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REMOTE SENSING FOR WATER RESOURCES AND HYDROLOGY:

An Assessment of the Corps of Engineers' Program

A report of the
Panel on Remote Sensing for Water Resources

of the
Space Applications Board

of the
Assembly of Engineering
National Research Council

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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SUMMARY

At the request of the U.S. Army Corps of Engineers, a panel of the National Research Council's Space Applications Board has reviewed the Corps' program of research and development and technology transfer on the application of remote sensing to problems of water resources and hydrology.

The Corps' current program consists of work units (coastal engineering, flood prediction and management, hydrology, environmental assessment, and development of techniques and equipment); integration of remote sensing with existing automated data systems; demonstrations; and assistance to users.

The panel suggests that the Corps increase its emphasis on remote sensing for coastal engineering so that analyses may be more quantitative and less subjective.

The panel found that much of the work in flood prediction and management is operational, and suggests that incorporating such operational activities in the work of the Corps' field offices would preserve scarce research and development funds for more significant long-range needs of the Corps.

The panel found that most of the work in the field of hydrology is on problems of cold regions. The panel recommends that the Corps' hydrologic remote sensing research and development be expanded to include other important problems, such as those related to water supplies.

The panel recommends greater emphasis on the Corps' work in developing new and improved techniques and equipment, which it views as true research and development.

The Corps' work in demonstrating remote sensing to its field offices and its assistance to Corps users in the field are very useful. It would be to the Corps' advantage to expand these demonstration and training activities to Corps' contractors and to state, local and regional governments.

The Corps should encourage research and development on the measurement of soil moisture by remote sensing. Advances in radio-frequency sensors and light detecting and ranging (lidar) could make possible the application of remote sensing to study of sediment distribution,

acid waste plume persistence, other coastal zone features, and to measurement of salinity in tidal waters.

The Corps should emphasize use of conventional data in existing water resources models, but in addition should develop models able to use remotely sensed data to full advantage.

Much of the Corps' current research and development in remote sensing for water resources results from field office requirements. To better meet its long-term strategic needs, the Corps should place more emphasis on headquarters guidance for research and development on remote sensing.

The Corps' work on remote sensing for civil works in the field of water resources and hydrology is underfunded. The panel believes that an increase in research and development in these areas would soon reduce the cost and increase the effectiveness of operations. It should be possible to evaluate the effectiveness of such an increase within one or two budget cycles.

With the Corps' broad responsibilities for water resources, it is important to the Corps that there be good coordination of the whole field of remote sensing for water resources and hydrology. The Corps currently provides much of this coordination on an informal basis. The panel recommends that the Corps consider formalizing its current activities in coordination of interagency programs.

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INTRODUCTION

This report is the result of a request from the U.S. Army Corps of Engineers for a review of the Corps' program of research and development and technology transfer in the application of remote sensing to problems of water resources and hydrology.

The request asked for recommendations on the future direction of the Corps' program, with consideration of its relation to the work of other federal agencies, such as the National Aeronautics and Space Administration (NASA), the U.S. Geological Survey (USGS), the U. S. Department of Agriculture (USDA) and the National Oceanic and Atmospheric Administration (NOAA).

To respond to this request, the Space Applications Board of the National Research Council formed the Panel on Remote Sensing for Water Resources. The panel was briefed in a two-day meeting by representatives of the Corps, NASA, USGS, NOAA and USDA. The panel staff and several members had follow-up meetings with Corps personnel. The panel did not visit the Corps' divisions or laboratories, nor did it interview Corps field personnel. The panel based its judgments on briefings by agency headquarters personnel, on follow-up meetings with Corps managers, on documentation supplied by the Corps, and on the experience of the panel members in water resources and remote sensing.

This report describes the civil works program of the Corps for remote sensing, provides comments on the program and makes recommendations for improving its effectiveness. It includes recommendations on the future direction of the Corps' program. Finally, it comments on the relationship of the work of the Corps on remote sensing for water resources and hydrology to the work of other federal agencies and recommends steps the Corps and other agencies might take to improve coordination of the work, and thus its effectiveness.

The civil works role of the Corps includes the following areas of activity that use remotely sensed data or information derived from such data:

- Planning and operation of water resource projects, including navigation and development, improvement, construction and maintenance of the nation's rivers and harbors

- Flood forecasting, and reduction and assessment of flood damage, including control and alleviation of the effects of floods by structural and nonstructural methods

- Production of hydroelectric power, including development, construction and maintenance of projects that provide saleable power

- Control of beach erosion, including restoration and preservation of coastal shores

- Management of water supplies, including storage for municipal and industrial purposes

- Recreation management, including maintenance and operation of public park and recreation facilities at water resource development projects

- Enhancement of fish and wildlife habitats

- Other environmental enhancement and monitoring.

The Corps has found that the synoptic view, rapidity of coverage and low cost per unit area of coverage offered by remotely sensed data from satellites make the data useful in discharging regularly certain responsibilities: regulation of wetlands; inventory of dams; flood management; and monitoring and controlling vegetation in navigable waters. The proceedings of the Corps' symposium of 1979 (ref. 1) also attest to use of satellite data by a large number of the Corps' divisions and districts for a wide variety of other problems.

The use of satellite data by the Corps is pervasive, but the uses are largely on a trial basis (with the possible exception of the dam inventory program and the flood plain management program). Discussions with Corps personnel indicate that the Corps is not now prepared to commit itself to the operational use of data from satellite remote sensing because plans for acquisition and launch of the next generation of land remote sensing satellites (Landsats D and D-prime) do not yet give assurance that the flow of data will not be interrupted if launches are unsuccessful or if one of the spacecraft or a sensor fails earlier than expected. This caution reflects prudent management.

Other considerations include uncertainty about the cost of satellite products, data delivery schedules, and data format for the privately operated land remote sensing system which the Executive Branch is currently projecting.

The manner in which the Corps organizes its research and development program on the use of remotely sensed data reflects the management structure of the Corps, as well as the source of the initiative and funding for the work. In addition, the purpose of most of the Corps' work in remote sensing for water resources is to encourage the transfer of remote sensing technology to the Corps' 47 divisions and districts. Thus, no clear distinction can be drawn between research and development and technology transfer in the Corps' program.

In the panel's view, only that work aimed at developing new and improved techniques for use of remote sensing, including work on modeling, constitutes research and development. The work on the use of satellite data on problems of specific sites, the demonstration work and the assistance to Corps users are really technology transfer.

COMMENTS ON THE CURRENT RESEARCH AND DEVELOPMENT PROGRAM

Work Units

One part of the Corps' work on use of satellite data, consisting of elements called work units, is referred to as the research program. Summmaries of the work units are included in this report as Appendix A. Each work unit involves about three to five man-years of effort.

The panel found it convenient to classify the work units into the following categories: coastal engineering; prediction and management of floods; hydrology; environmental assessment; and development of techniques and equipment.

Coastal Engineering

The work units on application of remote sensing to coastal engineering are designed to determine how satellite data may be used effectively in this field. The Corps is testing and evaluating data from existing satellites and simulated data from sensors for future satellites. Planned work includes analysis of sensor capabilities and studies of the need for enhanced sensor sensitivity and improved algorithms.

At the present level of knowledge, interpretations of imagery of coastal processes are largely subjective, rather than quantitative. This has limited the application of remotely sensed data in this field of water resources. The synoptic and repetitive characteristics of remotely sensed data, however, could make the data especially useful in studies of coastal processes. The panel believes that remotely sensed data also can be useful in analyses of estuarial activities and river mouth migrations. The panel suggests that the Corps increase emphasis on its work in this field, so that analyses may be more quantitative and less subjective. (See Appendix A, pages 27-28.)

Prediction and Management of Floods

This work concerns large river basins, rural land use, management of flood plains and reservoirs, and estimates of potential or actual damage.

As better mathematical models and sensors with greater resolution are developed, remotely sensed data will become more useful for land use classification related to urban flooding, mapping of small river basins and flood and flood plain management. Improvements in the ability to detect the specific location and amount of rainfall in real time and to measure soil moisture would improve flood prediction capability. The panel recommends that the Corps encourage and support research in these areas.

Some Corps activities in flood management and prediction--such as production of land use maps, stage area tables and maps for specific river basins--could be classified more properly as introduction of new technology into the Corps' operations rather than as research and development. Incorporation of these activities in the ongoing work of Corps field offices would preserve scarce research and development funds for more significant long-range needs of the Corps. (See Appendix A, pages 29-32.)

Hydrology

The Corps' activities on application of remote sensing to hydrology relate primarily to determination of ice conditions in rivers, lakes and oceans; to the analysis of snowcover; and to development of sensors for use in cold regions. The panel considers quantification of the water equivalent of snowcover important because it contributes importantly to efficient water resource management in irrigation and hydroelectric power generation, particularly in the western third of the United States. Quantifying the water equivalent of snowcover is difficult and expensive when done by conventional means. The panel recommends developing suitable remote and in-situ sensors that could make determination of water equivalent of snowcover more accurate, more timely and less expensive. Near-real-time determination of ice conditions in water bodies is important, especially for shipping on the Great Lakes and on large rivers. New high-resolution satellite sensors will help to accomplish this.

Most of the Corps' work that the panel has categorized as hydrologic research and development is focused on problems of cold regions. The panel recommends that the Corps' hydrological remote sensing research

and development be expanded to include other important problems--for example, those related to water supplies. (See Appendix A, pages 33-36.)

Environmental Assessment

The Corps' environmental assessment activities are intended to preserve the nation's natural resources and to make the United States a more enjoyable and productive place in which to live. The Corps' research and development program in environmental assessment consists primarily of refining existing capabilities in the areas of land use, habitat, cumulative impacts in cold regions, and wetlands mapping. The Corps is comparing the cost of collecting data by remote sensing with the cost of collecting data by conventional methods.

These environmental assessment activities have other uses in general hydrology, regulatory activities and in assisting state and local government users of remotely sensed data. The panel believes that the emphasis placed on these activities is appropriate. (See Appendix A, pages 37-39.)

Development of Techniques and Equipment

The Corps is adapting existing techniques and equipment and developing new ones to use remotely sensed data on problems important to the Corps, without constraint to specific sites. These techniques and equipment are intended to take advantage of advances in the technology of remote sensing, such as improved resolution or stereoscopic imagery.

The work includes development of techniques and equipment for processing data from future satellites, evaluation of Landsat data products using state-of-the-art techniques, and development of advanced computer-assisted extraction techniques. The activities in these work units more closely resemble traditional research and development than do the activities in other work units. The Corps closely coordinates this work with that of other federal agencies and in some cases supports joint research and development activities.

The panel concludes that the work of the Corps on new and improved techniques is important and would benefit from additional emphasis and support. Because the Corps' experience in developing software and hardware to meet its special needs is fed back to NASA, NOAA and other agencies, the work complements the work of other agencies. The panel

endorses research and development activities of this type by the Corps because of their potential widespread application in hydrology and management of water resources. (See Appendix A, pages 40-42.)

Integration of Remote Sensing with Existing Automated Data Systems

The Corps is bringing relevant models, data bases and data (including remotely sensed data) from various sources to bear on current problems in several discrete geographical areas of different hydrological types. The use of modeling, computerized data bases which include remotely sensed data, and automated data processing and analysis will improve the ability to assess the effects of changes in features that are important to hydrology. These features include locations and heights of dams, or construction of drainage systems. Changes in these features are important in planning. Secondary objectives are to have field personnel learn how to use these techniques, and to refine existing techniques or identify needs for new ones.

Most of the work on integration of remote sensing with existing automated data systems is part of a program called Spatial Analysis Method (SAM), and currently is focused mainly on floodplain problems.

The panel considers the combination and computerization of data bases, complemented by research and development that makes possible automated processing and analysis of data, a significant achievement.

Demonstrations

To encourage use of remote sensing, the Corps establishes full-scale cooperative programs with internal users. These programs usually take the form of demonstrations focused on Corps-approved activities having explicit data requirements. The demonstrations tend to focus on activities that could have widespread application in the Corps' field activities. For these demonstrations, the Corps selects some project activities whose data requirements can be met with existing technology and some that require advanced technology.

One successful demonstration has been a program for integrating disparate data into a common data base (as part of the SAM program). Another has been a program for inventorying dams in the United States.

The panel believes that these demonstrations are particularly effective in transferring remote sensing technology into the Corps' field operations.

Assistance to Users

The Corps assists its divisions and districts, and state and local agencies with which it has cooperative activities, in the application of remote sensing. It also assists private sector organizations when it is in the interest of the Corps that remote sensing be used in projects contracted to the private sector.

A major element in user assistance is the work of a Remote Sensing Committee. The committee evaluates the state of the art in remote sensing as it relates to Corps projects and regulatory responsibilities; provides for expert technical assistance on remote sensing programs; provides for dissemination of pertinent information; promotes coordination and communication on interagency and intra-agency institutional arrangements; determines requirements for remote sensing data, data processing, data handling and data storage; recommends priorities; and promotes accommodation of the Corps' needs in the research and development programs of NASA and other agencies.

Another aspect of user assistance is training of Corps personnel. When training capacity is not fully utilized, a limited amount of training is made available to persons from other government agencies, contractors and state and local governments.

The panel encourages continuing assistance to users throughout the period of rapid development of new sensors, applications and techniques.

COMMENTS ON THE FUTURE DIRECTION OF THE CORPS' PROGRAM

Need for Additional Research and Development on Certain Applications

Certain uses of satellite remote sensing require additional research and development before they are ready for trial use or demonstration. (See ref. 2 and Appendix B.) Of these, the ones important to the work of the Corps include real-time measurement of rainfall, measurement of soil moisture, certain water quality applications, detection and measurement of suspended solids and salinity, and assessment of hydrologic characteristics of estuaries.*

The panel believes that additional research by the Corps, in cooperation with NASA and NOAA, should be encouraged on these and some other uses of remote sensing important to the Corps' mission. The other uses include improved runoff forecasting and improved low flow predictions.

*Using high quality digitized infrared data from NOAA's Synchronous Meteorological Satellite and Geostationary Operational Environmental Satellite, an empirical technique has provided reasonably accurate estimates in real time of rainfall from short-lived, isolated thunderstorms (refs. 3, 4 and 5). Field tests of the technique indicate that, with additional research, remotely sensed data can be used to provide reasonably accurate estimates of rainfall from prolonged slow-moving thunderstorms that cover large areas.

The dielectric properties of a soil are strong functions of its moisture content. They determine the propagation characteristics for electromagnetic waves and affect the emissive and reflective properties at the surface. These last two properties can be measured in the microwave region of the spectrum by passive (radiometric) and active (radar) techniques. With additional research, data from microwave sensing, complemented by in-situ measurements and used with soil models, offer promise for remote sensing of soil moisture.

For water quality applications, such as lake eutrophication, lidar (light detection and ranging) offers potential for accurate measurement of phytoplankton. A recent workshop (ref. 6) concluded that better information on "ground truth," more basic research on the

Improving Understanding of Hydrologic Events Through Use of Satellite Data and Improved Modeling

At the present stage of development, most hydrologic models are empirical mathematical representations that use hydrologic data from traditional sources and are designed to best fit observed events. Traditional hydrologic data come from measurements made at discrete points on the earth's surface. Land use data have usually been obtained by manual interpretation of low-altitude aerial photography or by direct ground observation. The aerial photographs are often outdated. Repetitive aerial photographic or ground coverage is not easily obtained, especially if the surface area involved is large. In contrast, remote sensing from satellites provides a repetitive synoptic view not previously available.

The Corps' Hydrologic Engineering Center (HEC) develops models specifically for use on Corps problems and adapts models developed by others to forms suitable for use on Corps problems. While most of HEC's work is directed at improving the use of data from traditional sources, HEC has concluded that Landsat data provide some types of land use information accurate enough for use in hydrologic models. HEC has further concluded that for many applications Landsat data is quicker and less costly to obtain and interpret than low-altitude aerial photography. It also provides repetitive coverage of a given area every 18 days (when clouds are not present) and covers all of the United States and many other areas of the world (ref. 9).

However, the ground resolution of current Landsats sets a practical limit on the scale of mapping of about 1:100,000. Furthermore, the satellites do not provide stereo coverage or USGS-grade map accuracy.

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passive and active properties of both live and dead organic material in water bodies, and more research on tuneable lasers are needed.

Klemas et al (ref. 7) analyzed Landsat and Skylab multispectral imagery and photography to study sediment distributions, persistence of acid waste plumes, and other coastal zone features. Additional research and development are needed to bring the experimental instrumentation to an operational state.

Blume et al (ref. 8) have demonstrated that aircraft-mounted microwave radiometers can measure salinity with a mean deviation of one part per thousand. More research and development are needed to increase the sensitivity and accuracy of the instrumentation so that it may be applied more generally.

For example, in the work described in ref. 9, the size of the Landsat picture elements (about one acre) was approximately equal to the size of the grid cells in the data base being used. Because the size of picture elements for the next generation of Landsat satellites (Landsats D and D-prime) will be about one-fourth acre, the accuracy of land use classification and the number of uses of remotely sensed data may be expected to increase significantly.

As understanding of physical processes grows, it becomes possible, using synoptic data, to develop models representing linkages of physical processes. As existing models are modified to use remotely sensed information to supplement data from traditional sources, and as new models are developed to take full advantage of remotely sensed data, it must be expected that models will become even more useful and important to the Corps.

The panel recommends that the Corps place even greater emphasis on modifying existing models to take advantage of remotely sensed data, and that the Corps work on--and encourage NASA and others to work on--the development of models designed to take full advantage of remotely sensed data from current and future satellites. Parametric sensitivity studies will be needed to guide the modeling efforts.

The panel has reviewed the work by Peck et al (ref. 10), sponsored by NASA, and views it as a start on the process the panel envisions. The panel concludes that the Corps' activities in this area might be supported by HEC. Corps personnel familiar with remote sensing could play an active and productive role. The process represents a sizable task, and should of course be coordinated with NASA's effort.

Need for More Headquarters Planning for Meeting Mid- and Long-Term Needs for Remotely Sensed Data

While the research and development management procedures for the Corps' civil works program provide for some headquarters guidance on mid- and long-term objectives, a review of the procedures (ref. 11) indicates that field activities of the Corps have a dominant influence in establishing research needs and priorities (for remote sensing, as well as for other research and development work related to the civil works program). As a result, the emphasis tends to be on short-term goals.

The panel recommends that the Directorate of Civil Works complement the research and development planning of the field units by providing more guidance for work on applications of remote sensing, and particularly on needs for research and development that will permit making more effective use of remote sensing to meet long-term, strategic needs of the Directorate.

The decentralized organization of the Corps permits its field offices to exercise considerable latitude in the methods used. The panel believes that well-tested remote sensing techniques would be used more widely throughout the Corps, with resultant cost advantages, if more top-level encouragement and direction were given.

Funding of the Corps' Civil Works Research and Development Program for Remote Sensing of Water Resources and Hydrology

The fiscal year 1981 funding for the Corps' civil works program is about $3 billion, about 1% of which is allotted to research and development and about 0.02% of which is alloted to remote sensing related to water resources and hydrology.

In view of the Corps' intent (expressed to the panel by Corps personnel) to introduce cost-effective remote sensing techniques to its nearly 50 field offices as soon as practicable and in view of the need for research and development in several applications, the effort devoted to remote sensing research and development is too small. The panel believes that an increase in research and development activities would soon result in cost reductions and improved effectiveness of operations. It should be possible to make an evaluation of this effectiveness within one or two budget cycles. The panel judged that the amount allotted to research and development could be increased without an adverse effect on the Corps' budget for other programs.

RELATIONSHIP OF WORK OF THE CORPS TO WORK OF OTHER AGENCIES

Resolution of many problems in water resources and hydrology requires knowledge of the water content of the earth's mantle, for example, soil moisture or groundwater. A number of agencies work in these areas, and the following paragraphs summarize their cooperative activities related to water resources and hydrology.

The National Aeronautics and Space Administration

The Corps has emphasized to NASA the importance of NASA's program of research on remote sensing for water resources and the significance of the results of that program to problems of national concern--particularly, problems of the nation's rivers, harbors, wetlands and coastal regions; control, alleviation and assessment of damage from floods; a wide range of water pollution problems; and the problems of water supplies for irrigation, for generation of hydroelectric power, and for use by industry and the populace.

The panel recommends that Corps management affirm to NASA's new management its support for these remote sensing activities.

Much of NASA's water resource effort is currently focused on soil moisture, in a cooperative program with USDA. While the results of this work will be directly useful to the Corps, the work does not currently include consideration of terrain important to the Corps but not suitable for agricultural use--for example, urban and suburban land, and rugged and mountainous terrain.

The panel recommends that the Corps discuss with NASA and USDA the possibility of extending the cooperative work on soil moisture to cover most or all of the soils of interest to the Corps. The Corps should participate in such a program.

NASA's work on snowpack properties and on irrigated lands applies directly to the work of the Corps. The panel believes this work is not receiving adequate emphasis at present. It recommends that the Corps weigh the importance of better information on snowpack properties and on water used for irrigation, and consider whether NASA should be asked to place greater emphasis on this work.

In an earlier report (ref. 2), the panel recommended further experiments to identify situations in which satellite sensing could be used for the detection and measurement of suspended solids. In view of the importance of the effects of the movement of suspended solids into waterways, the panel encourages the Corps to urge NASA to explore this capability of remote sensing.

A recent memorandum of understanding between the Corps and NASA established arrangements for a cooperative and coordinated program of technology assessment and transfer. The Corps and NASA have worked out a good relationship, the Corps relying on NASA for research and development and concentrating its own efforts on the development of techniques for extracting and analyzing information for use in its own work.

The panel concludes that the memorandum of understanding between the Corps and NASA uses the special abilities of each to excellent advantage, and recommends that the Corps make every effort to encourage, support and extend this cooperative activity.

The National Oceanic and Atmospheric Administration

Most of NOAA's work on remote sensing related to water resources and hydrology is done in the Earth Sciences Laboratory, the Environmental Research Laboratory, the National Weather Service and the National Earth Satellite Service.

This work includes: rainfall forecasting; rainfall, snow and soil moisture measurements; flood warning and mapping; studies of circulation and currents in rivers and estuaries; and freezing and breakup of ice on the Great Lakes. Factors affecting crop yield, including precipitation and soil moisture, are measured as part of a USDA-NASA-NOAA cooperative project for agriculture and resource inventory survey using aerospace remote sensing (AgRISTARS). These measurements of precipitation and soil moisture can be useful for the Corps' rural projects. If the measurements could be made in urban areas as well, the data would help the Corps to deal with problems of runoff, flooding and water quality.

NOAA's work is coordinated with that of the Corps through informal monthly meetings and through participation in annual symposia describing the results of that work. Some joint research projects are planned. The panel believes that expanding this cooperation would be helpful not only to the Corps and NOAA, but also to state, regional and local governments.

The U.S. Geological Survey

USGS work on remote sensing for water resources and hydrology is centered in its Water Resources Division and in its Earth Resources Observation Systems (EROS) Data Center. About 80% of USGS's remote sensing work is in applications of proven technology, about 15% in applied research and about 5% in basic research.

The work of the Water Resources Division is done mostly in-house. According to USGS, the highest priority work is mapping irrigated acreage for water use studies, particularly in the U.S. High Plains area, where the Ogalala aquifer (a deep groundwater source) is receding rapidly. Landsat imagery is being used to help map this region's water resources and its water uses.

The Division makes routine use of Landsat data for mapping geologic structures related to groundwater exploration, for mapping snowpacks and estimating their runoffs and for estimating urban runoff.

The EROS Data Center currently spends about $12 million per year in archiving remotely sensed data and making it available to users at the cost of reproduction. It must be expected that the planned move toward creation of an operational land remote sensing system will result in cost increases for data. However, the cost of data, even at several times the cost of reproduction, is still a small fraction of the cost of extracting information on water resources from the data. The panel believes that remotely sensed data will cost the Corps significantly less than data collected by conventional means, and recommends that comparative cost studies be made.

The panel has previously stressed the need for further research on remote sensing of groundwater in shallow aquifers (by observing indirect indicators such as vegetation or geological features--see ref. 2). This work is important to a number of agencies, including the Corps, in the prediction of low flow conditions in rivers. Joint research efforts--both basic and applied--among USGS, USDA, NASA, DOI and the Corps should be encouraged.

Although current models are not readily amenable to use of remotely sensed data, the Water Resources Division of USGS needs the synoptic view that such data provide. The panel has already recommended that the Corps and other federal agencies place greater emphasis on modeling.

The U.S. Department of Agriculture

The Department of Agriculture's work in remote sensing for water resources and hydrology, centered in the Beltsville laboratory, is mainly in support of AgRISTARS.

An important aim of AgRISTARS, being done in cooperation with NASA, is to improve hydrologic modeling by adding the capability to use remotely sensed data. Objectives are to provide more accurate and timely estimates of soil moisture and to help understand the relationship of soil moisture to rainfall run-off. Existing models are being modified and new ones are being designed specifically to use remotely sensed data. This work, at the University of Maryland, is coordinated with Corps' work at HEC.

The work at Beltsville on soil moisture includes in-house investigations using truck-mounted microwave sensors and microwave sensors in NASA aircraft flying over USDA-instrumented watersheds in Oklahoma, Texas, Georgia and Florida.

USDA is working to correlate soil moisture in the upper 5 to 10 cm of soil with moisture at the deeper root zone of most crops. USDA would like to begin some flights, using dedicated aircraft, to see how soil moisture affects different plant canopies.

A small USDA project is designed to provide early warnings of floods in foreign countries. That work is responsive to the need of USDA's Foreign Agricultural Service to estimate flood damage in major foreign grain-producing areas such as the Soviet Union and China.

Other USDA work on remote sensing is directed at estimating effects of agricultural activity on water pollution, one of the major goals of AgRISTARS.

The panel recommends that the Corps encourage and participate in an expanded soil moisture program with NASA, NOAA and USDA.

Interagency Coordination

Two recent studies (refs. 2 and 12) have made recommendations for water resources research that relate to the work of the Corps. Both studies emphasized the lack of centralized direction and coordination in federal work on water resources. The panel agrees with those conclusions and recommendations of the studies that deal with the need for increased direction and coordination (see Appendix B), and recommends that the Corps continue its efforts to alleviate this problem.

The panel suggests that the Corps continue its informal meetings with other agencies that work in the field of water resources and hydrology, as well as its annual symposia, and recommends emphasis on seeking ways to integrate more effectively the programs of the various agencies.

CONCLUDING REMARKS

The panel notes that the first land remote sensing satellite, ERTS-1, was launched only nine years ago. It concludes that the Corps' extensive use of remotely sensed data from satellites reflects an effective process for applying new technology.

With the Corps' broad responsibilities for water resources, it is important that there be good coordination of the entire field of remote sensing for water resources and hydrology. The Corps currently provides much of this coordination on an informal basis. The panel recommends that the Corps consider the advisability of formalizing its current interagency activities in program coordination.

At present, the Corps' program in remote sensing properly seeks to maximize applications of the capabilities of current sensors to the mission of the Corps. The Corps would benefit if its long-range needs for water resource data were more specifically stated and if NASA, NOAA and other agencies were encouraged to facilitate provision of such data by remote sensing.

With the reduction (or possibly even elimination) of funding for NASA's technology transfer function, the Corps should be prepared to assume responsibility for transfer of remote sensing technology within the Corps, to the extent necessary to permit it to take advantage of more sophisticated data. This includes adaptation of existing water resources models to utilize remotely sensed data, as well as the development of new models to take full advantage of such data. For these models, data processing on an operational basis will be a major task. Planning for such processing should not be overlooked.

Up to this time, the Corps has designed its procedures for applying remote sensing to civil works so as to minimize the need for many highly specialized scientists and engineers and for much expensive equipment. Because the Corps is a decentralized organization with many field offices, the panel considers this approach appropriate for the current generation of sensors. When refined sensors with greater resolution become available, the panel suggests that the Corps consider centralized processing of the more sophisticated data such sensors will provide.

The panel recommends that the Corps focus on more general research and development, investigate a wider variety of applications, provide more top-down guidance for research and development, and, in general, increase emphasis on (and funding for) research.

New developments and new models should be made available to potential Corps contractors. This will require preparation and dissemination of manuals and guides and arrangements for appropriate training.

The panel believes that the Corps' work in the area of demonstrations has been remarkably successful and urges that this activity be expanded, but as field projects rather than research and development. For example, applications of remote sensing are needed in studies of shoreline and estuarial processes, the effects of openings in sandy coastlines and river channel migration. These applications could be important to many Corps field activities, and to state and local governments as well.

In the panel's view the Corps' cooperative work with USDA, USGS, NASA and other agencies is essential and appears to be well done. Some expansion of this work, taking advantage of the Corps' excellent contacts in state, regional and local governments, might yield considerably increased benefits to both federal and nonfederal users at negligible additional cost.

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Appendix A

WORK UNITS

NOTE: For the purposes of this report, the Corps' work units have been summarized and edited by the panel.

COASTAL ENGINEERING

Application of Remote Sensing to Coastal Engineering Problems

Objective

To develop improved and cost-effective techniques for acquiring coastal zone time-space interrelationships:

- Demonstrate and field test remote sensing techniques for coastal engineering applications
- In coordination with NASA, the Department of Defense and other agencies, evaluate and test the use of satellite data from current and future remote sensing systems for application to coastal engineering, and develop the necessary time-space interrelationships
- Develop and evaluate applications of active satellite microwave systems to help establish design requirements for future spaceborne systems
- Develop and coordinate the Corps' planned use for NOSS (a second-generation SEASAT) and its integration with the Landsat D program.

Description of Work

Test existing remote sensing technology and evaluate its cost effectiveness for acquisition of coastal data such as underwater bathymetry (using airborne lasers), data on sediment distribution and water quality (using film and filter combinations and lasers), and data on wave climate and ocean currents (using active microwave systems).

Aircraft missions with coincident ground truth will be conducted at the Field Research Facility, Duck, N. C., in conjunction with other organizations.

Analysis will compare remotely sensed data with data from conventional systems in the time and spatial domains. Topics to be addressed are underwater topography, wave climate determination, water quality, longshore transport and shoreline mapping. The feasibility of using SEASAT data for ocean wave, current and transformation detection will be evaluated and Landsat and SEASAT data will be compared.

Satellite Evaluation of Coastal Zone Phenomena

Objective

To determine and compare observable oceanographic and near-shore terrestrial features on imagery from Landsat (visual and infrared), SEASAT (microwave), NOAA 5 (thermal infrared), NIMBUS 7 (Coastal Zone Color Scanner) and Heat Capacity Mapping Mission (thermal infrared) imagery. To evaluate the application of such imagery to analysis of coastal processes and features--especially for sediment transport models--and to suggest guidelines for development of future satellite instruments suitable for the Corps' data bases and models.

Description of Work

The Gulf of Mexico near Mobile Bay is being studied and modeled, using satellite imagery, to evaluate dredge disposal sites and to gather data on turbidity and currents. Water samples have been collected to be compared with data from the NIMBUS-7 Coastal Zone Color Scanner. Other satellite systems will be compared with NIMBUS-7 to refine spatial data. Oceanographic processes in Cook Inlet will be studied. HCMM, NIMBUS-7, and SEASAT synthetic aperture radar (SAR) imagery will be evaluated for additional data they can provide. Circulation charts and maps that delineate major currents and processes of special importance will be prepared. A study of the detection and quantification of effects of glacial sediment on coastal areas of Southern Alaska, using satellite data, will be done. The all-weather capability of SAR imagery should be especially useful in Alaska where clouds obscure the coastal areas 50-70 percent of the time.

The study will begin with a literature and imagery search for the three test sites and an evaluation of state-of-the-art algorithm development. Capabilities of various sensors will be compared in light of the problems and the integration of spatial data. Future needs of sensor sensitivity and algorithm development will be delineated.

Background

Economical techniques for acquiring current, turbidity and biological data are needed to assess the environmental impact of coastal structures and dredging disposal sites. Findings can be used to evaluate future satellite systems, analyze SAR imagery for future investigations of wetlands and coastal tide lands, and provide guidance for the Corps in the application of microwave remote sensing to analysis of offshore and nearshore oceanographic processes and nearshore terrestrial features.

PREDICTION AND MANAGEMENT OF FLOODS

Updating Flood Damage Data Base Using Landsat Data

Objective

Develop and demonstrate the ability to rapidly define flooded areas as a function of river stage and land use, and develop timely and economical procedures for updating data bases on land use and historical flood conditions, using data from current Landsats and Landsat D.

Description of work

The Lower Mississippi Valley Division (LMVD) Flood Damage Estimation System will be used as the starting point. Changes will be made to permit more rapid, economical, and accurate calculations and to make use of optional pathways possible. Map display ability will be added.

Landsat digital data will be a prime source for the land use data base. The system will still accept data from other sources when Landsat data is not available or when there is a cost or time advantage.

The system will be designed for use on various computers with various peripheral devices. It will be transferable to Corps offices with minimal loss or change in system capabilities.

Periodically, personnel of the Waterways Experiment Station (WES) and LMVD will meet to review the program, revise methodologies as necessary, and ensure that products meet user needs.

Background

LMVD currently operates a Regional Flood Damage Estimation System, developed by WES. This system includes data for the levee-protected region along the Mississippi and Atchafalaya Rivers from the Gulf of Mexico to Cairo, Illinois, and is used for water management and control, alternate flood control project planning, and estimating regional flood damage.

LMVD intends to use the improved system in water management and flood control project planning for which the present system is unsuitable. The Division anticipates tripling the geographic region of coverage.

Flood Damage Estimation System

Objective

To obtain data on flooded areas of the Lower Mississippi Valley as a function of river stage, for use in the Lower Mississippi Valley Division's Flood Damage Estimation System.

Description of Work

Districts within LMVD provide USGS maps with water resource units delineated. The Waterways Experiment Station (WES) is interpreting land use from false color infrared aerial photographs and converting elevation and land use data to digital form for input to a master computer-based file. Analyses of relationships between flooded area and flood stage are performed using this master file. Procedures are being improved to provide additional data analysis abilities and to use Landsat satellite data on land use and historical flood conditions.

Relations between flooded area and stage will be determined as a function of water resource unit and land use.

Background

The processing of data for the levee-protected area of the New Orleans District has been completed. All data were placed in the technically-advanced form of the LMVD Flood Damage Estimation System, and were analyzed to yield stage/area relations. Similar studies for the Vicksburg and Memphis District regions are in progress.

Updating Regional Flood Location Data For Emergency Operations

Objective

To develop and demonstrate rapid repetitive coverage of the flood waters over the Lower Mississippi River Valley Division region which is involved in large floods. The capability will be used in flood damage control and emergency operations.

Description of Work

This work will produce a set of flood maps within 24 hours of satellite image acquisition, and each 24 hours thereafter. Satellite data will be acquired by existing receiving stations, so that purchase of special direct-reception equipment will not be required.

The primary source of data will be the TIROS N satellite and its successors. This satellite provides twice-a-day coverage of the central United States through a four-channel multispectral scanner with 1-kilometer resolution. Supplementary data (of slightly lesser quality) will be obtained from the GOES satellite One of the multi-spectral bands in TIROS (and GOES) can be used to detect flood waters. Flood location data will be registered on topographic maps at various scales, providing maps readily usable by the Lower Mississippi River Valley Division.

Background

Extensive floods occur frequently in the Lower Mississippi Valley. During floods, the Corps must gather information for its own use in flood control and for use by other Federal agencies and state and local governments. The extent of flooding and floodwater movement are normally determined daily by measurements from hydrographic survey boats and from permanent gauge locations scattered throughout the Valley. These measurements must be manually interpreted. The Corps intends to improve its methods so that information on flood extent is more timely and accurate. The system will be useful not only in the Mississippi Valley but also in flood control work involving any large river systems, such as those in the Republic of China.

Yazoo and Tensas River Basin Studies

Objective

To prepare land-use maps and stage-area tables for various headwater and backwater reaches in the Yazoo and Boeuf-Tensas River basins.

Description of Work

Land-use classes will be delineated from Landsat digital data and portrayed as overlays for USGS topographic maps. Elevation and land use data will be gridded for analysis by computer (the elevation data being obtained from the topographic maps). The computer analysis will simulate flooding in each reach of the basins and calculate stage-area tables.

Background

Procedures and products developed in the Tensas River Basin study have been applied to headwater and backwater reaches with satisfactory accuracy and economy, and the products were judged by the Planning Division of the Vicksburg District to be of superior quality to those produced using traditional methods. Further development was initiated by the District as a result of favorable initial results.

HYDROLOGY

Automated Procedures For In Situ Measurement of Hydrologic and Environmental Parameters in Cold Regions

Objective

To develop, assemble and evaluate electronic techniques for interfacing state-of-the-art hydrological, meteorological and environmental sensors to the GOES data relay system. To demonstrate the operational utility of data acquisition relay systems.

Description of Work

State-of-the-art hydrologic and environmental sensors (such as snow and ice gauges, temperature sensors, and water quality sensors) will be tested under cold weather field conditions. Modifications will be made and interfaces for relay systems developed and demonstrated. The spatial distribution of sensor sets will be statistically analyzed to determine appropriate sample spacing.

Background

As new sensors and electronics become available, older sensors and interface equipment should be updated. Sensors that are subject to freezing and thawing represent special problems, and need further development.

Remote Sensing of Lake, River and Sea Ice Conditions

Objective

To demonstrate and update the use of satellite imagery for monitoring ice conditions on rivers, lakes, and near-shore ocean. To provide quantitative, time series information on changes in ice formation, type, characteristics, movement and ablation in specific geographic areas.

Description of Work

Capabilities of future satellite systems to provide data on river, lake and ocean ice cover will be demonstrated for planning studies (including the Spatial Analysis Method, the Habitat Evaluation Program, and the Flood Plain Management Project) and applied where ice hazards exist. A number of sites in the northern Districts and Divisions will be selected for study. Corps operational personnel will participate in evaluations of the utility of the new data and will recommend any changes necessary in the study. Historical ice conditions will be evaluated and current-year conditions will be updated. Where ground truth data are available, comparisons with satellite data will be made.

Background

Satellites such as Landsat, NOAA, NIMBUS, and TIROS have made it possible to observe the formation, extent, and breakup of ice conditions on water bodies. Data from new satellite systems will have improved spatial and temporal resolution, and thus become more useful to the Corps for planning, design and operations.

Snow Cover Analysis Using Landsat Digital Data

Objective

To map snowcover and land use categories from Landsat computer-compatible tapes and to determine if an indirect relationship exists between snowcover or land use categories and ground-truth information collected on snowpacks.

Description of Work

Computer classifications of snowcover and vegetation categories will be made in studies of the Sleepers River Watershed in Vermont and the Kootenai River Basin in Montana. The areal extent of computer-mapped snowcover and vegetation categories will be used to estimate the water equivalent of the snowcover for each unit in the basins. This information is required by the Streamflow Synthesis and Reservoir Regulation model. Computations using conventional snowcover data will be compared with computations using satellite data.

Background

Prediction of water equivalent of snowcover will be less costly and more accurate if data can be extracted from Landsat computer-compatible tapes to supplement conventional snow survey data.

Land Use Identification by Satellite

Objective

To make satellite imagery a readily usable tool for land use and land cover identification.

Description of Work

- Test and improve existing procedures
- Develop and field test new procedures that use high resolution satellite data
- Determine the accuracy and sources of error in present procedures, and test NASA's new geometrically-corrected Landsat tapes
- Improve resampling methods for geometric transformation of spatial data
- Improve procedures for the transfer of technology to field offices
- Investigate the application of these techniques to other hydrologic and related studies
- Verify new procedures and integrate them into existing procedures.

Background

The work will help in defining land use and other geographic features important to hydrologic analyses. The most important variables in such analyses are characteristics of runoff surfaces such as land use, soil type, and soil moisture content.

Satellite imagery has been shown useful for hydrologic land use classification by previous NASA/Corps studies. This work unit will improve technical capabilities and methods of analysis and transfer the technology to the field in a practical format. Results of these studies in conjunction with satellite imagery should make land cover identification for hydrologic and environmental studies less costly.

ENVIRONMENTAL ASSESSMENT

Wildlife Habitat Identification and Mapping Using Airborne Sensors

Objective

To compare information content, reliability, and cost of acquisition and analysis of aerial photographs and Landsat data for wildlife habitat identification and mapping.

Description of Work

Using aerial photographs and Landsat data, habitat variables for a number of models will be categorized, based on commonality, natural associations, and detectibility. Landsat data analyses will include seasonal scene analysis to improve detection and mapping of vegetation cover types. The accuracy and consistency of this method will be evaluated in restricted geographic areas of selected Corps' Districts.

Waterways Experiment Station computer programs, designed to overlay areally distributed environmental parameters automatically, will be modified to produce habitat maps. Standard photo-interpretation techniques will be based on analysis using the Habitat Evaluation Program. Landsat and photo-interpreted data will be supplemented with ground-truth data. The accuracy and cost of producing each of the four habitat map series from Landsat data alone, aerial photographic data alone, Landsat data with ground-truth data, and photographic data with ground-truth data will be compared. The results will be used to prepare criteria for using the different types of data, alone and in combination.

Background

Increases in costs and manpower required for wildlife habitat impact studies have caused problems for the Corps' field activities. It has been difficult for the Districts to keep up with expanded requirements, and project planning schedules are often delayed. Versatile, rapid and economical methods are needed to produce wildlife habitat maps and to provide quantitative habitat data for Corps projects.

Detecting and mapping wildlife habitat by conventional photo interpretation of aerial photography continues to increase in cost. Advancements in information extraction from digital Landsat scenes have demonstrated the feasibility of using seasonal data from Landsat as a rapid and comparatively inexpensive source of habitat data.

Evaluation of Satellite Data Products to Assess Long-Term Cumulative Impacts on Cold Regions Terrain

Objective

To evaluate the use of sequential Landsat computer-compatible tapes (CCTs) and other satellite products in assessing surface impacts and recovery following permitting or construction activities.

Description of Work

Several sites in cold regions will be selected and sequential Landsat CCTs will be processed to measure changes resulting from construction activities. Site visits and conventional data will be used to correlate satellite interpretations.

The Prudhoe Bay region is a prime candidate for this demonstration. Many permits under the Water Pollution Control Act are active there, and surface drainage changes are easily observed, It will be possible at the same time to compare wetland mapping units using the NWI-CIR interpretations and seasonal Landsat classifications of impact. Sites in the New England Division will also be examined.

Background

Large construction projects modify the ground surface. Access roads built across flat frozen terrain may alter the surface or impede drainage to a degree detectable by satellites. Historical changes in frozen terrain are difficult to document, but satellite imagery can provide, repetitively, pertinent data on large features. This data, combined with data from other sources, can provide information necessary for mitigative actions to personnel involved in planning, operations and regulation.

Landsat Capabilities for Wetlands Mapping

Objective

To develop a capability to use Landsat data for detecting and mapping areas that are likely to be classified as wetlands by Corps' field offices. To apply that capability in selected Corps districts for evaluation. To establish criteria for use of the capability.

Description of Work

Wetland study sites will be selected jointly with Corps' districts to represent a wide range of wetland types. A map of each site will be prepared by the District Regulatory Functions Branch for use as a standard in evaluating the accuracy and reliability of Landsat data interpretations of the study sites. A survey of available Landsat data processing procedures will be made and the most promising techniques will be evaluated.

Background

The Corps is responsible for regulating activities in wetlands through the issuance of permits. To review applications for permits under the Water Pollution Control Act and to determine the need for field reconnaissance and detailed inspection prior to final disposition of applications, Corps field offices require data on locations of wetlands. Landsat provides the only available current data covering the entire United States, is readily updatable, and is inexpensive. In addition, Landsat shows promise as a tool for detecting unauthorized activities such as land clearing, and for monitoring authorized activities to check compliance with boundaries specified in permits.

DEVELOPMENT OF TECHNIQUES AND EQUIPMENT

Software Systems for Processing Advanced Satellite Data

Objective

To prepare for the advent of satellites with higher resolution, such as Landsat D and the French Systeme Probatoire d'Observation de la Terre (SPOT), and to define the most timely and cost-effective means of acquiring and processing these data for civil works applications.

Description of Work

- Analyze, model and develop techniques and software for extracting information on terrain from data provided by Landsat D and SPOT
- Obtain hardware and software tradeoffs and costs for computer processing of data from the Thematic Mapper (TM)
- Develop recommendations for characteristics of hardware and software systems

Simulation and analysis of TM data, using digital data from the Landsat return-beam vidicon (RBV), was scheduled for completion during fiscal year 1981. Delays in obtaining RBV data have necessitated substitution of SEASAT data for the RBV data. During FY 81, other data simulating TM data will be acquired and analyzed.

Background

Data from Landsat D, to be launched about 1982, will have a resolution of 30 meters. SPOT, to be launched about 1984, will have a resolution of 10 or 20 meters. The higher resolution of these advanced satellite systems offers high potential of alleviating many problems in the application of remotely sensed data.

Results to date indicate that there are several serious obstacles to near-term use of Landsat D data by the Corps. These problems include technical problems with the design, fabrication and deployment of the TM; lack of definitive requirements for use of MSS and TM data in the civil works program; uncertainties in future operations caused by the transfer of responsibility for land remote sensing from NASA to NOAA; and the inability of NASA to provide simulated test data.

Evaluation of Landsat D Data Products

Objective

To evaluate simulated high-resolution multispectral data from Landsat D and stereo data products for application to problems of water resources, geology and cold regions pertinent to the Corps' mission.

Description of Work

Available digital elevation data with a vertical resolution of 7 1/2 meters will be used with orthophotoquad coverage of a 7 1/2-minute quadrangle site to evaluate panchromatic, stereoscopic data (10-m resolution) from a high resolution sensor. The resulting slope and aspect information will be compared with that obtained using data from the current Landsat return-beam vidicon.

Recommendations on potential uses of Landsat TM and higher resolution data will be developed.

Background

Results of simulations will provide state-of-the-art technology for use by the Corps' Districts, Divisions and Headquarters in their planning, engineering and operational activities.

Computer-Assisted Information Extraction

Objective

To demonstrate the application of an analytical photogrammetric processing system and a computer-assisted photo interpretation research facility to extraction, analysis and manipulation of remotely sensed data.

- Evaluate, demonstrate and document the potential of an analytical photogrammetric processing system (the APPS-IV) for solution of data extraction and data base development problems

Description of Work

- Identify problems in data extraction and data base updating that can be addressed using the APPS-IV, augmented by a computer-assisted photo interpretation system (CAPIR)

- Develop a test plan and perform specific tests and demonstrations to demonstrate the utility of an APPS/CAPIR-type system for civil works applications.

Research by the Engineering Topographic Laboratory (ETL) on military projects, using APPS/CAPIR, will be monitored and assessed for possible civil works applications.

Instruction manuals for using APPS on civil works problems will be prepared as supplements to the Corps' Remote Sensing Manual.

Background

Currently, classical photogrammetric techniques are used to extract topographic and other terrain information from aerial imagery. A recently-developed class of photogrammetrics systems, typified by APPS, allows highly specialized terrain analysts, with as little as four hours of training in photogrammetry, to use their interpretation skills in performing photogrammetric operations.

To help trained human specialists extract information from stereoscopic imagery, ETL has assembled a research facility for computer-assisted photo interpretation. The facility can be used to demonstrate point positioning, mensuration, profiling, elevation and slope determination, and map and data base updating.

Appendix B

RECOMMENDATIONS OF RECENT REPORTS RELATING TO THE CORPS' REMOTE SENSING PROGRAM

In evaluating the Corps' remote sensing program, the panel considered the recommendations of two recent studies by committees of the National Research Council (NRC).

A report of the Water Resources Research Review Committee (WRRRC) of the NRC's Commission on Natural Resources (ref. 12) reviews a proposed five-year plan for the overall national water research programs of the 11 major departments, agencies and administrations concerned. The report of the Panel on Water Resources (ref. 2) provides an overall review of remote sensing activities related to water resources and hydrology, and recommends research emphasis for the 1980s.

The WRRRC report reviews a proposed water resources research plan for fiscal years 1983-87. The plan was prepared in response to the Water Research and Development Act of 1978. The WRRRC identifies 31 research areas where, in its judgment, emphasis should be placed. Remote sensing is not discussed, although it appears as a line item in the report's tabulations of several agency budgets.

Some important findings of the WRRRC are:

- The proposed five-year plan does not describe an integrated, coordinated five-year research program; rather, it is a compendium of individual agency programs
- Funding for research on water resources is at a modest level--about 2% of federal funding for all water resources activities
- No one federal agency or interagency group is charged by law or executive order with the responsibility for defining overall goals, determining priorities, or coordinating the work of the various agencies

- The deficiencies noted in the proposed five-year plan are continuing evidence that ad hoc management of the federal water research program will not produce the results Congress expected when it enacted the Water Research and Development Act of 1978.

Although the panel's present task does not include consideration of across-the-board federal policy on water resources, the panel concurs fully with WRRRC's findings. It believes that federal research on water resources needs integrated and coordinated top-down management, is funded at a very low level in light of total expenditures for federal water activities, and is largely based on ad hoc task force efforts that have not provided effective guidance.

The findings of the WRRRC report concerning the Corps of Engineers are:

- About 40% of the Corps' proposed water resources research program appears to be mission-oriented, and to be largely devoted to demonstration, technology transfer, and service, rather than research

- Although the Corps has classified its entire program as priority research, only a very small portion of the program seems in practice to be such

- As much as 20% of the program directed at problems of materials and construction methods is related to water resources only insofar as it serves the mission of the Corps

- A number of the Corps' research projects should be conducted in coordination with other agencies: these include projects on aquatic weed control, water quality, water conservation, soils, rock, concrete, mechanical and structural engineering, estuary models, and hydrologic methodology.

The Panel on Remote Sensing for Water Resources and Hydrology believes that the part of the Corps' water resources program that deals with remote sensing is almost entirely mission oriented. It has not attempted to assign priorities to the Corps' remote sensing activities.

The panel also considered the Corps' research on remote sensing for water resources in light of the recommendations of the National Research Council's 1980 report, "Remote Sensing for Water Resources and Hydrology--Recommended Research Emphasis for the 1980s" (ref. 2).*

*Some members of the present panel participated in writing ref. 2.

The report reviewed activities in remote sensing for water resources since the 1972 launch of Landsat and reached the following conclusions:

- There is need for greater emphasis on hydrologic modeling. NASA, in consultation with the Corps of Engineers, should select one water resources problem and make systematic sensitivity studies of pertinent parameters to determine which are most important, and to establish requirements for accuracy and other characteristics of remotely sensed data

- Either NASA or the Corps should begin conceptual development of a water resources and hydrology model designed to use remotely sensed data in a high-priority activity

The panel reaffirms its belief that hydrologic modeling is essential and should be emphasized by the Corps and by NASA. Sensitivity studies should be undertaken as high-priority work and research begun on water resources and hydrology models that use remotely sensed data to full advantage.

The Corps' Hydrologic Engineering Center and others have made a good start on using remotely sensed data in conventional hydrologic models.* However, neither adequate sensitivity studies nor the development of hydrologic models that use remote sensing to full advantage (in flood and flood plain management, for example) have been undertaken. Such models could reflect the effects of changes in land use or cultural structures on floods and on flood plain management.

The 1980 report of the Space Applications Board identified three important categories of remote sensing applications:

> Applications now ready for operational use include forecasting runoff from mountain snow packs, survey of aquatic vegetation, land use mapping, and surveillance of ice conditions.
>
> Applications that require further demonstrations and trials before being put into operational use include relating urban development to changes in runoff and assessing shoreline processes and river channel migrations.
>
> Important applications that require additional research and development include assessment of soil moisture, mapping of indirect indicators of areal extent and depth of groundwater, prediction of flood conditions, real-time measurement of rainfall, measurement of the effects and sources of acid rain, detection and measurement of suspended solids and salinity, assessment of lake eutrophication, and assessment of tidal regimes in estuaries.

*These are off-the-shelf models such as HEC-1, HEC-2, SWM, and STORM.

Some of these tasks fall in the missions of agencies other than the Corps. Some activities in the Corps' program of remote sensing for water resources and hydrology do attack the problems pointed out in the panel's report. However, the level of the Corps' activity would have to be increased significantly to be of help in solving these problems.