VIII. Water Resources

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Remote-sensing techniques can be extremely useful for all aspects of watershed analysis. For example, they have been used for determining runoff from watersheds, for estimating flood hazards, and for performing flood zone studies. In addition, such studies are extremely valuable in connection with identification and analysis of droughts. Soil moisture, which relates to runoff from the watershed, can be mapped. Ground water can be considered, and methods of improving ground-water storage as well as of identifying ground-water reservoirs represent possible uses of remotely sensed information. The interrelationship of all these many factors helps water resource researchers to obtain common, useful answers. Studies in water resources management and development have involved most regions of the United States and several foreign countries. The results of such studies can be incorporated into models that lead to planning, decisionmaking, and ultimate development.

This summary is subdivided into broad headings, arranged in an order intended to assist the reader in obtaining a better, more meaningful overview of the contributions that have been made, the areas of research that should be pursued, and probable long-term benefits that can be realized by undertaking continued activities of these types.

GEOLOGY AND HYDROGEOLOGY

Skylab and Landsat data are excellent for the identification of major watershed features, such as large-scale rock formations, drainage networks, major faults, and vegetated areas. However, because of the vast area visible by this means, remote sensing from space platforms cannot give the detailed information that may be of interest within a watershed. Aircraft-flown sensors are needed for classification of details where much greater resolution is required. By this means, data can be gathered at a scale chosen to obtain the desired detail for studies of particular small areas or points of interest.

ANALYSIS OF WATERSHEDS

Water resources represent one of the most valuable assets of any nation. To understand, to appreciate, and to properly use water resources, one must understand the overall complexities of watersheds and river systems. Figure VIII-1 illustrates the complexity and area of a major river system. The Mississippi River watershed, like that of any size river, is both complex and dynamic. In fact, rivers are the most rapidly changing of all geomorphic forms.

One can clearly identify and study stream networks and their characteristics using data from Skylab, Landsat, and aircraft sensors (W-8, vol. I-D). All sources of data are useful, and the ultimate value of remotely sensed data depends on the problem being studied. For an overview of the watershed and for the determination of some of its major features, Skylab or Landsat data are indispensable. Conversely, for studying in detail a short reach of river, riverbanks, or a remote watershed, aircraft data become more valuable because one can concentrate on a small area and obtain sufficiently detailed data to analyze even the most minute aspects of the watershed.

As a result of recent studies of watersheds and their characteristics, techniques have been developed that enable more accurate identification of impervious parts of the watershed, whether they are impervious as a consequence of natural formations or as a consequence of man's development of the surfaces. This capability to sense the imperviousness of a surface is an advance that will improve man's ability to assess the effects of such surface areas on the magnitude of runoff, the time of concentration, the time of peaking, and so forth.

SNOW AND ICE

In considering water resources, snow cover is an integral and important part of the hydrologic scene. Either directly or indirectly, snow cover affects most of

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the world population; snowmelt affects floods and droughts, and water for irrigation, for industrial production, for hydroelectric power development, for recreation, and for a multitude of other uses.

Using satellite imagery (W-24, vol. I-D), the extent of snowpack and its spatial variation with time can be mapped (fig. VIII-2). Furthermore, it is now possible to differentiate between snow and clouds by use of a scanner such as the Skylab S192 (because the Skylab data showed snow cover to have much lower reflectance in the near-infrared portion, 1.55 to 1.75 micrometers, of the spectrum). Previously, clouds over snow were difficult to identify. The ability to differentiate between snow and clouds is a significant breakthrough for both hydrologists and climatologists.

Multispectral comparison of satellite imagery has made possible delineation of that part of the snowpack actively undergoing snowmelt. Continued surveillance can identify the active and inactive parts of the pack as they relate to runoff of the watershed at any particular time.

PREDICTION OF RUNOFF FROM SNOWMELT

Associated with the snow cover is the prediction of runoff as a consequence of snowmelt. Large changes in snowcapped areas are often visible in successive satellite imagery over relatively short periods of time (W-23, vol. I-D).

Measurements of the satellite-derived snow cover area have been related to seasonal streamflow, and results indicate that snow cover is a potentially important index parameter for reducing error in runoff forecasts (W-26, vol. I-D). Even a small increase in the precision of predicting runoff can be an extremely important contribution because water and knowledge of its availability is so fundamental to both technology and economy. Because of the promising results regarding improved forecasts, NASA has activated a program involving six Federal and three state agencies. These groups are doing snow mapping and conducting tests related to snow area technology and use of operational systems to improve runoff estimates.

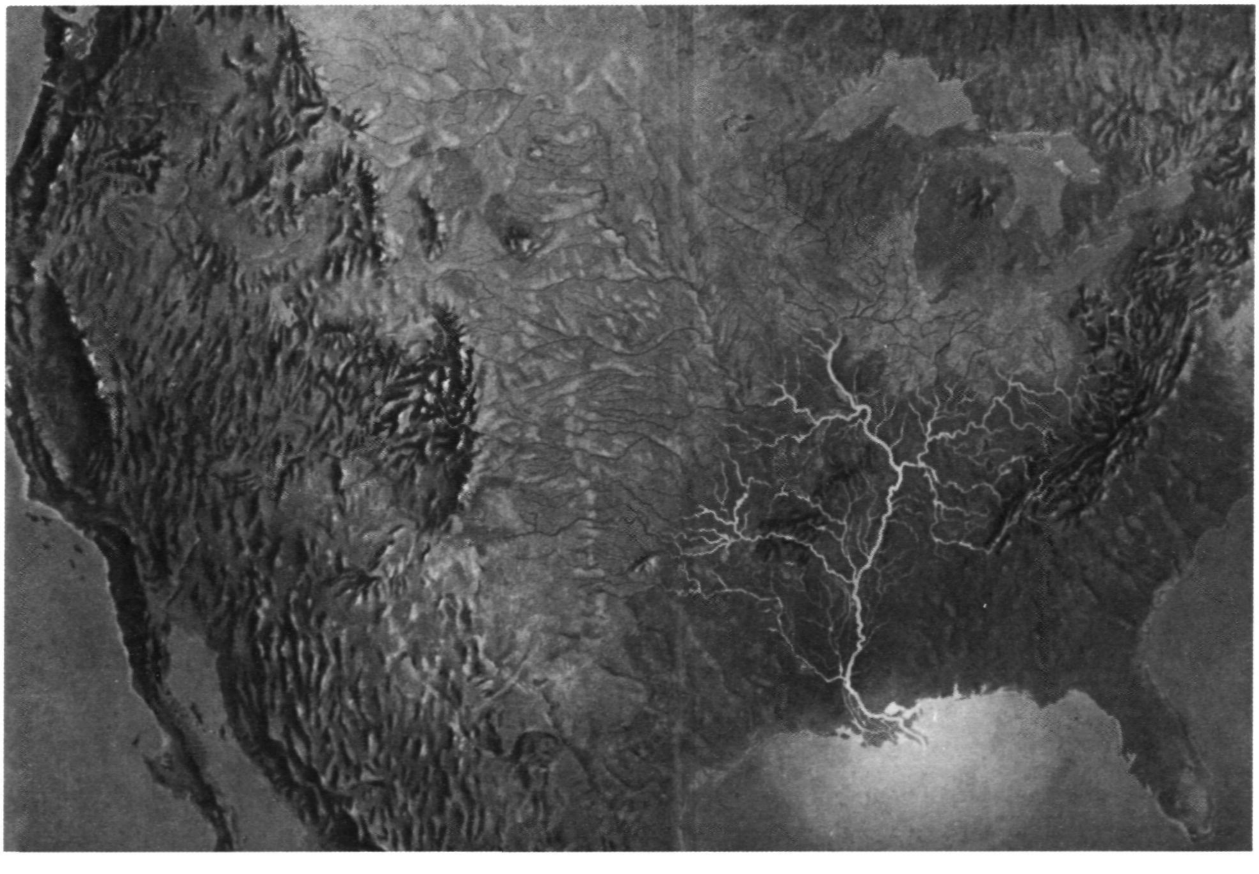
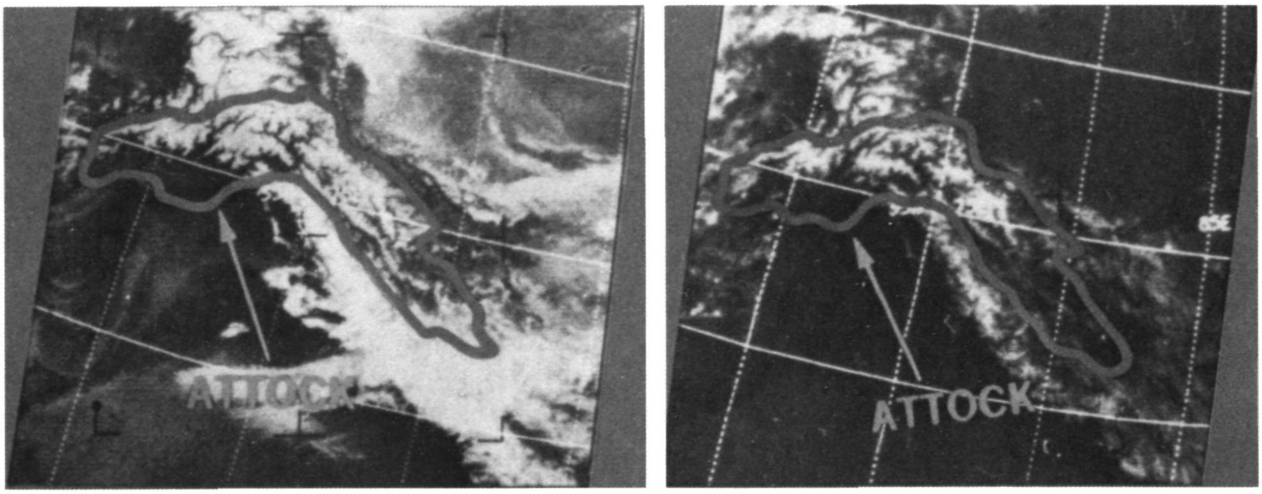


Figure VIII-1.– Extent of Mississippi River watershed.



(a) April 4, 1969: snow-covered area, 60 percent; predicted April to June runoff, 29 590 000 acre-feet.

(b) April 3, 1971: snow-covered area 44 percent; predicted April to June runoff, 24 990 000 acre-feet.

Figure VIII-2.– Satellite observations of the variation is snow cover at the beginning of snowmelt in the Indus River Basin. Imagery is from the Environmental Science Service Administration satellite ESSA-9.

HYDROLOGIC LAND USE CLASSIFICATIONS

Hydrologic land use classifications are important to river watershed management. Multispectral analysis of satellite and aircraft data can yield this vital information regarding the water surface, the agricultural activity and type of agriculture, urban development, residential construction, forested areas, marsh areas, and so forth in the watershed (W-13, vol. I-D). Such analysis techniques have been applied to satellite and aircraft data to provide a broad and detailed information base related to conditions in the flood-prone areas of the watershed. These data have been compared to conventional U.S. Geological Survey (USGS) flood-plain boundary maps, and unflooded regions were shown to exist within the USGS-identified flood boundaries. An important point should be made here. When remotely sensed data are used to study a watershed, an opportunity to look at the total watershed is created. Of course, the detail depends on the type of remotely sensed data available. Conversely, when flood-plain boundaries are based on field reconnaissance and field surveys, time limitations may prevent consideration of all conditions adjacent to the streams. Consequently, the occurrence of unflooded areas within flood plains may not be detected when conventional methods are used.

The cost of studying watersheds varies greatly depending on the details desired. Watershed mapping by satellite of the type mentioned could be conducted for an approximate cost of $4.30 per square kilometer. This technique enables the mapper to obtain an excellent understanding of at least 90 percent of the watershed being studied.

Other studies (W-19 and W-22, vol. I-D) indicate that significant financial savings result from using remotely sensed data properly. In one instance, the most economical method of performing a land survey involved using U-2 aircraft imagery, although both the satellite and the U-2 data provided less expensive and more effective information than could be obtained using conventional methods. Remote sensing enables an overall view to the degree of precision dictated by resolution requirements and budget limitations. Such information helps resolve differences in survey statistics regarding areas of irrigated land, fallow land, and other land uses. More precise information of this type assists greatly in planning and developing an area.

SOIL MOISTURE

Skylab microwave data, especially from the L-band, have indicated a high correlation between radiometer temperature and soil moisture content near the land surface (W-6, vol. I-D). Such information is extremely valuable to all groups and individuals interested in watershed utilization and development. For example, in considering runoff from watersheds, knowledge of the moisture values at any given time over the total watershed would add greatly to the precision with which storm runoff and sediment discharge from the watershed could be estimated for immediate and subsequent storms.

EVAPOTRANSPIRATION

When water availability and utilization from and on the watershed are being considered, knowledge of evapotranspiration rates is important. More specifically, it is vital to irrigated agriculture and water supply for all users. Maps estimating evapotranspiration rates from the agricultural landscape have been produced using Skylab S192 data (W-21, vol. I-D). These results were evaluated using ground measurements. Such studies can greatly benefit operational irrigation scheduling management systems.

PLAYA LAKES

The many small, shallow playa lakes in the High Plains of Texas, or similar lakes anywhere, are of great importance in the optimum use of water resources. These lakes also may affect the salinity of adjacent lands. In the High Plains of Texas (W-18, vol. I-D), nearly 70 000 irrigation wells are in operation. As a result, water is being mined from this region more rapidly than natural recharge can resupply it. Overuse of the ground water ultimately may affect the agricultural economy of the area significantly. Remote-sensing techniques are being used to obtain current statistical information on the number and areal extent of the playa lakes in this region. The State of Texas is considering these lakes as a possible source of water to help recharge the ground-water basins. If the lake water could be introduced into the ground-water reservoir, it would not only greatly enhance the local water supply but would greatly reduce evaporation losses in the region. Lakes of this type have very high evaporation losses.

Another important factor is the effect such lakes have on the salinity of adjacent lands. Salinity can be studied using satellite- and aircraft-sensed data, but salinity conditions are dynamic. Because of its transient nature, salinity varies considerably with time. After a period of wetness, much of the saline area may be difficult to observe as a consequence of the flushing action of the rainfall. Conversely, during extended dry periods, the saline areas grow in size and are easily identified. Therefore, analyses must be performed carefully to make certain that reliable results are obtained.

SURFACE RUNOFF

Many methods are currently used to estimate surface runoff from watersheds. Runoff coefficients for an empirical equation have been related to remotely sensed data, both from Landsat multispectral and aircraft passive microwave systems (W-15, vol. I-D). This relationship is simple and effective and considerable advantages are to be gained by continuing to utilize these simple, effective concepts. However, as a consequence of improved data provided by satellites and aircraft, more complex methods of estimating surface runoff are gaining attention. The capability, through remotely sensed data, to obtain information on land use, antecedent moisture, precipitation, evapotranspiration, geology, watershed geometry, vegetative types, and so forth will lead to advanced techniques for assessing and allocating water resources.

FLOOD HAZARDS

Flooding is an international problem. From the beginning of time, man has tended to populate the river valleys because they are fertile and because rivers have provided cheap transportation. Therefore, a great need exists for knowledge of flood hazards. Information is needed on the extent of inundated areas, frequency of flooding, and possible remedial measures that could help alleviate flooding. Also, the consideration of overall environmental aspects is important.

Figure VIII-3 is a schematic of a common flooding situation. At low flows, the area inundated is relatively small. In fact, for the most part, the water is confined to the well-defined channel. However, during periods of flooding, large areas adjacent to the river channel can be subjected to various degrees of inundation. Therefore, certain basic information on the extent and the potential frequency of flooding is vital for more efficient land use. Suitable evaluation of the potential for flooding should incorporate much of the information already discussed: watershed geometry and geology, vegetative cover, soil types, soil use, antecedent moisture, snow cover, and so forth.

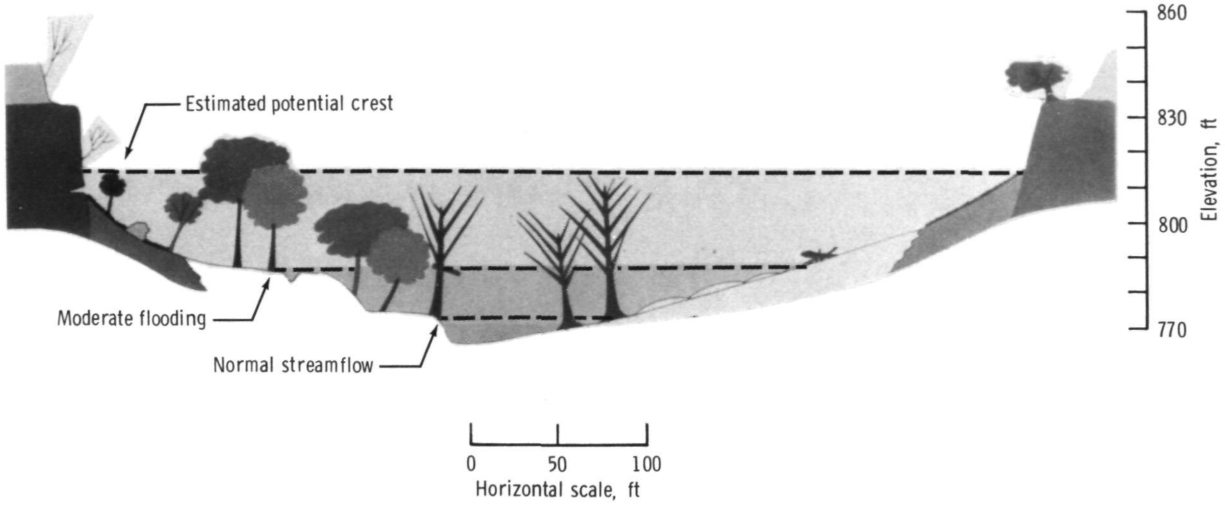


Figure VIII-3.– Schematic drawing of flood crest estimations.

WATER QUALITY SURVEYS

Remote sensing is of great value in assessing the water quality of both rivers and lakes. In one water quality study (W-12, vol. I-D), analysis of Landsat data produced eight distinct classes of water. Investigators have also found they can classify water, both in lakes and in rivers, to some extent by depth. With the advent of new water-penetrating film, more work is expected on this topic and very useful results should be produced. Studies of this type show that the identification of water quality problems related to the biomass and the sediment in a system is feasible.

Another aspect of water quality involves the inflow of contaminated streams to main stem streams. Hence, information concerning the mixing of flows from sewage treatment plants, industrial plants, and so forth with the water in a particular river is urgently needed.

One study of lateral and longitudinal mixing (W-11, vol. I-D) used thermal scanning and a two-dimensional mathematical model. The study indicated the possibility of differentiating, by using remotely sensed data, between a polluted effluent entering a stream and the better quality water in the stream. Such studies also give vital information concerning the rates and extents of mixing with respect to time and space.

Additional work is required in this area. The manner in which pollutants entering a stream, either from point or nonpoint sources, mix with the system must be determined. A great distance is sometimes required before thorough mixing is achieved. For example, a thermal plume from a steam powerplant was tracked 15 statute miles downstream of its source in one instance. Such studies will continue to provide valuable information about the environment and thus enable better utilization of total resources.

RIVER MECHANICS

In the preceding paragraphs, the broader view as it pertains to watersheds, water resources development, and some of the factors that can be sensed on the watersheds was discussed in detail. It is possible to make detailed studies of the river scene by use of data from aircraft sensors. In one study (W-10, vol. I-D), flows coming together at different velocities downstream of an island were photographed. The different velocities result in a shear flow that generates a line of large vortexes, which extend to the bed of the stream. The increased depth below this line of vortexes can be mapped from aerial photographs. Use of these techniques to study water movement can provide extremely valuable information about the location of a navigation channel, the distribution of sediments in the cross section of a river, the lateral and longitudinal distribution of velocities through a system, and so forth.

In the broad perspective, by using remotely sensed information from satellites and aircraft, geologic controls along the rivers can be determined and major structures of interest can be identified. Also, the different types of soil making up the riverbanks and the land adjacent to the rivers can be identified; the types of vegetation can be observed and related to soil type; and the rivers can be classified according to form. Finally, because rivers are dynamic, a sequence of photographs taken periodically provides extremely valuable information on the rate of change with respect to time. Such information is important in the development of water resources systems.

CONCLUSIONS AND RECOMMENDATIONS

The general conclusions resulting from this session attest to the great value of remotely sensed data in water resources studies. The papers and discussions in the water resources session not only add to the current storehouse of knowledge but it is anticipated that they will also help establish a path of endeavor that should lead to even better results in the future.

The following predictions can be made.

1. With the further development of remote-sensing techniques, more sophisticated and accurate models of runoff, sediment yield, water quality, salinity, and so forth will be developed for utilization in the future. Many such studies have been completed at least through the preliminary phases.
2. In the future, there will be greater utilization of simultaneous satellite, high-altitude aircraft, and low-altitude aircraft sensing missions to give adequate information for more detailed studies.
3. As we proceed into the future, much more interdisciplinary effort will occur with a greater tendency for those working in geology, land use, watersheds, water quality, agriculture, and so forth to cooperate in arriving at more meaningful and better answers to specific problems.

The following recommendations are offered.

1. The availability of data will be an important issue in the future. Some users of remotely sensed data will be increasingly interested in obtaining recent information on a near-real-time basis. Better methods of making data more readily available at an economical and timely rate must be developed.
2. Because many users of remotely sensed data do not have access to advanced and refined machine-processing equipment, such equipment should be made available to small users at a reasonable fee.
3. Work should be continued on watershed parameters.
4. Researchers should evaluate the significance of future snow and ice studies carefully.
5. More cooperation must be established between workers in remote sensing and in modeling. The work group stressed that there should be a marriage between remote sensors and modelers to get the most benefit from both fields.
6. Better working relationships must be developed between research communities and data users.
7. It is essential to stress the importance of practical communication, cooperation, education, and use of results produced from water resource studies.
8. Where a simple and effective concept exists, considerable advantages are to be gained by continuing its use.
9. In all aspects of using remotely sensed data, field verification work continues to be an important and fundamental part. Without such ground-truth information, the accuracy of the analysis of data from satellites and aircraft will be greatly reduced.

Finally, many of those participating in the water resources session are looking forward to the possibility of advanced satellites that relate specifically to problem areas such as hydrology, snow, rivers, and water quality.

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