness. The reasons are:

Reliability of transmitter system,

Easy interface with present *in situ* measuring devices,

Ability to rapidly transmit data to central data banks,

Digital format of data, which reduces intermediate processing requirements, and

Sensors located according to performance rather than where most convenient for servicing

Benefits

Wetlands and water impoundment studies form a basis for relating surface water and vegetation to ecological models. Establishing these models requires a base of data and using them will require continuing observation. The benefits

may be largely social in nature. ERTS-1 data have made it possible to solve several problems that were attempted earlier with data from high-altitude aircraft, which proved to be inadequate for the purpose. Quantification of benefits from the use of DCS will require more experience. The primary savings in costs will be in reducing the requirements for manpower or in allowing the present level of manpower to do a more complete job and thus to support a larger proportion of the requests for state and federal cooperation. A side benefit will be the more rapid availability of data for management agencies outside the USGS.

The present budget level of the Water Resources Division is between $40 million and $50 million. A 10 percent improvement in efficiency can be expected over the next few years so that a benefit of $4 million to $5 million may be possible. The benefits will probably be larger but more experience will be required for verification.

Immediate Needs

More reliable automated sensors for water quality parameters are a major factor needed to improve efficiency of collection using the DCS and *in situ* sensors. Longer times between servicing can result in lower manpower requirements. Reducing manpower requirements is the most direct way of obtaining dollar benefits.

U.S. Bureau of Reclamation

Introduction

One of the important activities of the U.S. Bureau of Reclamation (USBR) is the construction of facilities for storing, diverting, or delivering water for municipal and industrial uses, irrigation, improvement of water quality, power generation, flood control, river regulation, recreation, pollution abatement, and other purposes. Facilities include storage and diversion dams and reservoirs, water transportation and distribution systems, hydroelectric and pumping plants, and related structures.

The USBR program is administered to assist state, local, and other federal agencies to stabilize and stimulate local and regional economies, to enhance and protect the environment, and to improve the quality of life through development of inland water and related land resources throughout 17 western states in the continental U.S. and in Hawaii. The USBR has 153 projects in these western states. The projects include 288 storage dams, 138 diversion dams, and over 11,000 kilometers of irrigation canals. Nearly 90 percent of the construction costs of USBR projects is repaid over a period of years directly to the U.S. Treasury by users of the facilities. Nearly 40,000 square kilometers of farming land can receive water from USBR developents. This is approximately one-fourth of the total irrigated acreage in the U.S.

Organization

The U.S. Bureau of Reclamation, under the direction and control of a commissioner, consists of the following principal segments:

Commissioner's office in Washington, D.C.,

Several engineering and technical-support entities located at the Engineering and Research Center in Denver, Colorado,

Seven regions with office locations as follows:

a. Pacific Northwest in Boise, Idaho
b. Mid Pacific in Sacramento, California
c. Lower Colorado in Boulder City, Nevada
d. Upper Colorado in Salt Lake City, Utah
e. Southwest in Amarillo, Texas
f. Upper Missouri in Billings, Montana
g. Lower Missouri in Denver, Colorado,

Special purpose offices including those for river basin planning, and

Operating offices within the regions.

About 8,000 persons, approximately one-fifth of whom comprise the professional staff, are employed. Professionals in all fields are utilized in planning, design, construction, supervision, operation and maintenance, and administrative functions. Construction work is carried out by private contractors selected through competitive bidding.

Committee for Remote Sensing Programs

The EROS Committee, a multidisciplinary group, was formed at the U.S. Bureau of Reclamation's Engineering and Research Center (E&R Center) in Denver to insure that all divisions of the Center are informed of remote sensing programs of interest to them and to facilitate their participation. In 1970, the Committee was given the responsibility for guiding the remote sensing studies undertaken by the USBR with EROS program support and related remote sensing investigations at the E&R Center and for coordinating these programs with the USBR office in Washington, D.C., the regional offices, and the USDI-EROS program office.

The Committee is composed of nine members representing each of the major divisions at the E&R Center. Its functions include:

To give advice on actions appropriate to financing research and other activities for remote sensing programs;

To recommend applications;

To promote activities for increasing the working knowledge about remote sensing techniques; and

To assist in disseminating information on remote sensing.

In 1973 technical coordinators for remote sensing were designated in each of the seven regional offices. This was made necessary by the increased uses of remote sensing data. Each coordinator is responsible for identifying and initiating remote sensing applications in each locality and for reporting activities and needs for assistance and advice to the E&R Center Committee and to the Washington Office. In some regional offices separate multidisciplinary committees are also being formed to handle a rapidly expanding technology.

Remote Sensing Activities

Remotely sensed data from both aircraft and spacecraft are recognized as valuable tools in the investigation, planning, development, and management of projects related to inland water resources. The USBR must be considered one of the major users of these data since its activities cover a wide variety of earth resources disciplines, for example, agriculture, geology, engineering, cartography, hydrology, and meteorology. Staff competence is being developed to plan and implement programs for logical and timely incorporation of remote sensing data into USBR operations. Programs are in progress or have been completed to evaluate the application of remote sensor data to several specific problems and to identify sources of data that can be useful in operations. Programs directed toward the solution of typical problems have helped to develop techniques and procedures necessary for operational utilization of the data.

Environmental Protection Agency

"Accurate and timely information on status and trends in the environment is necessary to shape sound public policy and to implement environmental quality programs efficiently." This statement from the third annual report of the Council on Environmental Quality underlines the fundamental need for the Environmental Protection Agency (EPA) to acquire pertinent environmental data.

Environmental quality data have been collected on a nationwide basis for a number of years but the ability to discern trends on a national or even a regional scale is lacking. Further aggravating this situation is the fact that the list of mandated and suspected pollutants requiring surveillance is growing.

EPA currently spends approximately $33 million annually on environmental monitoring. State and local pollution control agencies spend approximately twice that amount. The private sector is estimated to spend in the order of $50 million to $100 million annually on source monitoring. Even at these levels of expenditure, monitoring coverage, both spatially and temporally, is extremely sparse because of the relatively high unit costs of monitoring. With the current state of the art, monitoring expenditures will have to be increased severalfold in order to provide essential data on standards violations, emerging problems, and overall successes or failures of pollution abatement efforts. Because of

the magnitude of these expenditures, effort toward improving monitoring efficiencies is warranted. In that monitoring is an iterative process generally to be continued indefinitely, any improvement in the efficiency of monitoring systems will represent cumulative savings that are realized from that point forward. Accordingly, even at the current level of activity, a one-time increase of only 5 percent in monitoring efficiencies will result in an annual saving to the public sector of approximately $7.5 million.

Considerable effort has been expended by the National Aeronautics and Space Administration (NASA), the Department of Defense (DoD), and other governmental agencies, and a number of organizations in the development of remote sensing systems for deployment in satellites, in aircraft, and on the ground to observe and record certain conditions and characteristics in the biosphere. Sufficient work has already been done inside and outside EPA to demonstrate the feasibility of utilizing certain of these remote sensing techniques, when complemented by *in situ* measurements and associated data-processing systems, for meeting some environmental information needs of EPA and state pollution control agencies. In addition, several of these advanced techniques appear to have a good potential, with some adaptation, for meeting a number of other environmental data needs of EPA in a more effective and efficient manner than the approaches now employed.

EPA, through its Office of Research and Development, has instituted an advancement program directed to develop a more effective data system for meeting these data needs. In order to strengthen this activity, and in consonance with section 104(a)(5) of the Federal Water Pollution Control Act of 1972, EPA initiated discussions with NASA early in 1973 with the thought of drawing upon NASA's expertise and capability in the areas of system development, technology, and management. As a direct outgrowth of these discussions, a joint NASA and EPA planning and coordination meeting was held at the Lewis Research Center, Cleveland, Ohio, from February 12 to 14, 1974. Representatives attended from NASA Headquarters and 10 centers and from EPA Headquarters and 9 organizations. Focusing on problems of the Great Lakes area, a series of projects were defined by expert working groups which matched EPA needs with NASA capability and interest.

The program to be implemented by NASA Lewis Research Center and EPA Region V will center on the development, demonstration, and limited operational testing of new and improved monitoring systems for use in the Great Lakes Basin. Much of the program can be expected to have application in other areas of the U.S. Media of concern include water, air, and land.

Program Plan for Environmental Monitoring Systems for Great Lakes Basin

The objectives of the program are (1) to develop and demonstrate the operational feasibility of new and improved cost-effective environmental monitoring systems for use in the Great Lakes Basin and (2) to develop and implement approaches for technical and operations transfer of systems to users. The program is divided into the following major work areas, which are listed in order of current emphasis and concern within EPA Region V:

Water Monitoring Systems

Modeling, Data Management and Data Systems Design

Land Pollution and Land Use

Air Monitoring Systems

Water Monitoring Systems

Phases of water monitoring systems to be investigated include:

Shipboard Monitoring System to design, develop, and install an automated multiparameter water quality monitoring system on the EPA ship *Roger Simon*. The system will include automated sample acquisition, depth and position identification, multiparameter analysis, and data processing and transmission. Until other systems are available on an operational basis, Great Lakes Research and Trend Monitoring will depend on mobile platforms (ships). A few ships presently available have limited capability for comprehensive and rapid field assessment.

In situ Automated Monitoring System to design, develop, and field test concepts of *in situ*, multiparameter, all season, and clear water automated systems for remote monitoring of water quality. The purpose is to reduce field manpower requirements and to expand the number of parameters that can be measured repetitively and accurately. Evaluations will be made of on-station data storage, ERTS-1 relay, hard-wire transmission, improved sensor development, telemetry and sonar, atmospheric input measurements, monitoring station deployment strategy for various purposes (baseline, trend, enforcement, etc.), and cost-benefit analysis.

Remote Sensing Monitoring System to develop and demonstrate the feasibility of using remote sensing monitoring systems for evaluating water quality in the Great Lakes Region. Three categories are needed for large areas: (a) surface temperatures (modeling, thermal discharge), (b) suspended solids (modeling, thermal discharge), and (c) chlorophyll concentration. The use of laser for algae studies, high-altitude color scanner, and satellite imagery will be included in the overall evaluation and cost-effectiveness study.

Modeling, Data Management, and Data Systems Design

The program includes, within Modeling, Data Management, and Data Systems Design, the following:

Data Management and Display System to design, develop, and demonstrate an interactive data management display system. Emission inventory, ambient pollution level, and meteorological data are collected in many forms by several agencies. Because of format and access difference and lack of interpretation models, these data are not readily available to EPA management in a form useful for assessment and planning purposes. A prototype system will be developed and expanded which processes the data from entry into the system to output of usable information including graphic display.

Thermal Material Transport and Dispersal Models, since no general thermal material transport model exists for the Great Lakes. The project is dependent on continuation at Case Western Reserve University of the EPA Grosse Isle Laboratory funded effort for the modeling of whole lake transport, temperature distribution, and near-shore waste-heat dispersal. The project will program these general models for specific lake geometries and will verify the models by actual measurements of temperature and currents.

Improved Air Quality Models, in that available models are presently being subjected to comprehensive validation and refinement by EPA in the Regional Air Pollution Study program in St. Louis. For the Great Lakes, models will incorporate particular complications associated with strong pollution sources along the shorelines of the lakes, tall buildings, and lake effects on meteorological factors including large changes in precipitation from year to year.

Storage and Retrieval

STORET* River Coordination System (AUTOMAP)** for which the objective is to complete the development for the rivers in the Great Lakes Basin. This system has been partially developed but never completed nor implemented.

Land Pollution and Land Use Monitoring System for Nonpoint-Source Pollution From Runoff in Rural Areas

This phase covers development of remote sensing monitoring systems for assessing the contribution to water pollution from runoff in rural land areas. Satellite and aircraft remotely sensed data will be acquired and processed to classify specific soil and crop types. On the basis of crop types, fertilizer and pesticide application will be estimated. Runoff characteristics will be assessed to determine the impact to receiving waters.

Air Monitoring Systems

While the objectives of the proposed air monitoring systems are primarily related to the needs of the air regulatory program, there are interrelationships with water resources and the technique may be applicable in both areas.

Ground-Based Regulatory Air Monitoring System to develop and demonstrate three types of ground-based regulatory monitoring systems. The methods in use at present are intrusive, complicated, and expensive. Separating sources in a complex urban setting is difficult and often fails to satisfy legal requirements

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*STORET is a data storage and retrieval system.

**AUTOMAP is a method for using STORET data and making three-dimensional plots of the data.

in assessing violations. Three systems will be developed: (a) a quantitative time- and direction-resolving particulate sampler with source signatures based on cluster correlation analysis, (b) a remote passive ultraviolet absorption spectrometer for defining SO_2 concentration profiles, and (c) lidar* probe for measuring thermal structure of the lower atmosphere from the ground.

Baseline and Trend Air Monitoring System 1 to develop and demonstrate a baseline trend air monitoring system for regional needs. Existing systems are not optimally designed, and they measure only a few of the pollutants under control of the Clean Air Act. The system will be capable of monitoring the six primary air pollutants, trace metals, and hydrocarbons at unattended long-term stations. A network strategy to reduce data handling and costs will be developed. Airborne remote sensing will be used together with *in situ* measurements to validate the technology.

Program Schedule and Cost

The total program duration is 7 years with several of the programs becoming operational in from 2 to 5 years. The program schedule is shown in Table IV, which also includes major milestones and designates a time schedule with decision points assigned to fiscal years between 1975 and 1981. Costs for the program are presently estimated as:

1. NASA

Direct man-years:	180
Research & Program Management...	$5.8 million
Research & Development.....	1.4 million
Total:	$7.2 million

2. EPA

Direct man-years:	35
Research & Program Management...	$1.1 million
Research & Development.....	7.5 million
Total:	$8.6 million

*Light detecting and ranging; analogous to radio detecting and ranging (radar) but using the coherent light output of lasers.

PROJECT	FISCAL YEAR* 1975	1976		1977	1978	1979	1980	1981	
WATER MONITORING SYSTEMS									
Shipboard Monitoring System	1	2	3						
In Situ Automated Monitoring System		1			2	3			
Remote Sensing Monitoring System		1	2	3	4	5	6		
MODELING, DATA MANAGEMENT AND DATA SYSTEMS DESIGN									
Data Management and Display System	1				2	3			
Thermal Material Transport and Dispersal Model			1	2					
Improved Air Quality Models	1		2			3			
STORET River Coordinate System (AUTOMAP)	1	2	3						
LAND POLLUTION AND LAND USE MONITORING SYSTEM FOR NON-POINT SOURCE POLLUTION FROM RUNOFF IN RURAL AREAS					1			2	3
AIR MONITORING SYSTEMS									
Ground-Based Regulatory Air Monitoring System		1		2		3			
Baseline and Trend Air Monitoring System 1				1		2	3		

* Numbers 1 to 6 designate decision points.

TABLE IV DEVELOPMENT OF ENVIRONMENTAL MONITORING SYSTEM FOR THE GREAT LAKES BASIN

U.S. Army Corps of Engineers

The first Earth Resources Technology Satellite (ERTS-1) was launched in July, 1972, an event which dramatized the tremendous advances being made in the field of remote sensing. In recognition of these advances, the Civil Works Directorate, U.S. Army Corps of Engineers, in fiscal year 1973 initiated a systematic evaluation and field testing of research proven remote sensing concepts. The first year was devoted to an evaluation of technology and was generously supported by NASA. This led, in fiscal 1974, to a program of applied research, a substantial training and orientation program, and selected related demonstration projects. Fiscal 1975 marks the year in which a fully coordinated and documented group of demonstration projects will be implemented to provide a basis for evaluating the benefits of remote sensing technology.

While the ERTS program is a keystone of Civil Works activities in the field of remote sensing, it does not play a predominant role in those activities. The Civil Works Directorate emphasizes multistage and multisensor testing with the objective of defining an optimum combination of sensors and processing techniques for each of the applications in which remote sensing technology provides identifiable benefits. The benefits relate generally to two classes of activities:

> Effective and efficient acquisition of specific types of information, and
>
> Effective and efficient identification of changes in previously observed conditions.

In developing our demonstration program, we have relied on field office involvement. The field offices have been asked to identify information requirements as well as ongoing projects for which demonstrations of remote sensing techniques might be developed. As the demonstrations are run, personnel having a direct responsibility in the ongoing project participate in the planning and coordination of the demonstration, provide supportive or auxiliary data, and evaluate the results. It has been found that the use of such parallel demonstrations leads to the most effective method of evaluating the capabilities and potential for further development of remote sensing techniques. It also leads to the greatest acceptance by the ultimate user when the results warrant such acceptance.

The information requirements obtained from the field offices have been grouped into the following 12 general categories:

1. Land cover--identification of type and location of land cover and, where possible, land use. Categories include urban, rural, agricultural, vegetation, natural resources, wetlands, and surface water. These data can be updated to monitor land cover change. Applications for this approach include location of waste-water treatment sites, relationships between land use and pollution type and load, relationship of land use to socioeconomic data, location of land sites for dredge disposal, and others.

2. Littoral processes--identification and monitoring of water circulation patterns, sedimentation rates and patterns, shoaling, bottom profiling, wave mechanics, sand inventories, and coastal erosion and deposition location and rates. Applications for this approach include physical and mathematical model verification, near shore and offshore construction requirements, identification of areas requiring dredging activities, location of beaches requiring sand replenishment, and others.

3. Subsurface water--identification of location, route, and flow patterns of water below the surface of the ground with use of surficial and subsurficial geology, vegetative cover, and soil moisture as indicators. Applications include identification of areas of seepage around and/or through structures, drain tile locations, water-table definition for land acquisition requirements in reservoir planning, levee stability, and others.

4. Water quality--identification of salinity, dissolved oxygen, conductivity, turbidity, temperature, and organic substance in water bodies. Applications include assessment of eutrophication or suspended sediment in water bodies, adequacy of reservoirs to support recreational activities, and others.

5. Geology and soils--identification of rock type and genesis; igneous, metamorphic, and sedimentary; relationship of type and depth of overburden to parent material; location of fault size, type, and activity; mapping of caves, caverns, and sinkholes; identification of Pleistocene formations (kames, drumlines, moraines, etc.); identification of drainage patterns; and delineation of limestone formations. Applications include dam locating, road route selection, dam stability evaluation, construction materials location, definition of constraints to construction, and others.

6. Environmental impact--identification of predictive or evaluative factors in nature that have been or will be impacted by land use activities and construction projects. Applications include project siting, effect of fluctuation of water level on vegetation, influence of strip mining on erosion, monitoring coastline conditions for permit awards, and others.

7. River engineering--identification of limits of backwater areas, river alignment, river flow patterns and rates, transverse and longitudinal surface sediment distribution, velocity fields, bed form effects, assessment of the physical vulnerability of natural and manmade structures. Applications include definition of construction requirements in river systems (riprap, bed form structure), dredging requirements, flood abatement structures, improvement of natural and manmade levee systems, location of areas of high erosion potential, identification of dredge-disposal sites, and others.

8. Flood plain mapping--mapping extent of flooding waters and identification of flood plain features that represent flooding frequency interval boundaries. Applications incluxe flood plain management, flood protection control, flood plain surveys, pre-flood damage potential assessment, post-flood damage assessment, spillway management, setting up priorities for areas requiring disaster relief, and others.

9. Runoff prediction--identification of distribution and quantity of snow cover, assessment of snow water content, determination of soil permeability, and evaluation of the potential precipitation of clouds. Applications include prediction of runoff potential, determination of storage capacity and release rates in reservoirs, flood damage prevention, and others.

10. Data communications--utilization of ground-based data collection platforms that report river stage, rainfall, information on coastal winds and tides, water quality parameters, and snow depth. These data are relayed by satellite-to-ground receiving stations several times daily and transmitted back to the user on a near real-time basis. Applications include the definition of reservoir stage-storage relationships, supplement or replacement of existing microwave data collection systems with a more cost-effective satellite system, prediction of runoff potential, warning mechanism for water quality degredation, and others.

11. Digital processing--development of use of computer for interpretation, display, and storage of remotely sensed data. Input includes computer-compatible tapes, scanner data, thermal data, photographic data, and data collection platform recordings. Output includes alphanumeric products, film reader and writer products, calcomp plotter products, computer cards, results for correlation and regression studies, and others.

12. Ice mapping--mapping location, extent, and movement patterns of ice bodies. Applications include location of navigation hazards, prediction of rise in water levels, and others.

Finally, the USCE has initiated, in response to field office requests, an extensive training program related to remote sensing. Training courses are being offered in photointerpretation, Side Looking Airborne Radar (SLAR), and on the characteristics and uses of thermal infrared systems. Training courses in other aspects of remote sensing, for example, the characteristics and uses of multispectral imagery and computer data, are being considered.