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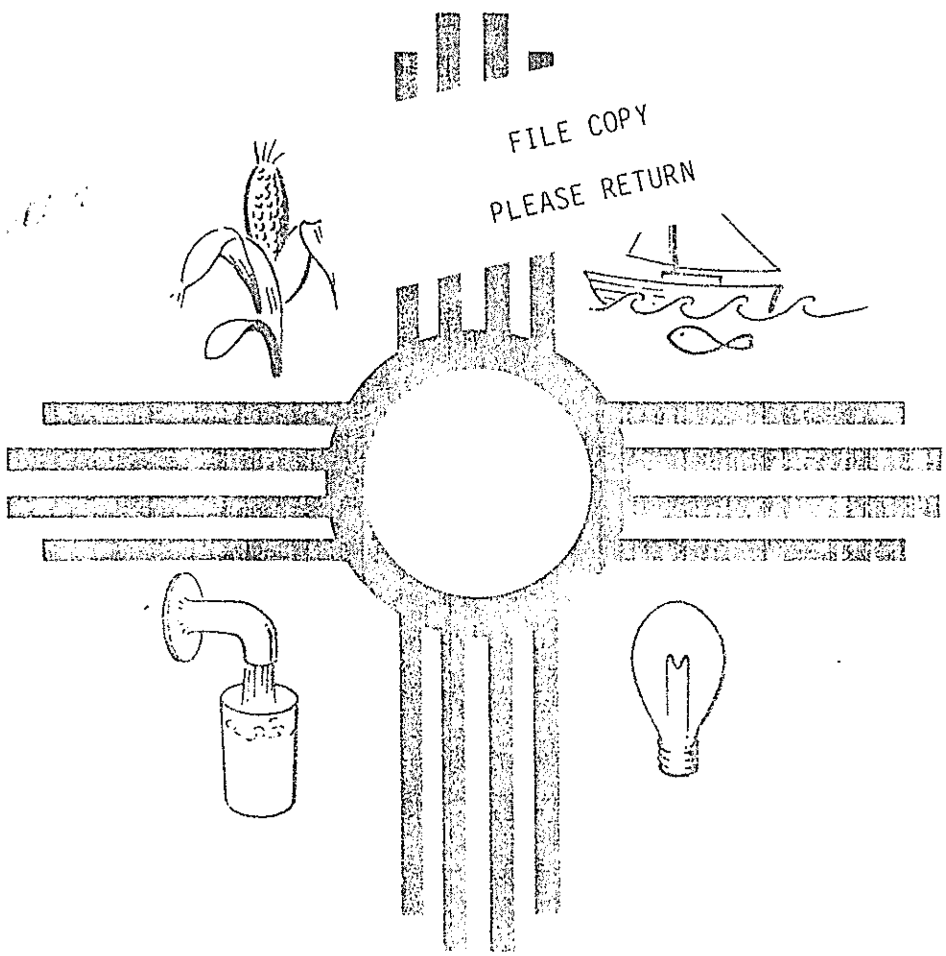
WRRI Report No. 077

EVALUATION OF REMOTE SENSING TECHNIQUES APPLIED TO WATER RESOURCE PROBLEMS OF NEW MEXICO

Technical Completion Report

Project No. 3109-204



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ABSTRACT

Remote sensing techniques are reviewed in terms of their application to hydrologic problems in New Mexico and the arid southwest. The evaluation includes aerial cameras, thermal infrared scanners, active and passive microwave scanners, and multispectral scanners. A report on the needs for improved hydrologic data in New Mexico served as the basis for matching proven and potential remote sensing capabilities in such areas as water quality monitoring, water conservation and preservation, water transportation and distribution, and others. Included in the discussion is an assessment of hydrologic model development and remote sensing. Results of the study indicate a number of application areas that could be addressed, now, using proven remote sensing techniques. Others could be developed through the creation of better models. The report contains a list of specific modeling ideas and recommendations for further research into these areas.

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Evaluation of Remote Sensing Techniques
Applied to Water Resource Problems
of New Mexico

INTRODUCTION

This report discusses remote sensing techniques as they might be applied to the needs and problems of water in New Mexico. The objectives of the evaluation were: 1) to review the remote sensing literature; and, 2) to match the most promising techniques with specific hydrologic research areas recognized in the state. The topical base of needs and problems forming the basis for the match were outlined by Creel (5), and have been reproduced in this report as Appendix IA.

Creel listed some 91 water related topics for consideration as research avenues. Although they are presented under the rubric of "needs and problems", the syntax of the statements does not lead one to interpret a specific addressable problem. For example, his statement "surface water resource inventories" does not convey the essence of a problem. Is there a requirement for more inventories? better measurement accuracy? or, a refinement of the categories of surface water to be included? Without additional information of this kind one takes a risk interpreting the statement. Of course, interpretation is more hazardous for some statements than for others. For purposes of this report we have singled out 36 statements, the syntax for which, suggests that the topic has a technical solution. These have been further condensed into eight major research topics:

- -Improved Water Information Dissemination Techniques and Programs,
- -Population Growth and Water Supply Relationships,
- -Ground Water Resource Inventories,
- -Environmental Resource Evaluation of River Basins,
- -Evaluation of Water Transportation and Distribution Systems,

-Water Conservation and Preservation Techniques,

-Water in Relation to Land Use and Development,

-Improved Methods of Water Quality Monitoring.

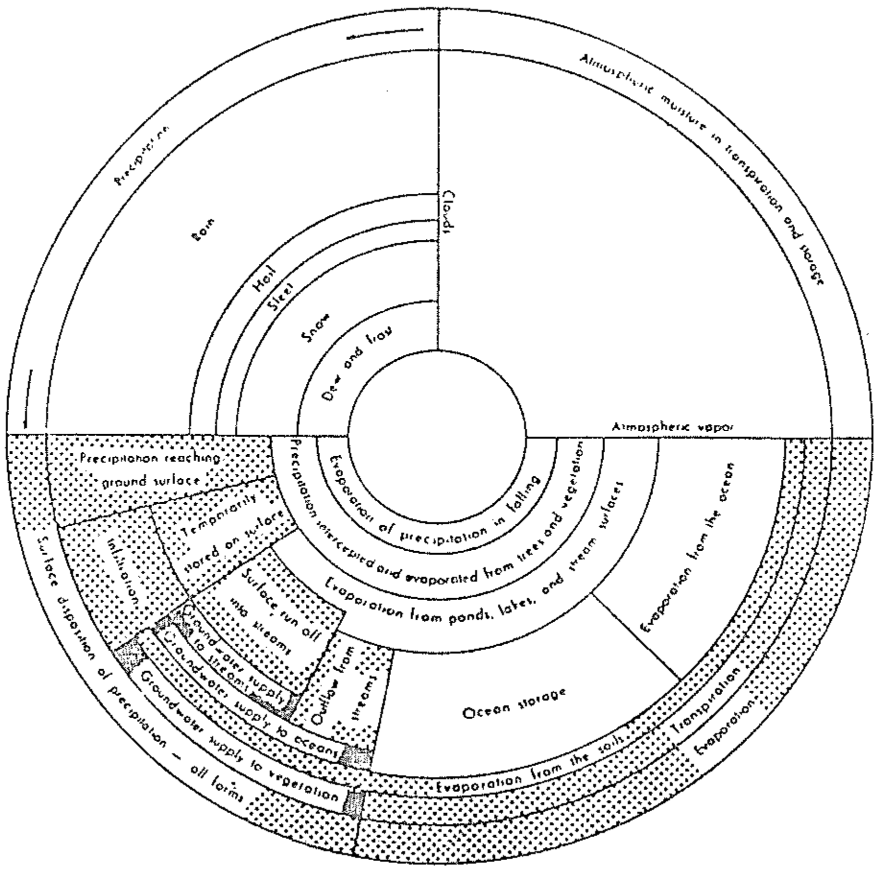
Appendix IB lists these eight topics and their associated subtopics. These subjects are the focus for discussion in our section titled *Review of Systems and Applications*. Figure 1 indicates the parts of the hydrologic cycle involved when the eight topic areas are interfaced with remote sensing. The stippled portion of the diagram shows topic areas for which we believe there are documented remote sensing applications; the shaded portion shows possible application areas. The remainder of the diagram refers to topic areas outside the purview of this report. We recognize that there are remote sensing techniques applicable to almost every phase of the hydrologic cycle, but we have excluded such systems as weather satellites from consideration in this report because they are global in scope and the data are readily available for use in New Mexico. For this report we have restricted the scope of sensing devices to those that produce an image.

"Remote sensing" has largely replaced the well known term "photo reconnaissance". This change in terminology was brought about by the development of several sensors which, together, span a wide segment of the electromagnetic spectrum. These sensors, unlike typical photographic cameras, record earth data either in digital format or create an image of the terrain by using the analog signal to modulate the intensity of a light source in a cathode ray tube. In all cases the end product is a photograph-like image. Sensors reviewed include: conventional aerial photographic techniques, near infrared, thermal infrared scanners, active and passive microwave scanners and multispectral scanners aboard Landsat. Although these sensors for the most part, are well proven data collectors, they should be used alongside proximal sensing methods.

We have consciously excluded from consideration non-imaging systems such as gamma ray spectrometers or radar scatterometers. Sensors such as thermal probes for ground water studies, (Mclin, et al., 28) were not included mainly because they represent

FIGURE 1

Possible Remote Sensing Applications
to the Hydrologic Cycle in New Mexico



Areas of documented Remote Sensing Applications.

Areas of possible Remote Sensing Applications, needing concentrated research.

Areas of the Hydrologic Cycle lying outside the purview of this report.

Diagram modified from: Van Riper, Joseph E., 1971, Man's Physical World, McGraw Hill Book Company, p. 176.

proximal sensors rather than remote sensors. Field checking techniques such as on site photography are also considered to be proximal sensors. Landsat Data Collection Platforms, (DCP), were *included* because of their direct tie with the orbiting Landsat satellite.

LITERATURE REVIEW

The Technology Application Center, University of New Mexico, can search a wide base of computerized literature files. This capability was used to conduct a search of remote sensing and hydrologic literature contained in the National Technical Information Service (NTIS)[1], and the GeoRef[2] files. In addition, the Water Resources Research Center at the University of Arizona was used to procure a search from the Water Resources Scientific Information Center (WRSIC)[3]. The searches were based on keywords taken from the 36 topics selected from Creel's report. These keywords were used to select references related either to the New Mexico environment or to hydrology in general. These bases were also searched for hydrologic models relating to the research subjects in Creel's report.

The design of the search strategy is given in Figure 2. The computer searches resulted in the retrieval of approximately 600 abstracts which were then reviewed to cull out duplicates and those with no relation to the research questions[4]. This

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[1]Information on the NTIS file system can be obtained from: National Technical Information Service, U.S. Dept. of Commerce, 5285 Port Royal Road, Springfield, VA 22151.

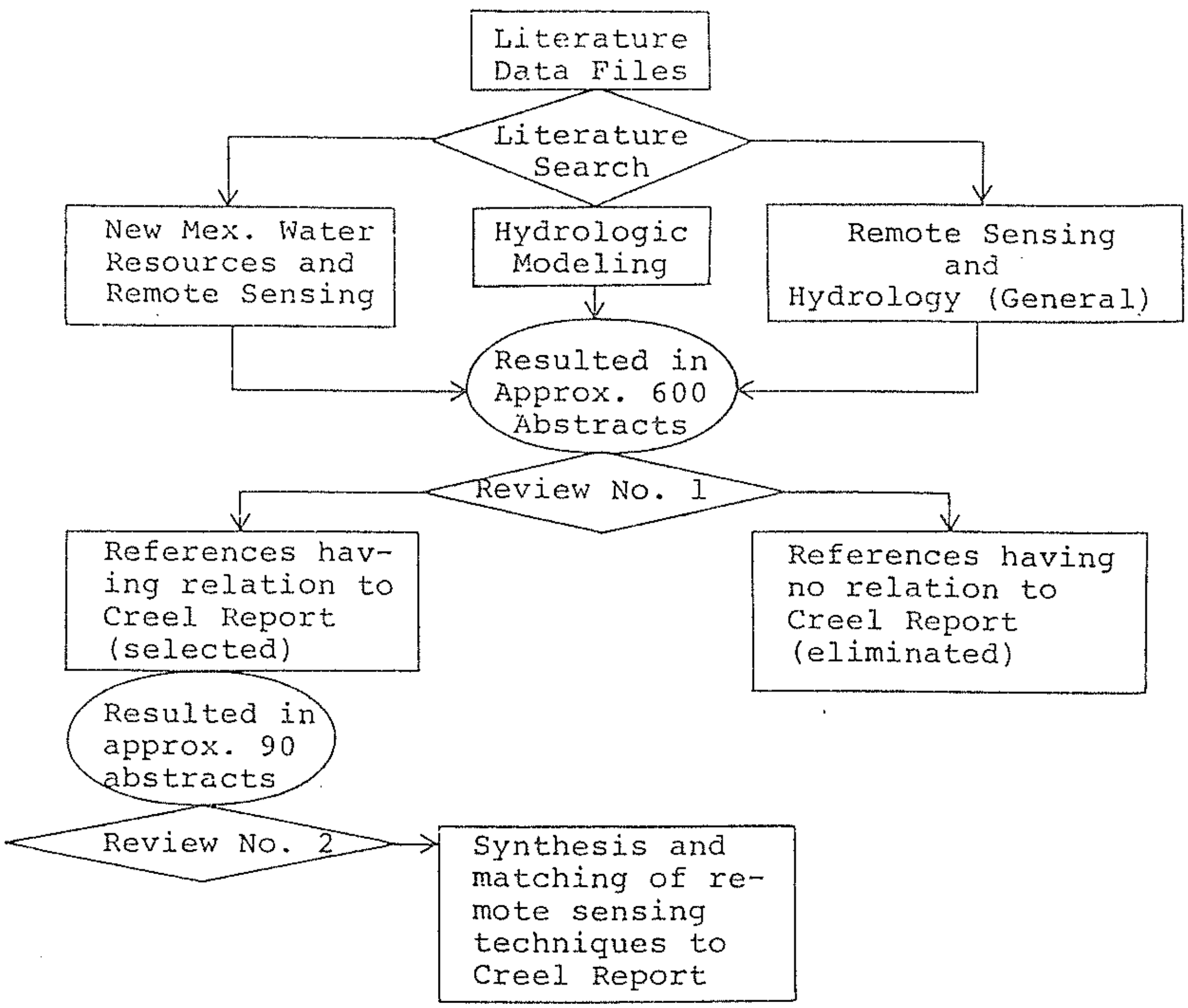
[2]GeoRef System information can be obtained from the American Geological Institute, 2201 M Street, N.W., Washington, DC 20037.

[3]The WRSIC information file can be accessed through the Office of Arid Lands Studies or Water Resources Research Center, University of Arizona, 845 N. Park Ave., Tucson, AZ 85719.

[4]The Computer abstracts are available from the Technology Application Center, University of New Mexico, Albuquerque, NM for the cost of duplication.

FIGURE 2

Remote Sensing and Hydrology
Search Strategy



selection left only about 90 abstracts which we felt had either direct potential for application or had indirect potential for formulating conclusive research in the subject areas. Thus, the selected bibliographic entrees in Appendix II represent a highly condensed version of the original search. Also in Appendix II are references of models which may be useful in adapting remote sensing techniques to these environs. In Appendix III the references have been wedded to the eight major topic areas extracted from Creel. We have done this to permit the reader to quickly retrieve material on a specific hydrologic topic area in New Mexico.

REVIEW OF SYSTEMS AND APPLICATIONS

Remote sensing, in all its types and forms is a data gathering tool. The determination of which remote sensing technique is most useful for a given problem depends on the type of data needed and the subject under analysis. Although there is much excellent research being performed in remote sensing and hydrology, the literature review indicates that little attention is being given to levels of accuracy or economic feasibility. Perhaps this derives from the infant nature of the technology or from a premature desire for operational applications. For whatever reason, the following discussion focuses primarily on a review of sensors and potential applications rather than proven techniques that can be easily or readily adapted for use in New Mexico. As a means for limiting the discussion of each sensor, we will relate back to the eight basic topic areas identified for New Mexico. Table 1 presents a synopsis of sensors, and their application areas. Table 2 renders a comparison of sensors, their operational wavelengths, and their major characteristics.

Aerial Camera Systems - Photographic camera systems are the most widely known and used of all remote sensors. The capability of these sensors to provide readily interpretable and geometrically correctable data is a major factor in their popularity. Several different camera systems are available.

TABLE 1

Remote Sensor Hydrologic Resource Applications

Sensor	Snow Cover	Soil Moisture	Water Quality	Ground Water	Runoff Detection	Watershed Land Use	Resource Mapping	Sediment	Surface Water Inven.	Real Time Water Res. Data	Erosion	Major Investigative Topics (Listed in Appendix I)
Radar	x	x	x	x			x					I, III, IV, VIII
Passive Microwave	x	x										I, IV
Thermal Infrared	x	x	x	x	x	x						I, III, IV, VII
Near Infrared	x	x	x	x	x	x	x	x				I, III, IV, VII, VIII
Aerial Photography	x	x	x	x	x	x	x	x	x		x	I, III, IV, V, VII, VIII
Satellites	x	x	x			x			x	x	x	I, III, IV, V, VI, VII, VIII

TABLE 2

Remote Sensors and Associated Characteristics

Remote Sensor	Wavelength	Characteristics
Camera System:		
Conventional black-and-white and color film	0.4-0.7um	Good spatial detail; good contrast; day only.
Infrared films (black-and-whtie and color IR)	0.6-0.9um	Vegetation vigor; tracing of water courses due to vegetative indicators; day only.
Multispectral camera system	0.3-.9um	Narrow spectral bands are recorded, providing multiple band coverage of the same scene; day only.
Thermal Infrared Scanner	1um-100um (2.5-14um windows)	Imagery obtained through scanning field of view; diurnal, penetrates haze, smoke.
Radar	10^{-1}-10^{2}cm	Usually narrow band system; artificial illumination of field of view; diurnal and all weather.
Passive Microwave (radiometers)	10^{-1}-10^{2}cm	Measures naturally reflected, self-emitted, and transmitted radiation. Can measure in very narrow bands; diurnal.

One of the most common systems is the single lens camera which takes one photograph at a time. These cameras provide standard formats and scales and can be obtained either in color or black-and-white. Another popular system is the multicamera. These are used when several spectrally separate images are needed. Each photograph contains the exact same field of view but is taken through a different filter and, or, on a different film type.

Except for the focal length of the camera system, film type is probably the single most important parameter determining resolution and characteristics of the final imagery. Table 3 gives some of the basic considerations of the major films. Black-and-white panchromatic, color, black-and-white infrared and color infrared or false color. A combination of film type and camera system enables a wide range of aerial photographic forms to be made available to resource managers. Aerial photography is used in surveying almost all types of water resource phenomena.

When a search of relevant remote sensing literature is performed, one finds that film type is discussed more often than are the camera systems. Lindgren (24) found color infrared photography to be valuable in determining the "sources and extent of certain types of water pollution". Further utility of color infrared photography is discussed by Sondregger (51), who used panchromatic, color and infrared systems to delineate geologic fracture traces in limestone topography. These fracture traces were indicative of underground water supplies. Color infrared photographs were used by Tschantz (55) to collect land use and hydrologic data for reclamation projects around strip mined areas.

Detecting pollutants in drainage systems is one of the foremost hydrologic applications of photography. Its success is largely dependent on the type, amount and duration of the pollution. Not all types of water pollution are detectable by remote sensing techniques and even fewer are detectable by aerial photographic techniques alone. The major forms of pollutants and associated parameters observable are water color, algal blooms, oil slicks, sedimentation and runoff mixing zones.

TABLE 3

Some Basic Considerations of the Major Film Types

Film Type	Use	Tonal Range	Con-trast	Exp. Lat.	Image Clarity
Black-and-white Panchromatic	General reconnaissance and mapping.	L	G	G	G
Color	General reconnaissance and mapping, good black-and-white prints can be developed from the negatives.	G	G	G	G
Infrared black-and-white	Good for vegetation mapping and delineation, tracing water courses and locating soil seepage areas through vegetation response.	L	E	F	G
Color infrared or false color	Same as above: very good for determining vegetation stress and tracing soil moisture.	F	E	L	G

Ratings: E-Excellent; G-Good; F-Fair; L-Limited

The basic use of aerial photographs for water quality surveillance is in point source detection. Once the originating source of the pollutant is known, the rate and direction of discharge and the dispersion pattern can be monitored. Not only is the detection of water pollution necessary but determining its effects on ecosystem habitats is a major resource problem. Aerial reconnaissance is a standard aid in the delineation of many pollutant sites and in the selection of field sites for analyzing disturbed habitats. Because of the ability multiband systems have for defining subtle tonal variations in water, their use has become recognized as data sources for industrial water pollution. Although information interpreted from air photos must often be verified legal precidents have been set to admit such information in court as legal evidence against polluters.

Aerial photography is also valuable in its ability to provide temporal data. Nettles, et al. (36) and Root, et al. (46) describe the temporal change of various land uses affecting watershed runoff in a South Carolina watershed and in the Denver suburbs, respectively. Further we have found a growing interest in the use of conventional aerial photographs as historical documents in water rights cases, erosion impact assessments and land access cases. We expect that, as the need for environmental impact statements increases, there will be a growing demand for photography as both long (greater than 10 years) and short term (less than 1 month) historical documents.

Considering the longevity of technique development in air photo interpretation and the breadth of proven and routine applications, it is difficult to find an area in Appendix IB where photography could not assist. Our difficulty is magnified in this connection because Creel did not formulate his topic lists as specific problem statements. Without reading too much into his list, however, we feel confident that aerial photography (either black-and-white, color or color infrared) can be used <u>now</u> in topic areas II, IV-C, D, E and G and V-D.

Thermal Infrared - Objects emit thermal infrared (TIR) energy in the 8-14 micron range of the invisible spectrum. The remote sensor utilized in airborne thermal reconnaissance is known as a thermal infrared scanner. This scanner is principally a highly conductive, heat sensitive device encased in a near 0° Kelvin liquid such as nitrogen or helium. A detector records energy emitted from the ground and generates an electron signal. This signal is sent to a cathode ray tube, where it is converted into a visibly detectable light. The strength of the light is dependent on the intensity of the emitted energy impinging on the detector. Thus, each scan line recorded by the detector is transferred into a light scan and recorded on film.

Thermal imagery portrays relative temperatures for objects in the scene as different grey tones. If ground temperatures are known, some meaningful relative temperature delineations can be made from geometrically correct, (relatively free of aircraft pitch and yaw), thermal images. It has been reported that fairly accurate relative temperature data, ($\pm$ 2°C), can be determined from some thermal imagery, (Van Lopik, 25).

The most widespread use of thermal infrared imagery in hydrology is in monitoring temperature related water quality phenomena, (Tschantz et al., 56; Van Lopik, et al., 25; and Williams, 58). The detection of freshwater upwelling in lakes and rivers, thermal pollution like that generated from some industrial activities, runoff influx and mixing zones, are indicative of a few water quality parameters interpretable from thermal sensors.

According to Sers, (50), thermal infrared sensors can be used for detecting shallow groundwater aquifers due to thier capacity to act as heat sinks. The result of the heat sink effect is to cause the aquifer system to appear as a relatively warm area during an early morning scan. Heat anomalies caused by geothermal water reservoirs such as around Lordsburg, New Mexico, are detectable because of the heat flux variation emitted from the ground surface. A high soil moisture content also causes variations in the emission of heat during the diurnal period. Thus, an early morning TIR scan over a flood plain could determine the latteral extent of the plain, affording valuable information to land use planners and wetlands management.

Thermal scanners are commercially available for sale or hire and are currently being employed operationally as a means for monitoring industrial cooling ponds; heat outflows into lakes, rivers and oceans, and as a reconnaissance device for geothermal "hot spots" and subsurface moisture. In New Mexico we believe the techniques could be employed now for such topic areas as I-A, IV-A and VIII-G. As our models, skills and techniques improve, there is no reason to discount future use of thermal scanners for the additional topics IV-C, VI and VIII-C and D. Topic numbers refer to entrees in Appendix I-B.

Radar - The term radar is used for all active microwave systems. These sytems record the reflection from a transmitted microwave pulse off the terrain. Since it is essentially an invisible "flash light" transmitting its own energy, radar units are one of the few all weather, day and night sensors. The energy transmitted is low frequency to generate roughly one-millimeter to one-meter wavelength signals. Of the many radar systems operating in this range the Side Looking Airborne Radar (SLAR) is perhaps most common.

The main use of radar in hydrologic studies is in the detection of water quality parameters, soil moisture data collection and drainage basin analysis. Most of the radar work in hydrology has focused on wetland environments but it appears that many of the techniques may be useful in arid regions as well.

Data collected on water quality are concerned with particulate matter intrusions into water bodies. The detection of turbid water and algal blooms is attributed to their relatively high backscatter coefficients, particularly at shallow antenna depression angles. The variable nature of these water quality parameters, when combined with system interrelationships of polarization, look angle, frequency and resolution, preclude quantification of the data. Little or no information on eutrophic conditions of a water body can be obtained directly from radar imagery, though important qualitative information is obtained.

Soil moisture is another highly significant application area for radar. At these frequencies the addition of moisture to a soil is equivalent to the addition of a metal. Bare earth that would otherwise image in dark tones will, with the addition of moisture, appear as brighter areas. Moisture in the surface few inches of the profile accounts for the majority of the reflection and can be easily confused with salt accumulations, gravel deposits or vegetation. The ability to map soil moisture from radar imagery depends on knowing the penetration capability of the specific radar frequency, the soil type, drainage characteristics and vegetative cover type. For ground based sensing, Morey (34) has reported on a ground based profiling radar that can detect soil moisture variations and subsurface artifacts such as pipes and geologic structures. The depth of penetration is reported to be 25 feet in dry sandy soil with decreasing penetration for heavier and wetter soils.

These two systems (SLAR and ground based profilers) represent different forms of radar. It seems quite feasible that they could compliment each other in a search for near surface ground water, buried pipelines, archaeological structures, or possibly subsurface duricrust. Another approach might be to combine interpretations from radar imagery with those from aerial infrared photographs to locate potential near surface aquifer sites.

In terms specific to the intent of this report, we believe that radar sensors could be applied to the following subjects as listed in Appendix I-B: topic areas IV-D, E, G, H; and VIII-E. We hasten to add that model building to define the techniques, demonstrate the feasibility and evaluate the cost effectiveness must all be worked out prior to a final proof of application.

Passive Microwave (Radiometers) - Passive microwave units measure the total radiation emanating from an object at a particular frequency. Unlike radar, which is an *active* microwave system, *passive* microwave does not generate an illuminating energy wave to reflect from the field of view. The image geometry characteristics of these sensors does not allow accurate nor detailed mapping to be done from the images produced.

Passive microwave systems have been applied to snowfield profiling, (Meir, et al., 30) and for studying soil moisture, (Poe and Edgerton, 39). Poe and Edgerton utilized several different microwave bands within the 0.1-10 centimeter range to investigate soil moisture content in agricultural soils of the Phoenix Valley in Arizona. They found that highest correlations between recorded brightness temperature and soil moisture were obtained in the lower frequency bands.

There is, at present, considerable interest in the use of passive microwave systems for saline seep and soil moisture determinations. The state-of-the-art, however, is such that no commerical systems are avialable for routine application. We are at the stage of model building and demonstration for this sensor. In future we might expect that passive microwave data will provide input to the following problem areas in New Mexico: topic area III-B; IV-H; V-A and C; VI; and VIII-C.

Landsat Satellite Data - In July, 1972, and again in January, 1975, the Earth Resources Technology Satellites (ERTS I and II, now renamed Landsat I and II) were put into a near polar orbit at an altitude of about 568 miles. These satellites pass over an area on the earth's surface every 18 days; thus, providing a form of time lapse imagery for that area when no clouds are present. Each scene recorded by the satellite covers an area of approximately 13,225 nautical square miles.

The Landsat imaging system is composed of a mirror scanning device which relays spectral energy to a set of detectors. These detectors divide the optical energy into four bands: green, .5-.6um; red, .6-.7um; and two near infrared channels, .7-.8 and .8-1.1um. Each band is then digitized and relayed back to a receiving station on earth. Black-and-white images and false color composites are produced from the Landsat digitized scans via computer techniques. The nominal instantaneous field of view (IFOV) recorded by Landsat is 80 meters. The IFOV represents an individual picture element known as a pixel point.

The Landsat satellite is the only remote sensing system which provides temporal data in four separate bands of the electromagnetic spectrum for the same field of view. The uniqueness of this four channel scanning system enables images to be compared and contrasted to one another, thereby accentuating desired physical features. This method of image comparison is known as band ratioing. By ratioing one multispectral band to another via different color filters and light intensities, investigators can enhance particular features of interest.

The data from Landsat, by virtue of its temporal nature has allowed resource managers to undertake one of the most detailed and far reaching resource monitoring programs ever. The images are or could be useful to managers involved with almost all manner of natural resources. Landsat images contain sufficient spectral and spatial resolution to meet USGS mapping requirements at a scale of 1:250,000.

The major use of Landsat data has been in the survey and reconnaissance mode. In New Mexico, using standard photo interpretation techniques, Morain, et al., (33) have used the false color composites generated from the Landsat satellites to map the land use and cover types of New Mexico at a scale of 1:1 million. The accuracy of this map exceeds the 80% accuracy level capability reported in a pilot study by the Forestry Remote Sensing Laboratory (11) in 1970. A program to map non-point sediment sources in the state at a scale of 1:250,000 from Landsat imagery may be initiated during summer of 1976.

In the field of hydrology Reeves (41), Inglis (19) and White (57) have utilized Landsat imagery to investigate surface fluctuations in west Texas and New Mexico water bodies. Most of these studies have found Landsat imagery to be useful for lake level monitoring. Data collected by White in New Mexico indicate that while lake level fluctuations are detectable, the ability to determine surface acreages with consistent accuracy via established techniques is not yet reliable. It is most likely that further research into this problem will develop a reliable means for establishing acreages of standing water bodies. Additional modeling may then provide a means for estimating water volumes.

Perhaps one of the most exciting capabilities of the Landsat satellite payload is its capacity to relay real time data from earth based telemetry systems known as Data Collection Platforms (DCP). These platforms have been utilized to monitor stage levels in streams and reservoirs (Schuman, 49; Halliday, 12). Furthermore, these same platforms have been combined with *in-situ* water quality instruments (Paulson, 38 and Woffinden, et al., 59). This combination is used to relay directly sensed water quality and quantity data to resource management personnel via Landsat. The data transmitted from the DCP's can be directly compared to the Landsat image of the area taken at the time of data collection.

The combination of repeated coverage by Landsat with correlative data derived from Data Collection Platforms, (DCP's) makes satellite sensing an attractive and economic tool for monitoring a number of water resource problems in New Mexico. In some cases, such as measuring surface extent, there are models and algorithms available and in use (see section on Hydrologic Modeling). In others the techniques have been developed and tested but as yet have not been pushed to routine operational status. In terms of Appendix I-B we believe, on the basis of existing reports and our own experience, that Landsat imagery or the data tapes could address topics I-A, IV-A, D, E, G and H, VIII-B, D and I.

HYDROLOGIC MODELING AND REMOTELY SENSED DATA

There has been little effort placed on incorporating remotely sensed data into hydrologic models. This fact is an unfortunate result of poor communications between the remote sensing field and researchers involved in systems analysis and modeling techniques. The capacity of remote sensing to provide temporal, spatial and spectral information makes it one of the most promising sources of data for dynamic modeling. We strain to imagine any hydrologic model that does not contain at least one temporal, spatial or spectral parameter; and strain even more to believe that these parameters are more easily or economically obtained on the ground without imagery. Assimilation of remotely acquired data into a hydrologic model depends on:

a) The accuracy requirements and permissible standard error of the data input;

b) the ability to quantify interpreted imagery data; and

c) the accuracy requirements for the model to be useful.

As with any data collection, the parameters upon which the data rely must be understood for them to be meaningful. For example, groundwater aquifers are largely controlled by the geology and terrain features of the region. If the structural geology and geomorphology of the region are not known, little information as to the probability of groundwater can be obtained.

Quantification of remotely sensed data depends on the type and mode of the model. Data can be numerically structured in four basic forms: nominal, ordinal, interval and ratio. The requirements of the model and any mathematical or statistical methods which are to be applied will determine the type of data form needed. Exactly what remotely sensed data can be quantified and into what type of data base, has received very limited attention.

Incorporating remote sensing with hydrologic modeling can be approached at least two different ways. The first method is to develop the model with the use of a remote sensing data source. The model accuracies are therefore limited foremost, by the remote sensing data. In the second method, existing models developed to utilize broad topics, or default parameters, can be adjusted to use more specific data. These models can often be modified by subdividing the broad topics or replacing the default parameters with data acquired through remote sensing. For example, an agglomerated data topic like watershed soil drainage, can be subdivided into catenary soil sequences interpretable from satellite and aerial photography. The increased data detail available could enhance the models accuracy.

Models Utilizing Remote Sensing Data - The Stanford Watershed Model is probably the most referred to hydrologic model currently adaptable to and utilizing remotely acquired data.

This model has provided a springboard from which numerous other watershed models have developed. One such related model is the Stanford Sediment model.

The Stanford Sediment model (10) utilizes several data parameters which are obtainable through remote sensing techniques. Typical parameters for which data are needed are such physical attributes as sediment and erosion sources and types. These two model parameters are rather broad topics. Remote sensing can provide data on these two topics directly, or, they can be subdivided and more detailed interaction data obtained. Aerial photos can be used to acquire data on sheet erosion areas, intensities of rill erosion and gully erosion. Each of these are contributors to total sediment production as well as erosion source and type.

The capacity of most remote sensing techniques to provide spatial information makes it a prime data source for interaction models such as those described by Ragan, and Jackson (40). This model utilizes Landsat data tapes to delineate land use and associated runoff. The ability to determine the infiltration capacity in a watershed is dependent on the spectral responses of various impermeable/permeable surfaces. Areal measurements of these various surfaces enables a value to be assigned to each type of surface. Thus, the spatial association and spectral information can provide an essential element to the runoff model. This same technique could be applied to urban landscapes.

An excellent example of the use of temporal data provided via a remote sensing platform for hydrologic modeling is presented by Higer, et al., (15). Data collection platforms installed in the Florida everglades provide near real-time data on water volumes. These data are then fed into a dynamic water management model. From the time of the Landsat overflight, once every 18 days, to the time the data are provided to users, roughly two hours have elapsed. The immediate availability of these data make a more effective water distribution system possible. Whether or not the technique would be applicable in New Mexico as a means for allocating irrigation water is a subject for further study.

The spectral qualities interpretable from some remote sensing techniques may provide a medium for modeling. Idso, et al., (18) have developed a model for determining the total 24 hour evaporation coefficient for a field. The basic data parameters used in the model are the standard weather service daily solar insolation records, maximum and minimum air temperature, maximum and minimum surface temperatures and a one time measure of the moist surface albedo. The use of remote sensing in this model is in determining surface temperatures. This type of data may be obtainable through spectrometer and radiometric techniques. However, the ability to accurately determine such temperature values is hindered by the problems which arise.

One such problem is outlined by Jackson, et al., (20). They found that the most accurate approximation of the 24 hour average soil moisture content can be obtained within an hour before solar noon. Although his paper is concerned with soil moisture, the same data timing concept can be applied to surface temperature. Furthermore, the spectral responses recorded by spectrometers or radiometers are strongly affected by the amount of soil moisture content. This fact may cause erroneous temperature data to be acquired.

Models Developed Around Remote Sensing Data - The models and remote sensing attributes mentioned above do not exhaust the types of applications, nor the potential applications of remotely sensed data for modeling purposes. Several other research projects have investigated possible uses of remote sensing for models, some of which have been included in Table 4. In it we present a few different modeling ideas which hopefully will serve to demonstrate some of the research areas adaptable to data effectively provided by remote sensing.

The Earth Observations Division in the Science and Applications Directorate at the Lyndon B. Johnson Space Center, Houston, Texas, has developed an algorithm for detecting and mapping areas of surface water. This algorithm is a computer-aided procedure developed to aid in the National Program of Inspection

TABLE 4

Modeling Ideas For Which Remotely Sensed Data May Be Useful

Author	Use of Model Concept	Data Needs of the Model	Potentially Useful Remote Sensing Tech.
Crawford, et al. (4)	Agricultural pesticide runoff.	Sediment loss and soil infiltration zones.	Multispectral imagery, aerial photography, passive microwave.
England, C.B. (8)	Watershed modeling.	Soil type/ catenary sequences, soil moisture infiltration rates, evaporation/evapotranspiration, land use, land forms.	Aerial photography, multispectral imagery, Side Looking Airborne Radar, thermal infrared, passive microwave.
England, C.B. (7)	Watershed modeling.	Runoff, soil infiltration areas, ground water recharge, erosion channel delineation.	Aerial photography, Side Looking Airborne Radar, passive microwave, satellite imagery, multispectral imagery, radar, thermal infrared.
Fleming, George (10)	Watershed sediment transport model.	Sources of sediment cover types, stream network.	Aerial photography, multispectral imagery, satellite imagery, radar, Side Looking Airborne Radar.
Hamdan, et al. (13)	Network analysis of ground water/surface water systems.	Delineation of network flows. Node and linkage distributions.	Aerial photography, multispectral imagery.
Hanks, et al. (14)	Irrigation runoff.	Soil infiltration, soil moisture content, evaporation rates.	Thermal infrared, aerial photography, multispectral imagery, Side Looking Airborne Radar, passive microwave, radiometric techniques.
Hughes, W.C., (17)	Increasing Pecos River Basin water supplies by reducing evaporation.	Vegetation cover types, locations and amount of drainage area covered.	Aerial photography, multispectral imagery, satellite imagery.
Kabanova, K.S., (21)	Network analysis of runoff areas and monitoring stations.	Runoff channels hydrologic network delineation.	Aerial photography, satellite imagery, radar.
Miller, R.R., (31)	Monitoring water supply systems.	Recording, retrieving and dissemination of water supply data.	Landsat satellite and data collection platforms, Landsat imagery, aerial photography, radar.
Moody, et al. (32)	Network planning model.	Retrieval and dissemination of water resource data.	Aerial photography, satellite imagery, Landsat Data Collection Platforms, radar, multispectral imagery.
Rodda, et al., (45)	Hydrologic network design models.	Spatial distribution of hydrologic network, hierarchical delineations of network nodes and linkages.	Aerial photography, satellite imagery, Side Looking Airborne Radar, radar, thermal infrared, multispectral imagery.
Ruff, J.F., (47)	Water resource model, watershed modeling.	Water supply, quality and distribution.	Multispectral imagery, aerial photography, satellite imagery, Side Looking Airborne Radar, Landsat data collection platforms, radar, thermal infrared, passive microwave.
Ruppert, et al., (48)	Interbasin transfer/ ground water depletion.	Ground water recharge areas, runoff areas, water importation routes, crop identification, water utilization zones.	Multispectral imagery, aerial photography, satellite imagery, Side Looking Airborne Radar, radar, passive microwave.

of Dams as authorized under Public Law 92-367. This procedure is known as Detection And Mapping (DAM) and is *operational* for use within any state. Input into the computerized program is derived from Landsat imagery and Computer Compatible tapes (CCT's), existing topographic maps and available weather data. This program provides an accurate and current inventory of most surface water sites (greater than 5 acres), and is cost effective.

There is a movement today in many research circles away from discriptive interpretation and explanation, and toward simulation of physical processes. Many old models are being revamped and updated. Thus, remote sensing applications are at a new threshold in their evolution. Numerous water resource models are being developed. These models, combined with those already in use, present a formidable number. Therefore, no single listing will be able to match the useful models to the potentially applicable remote sensing techniques. Each investigator must review those models most useful to his research and then determine the degree to which remote sensing can help.

SUMMARY AND RECOMMENDATIONS

From this review of sensors, techniques and applications it is clear that remote sensing can be efficacious in hydrologic data acquisition. The wide range of remote sensing platforms and their individual variations assures natural resource managers of a useful and time saving data collection technique. The main problem to New Mexico water resource personnel wishing to use remote sensing in their programs is defining the type of data needed for analysis.

On the basis of our review of this literature (both in hydrology and remote sensing) we would recommend that modeling and the perfection of interpretation techniques be undertaken in the following specific areas as listed in Appendix I-B:

I. A. Gaps in baseline environmental resource evaluation information.

III. B. Water infiltraiton capacities in relation to basin recharge.

IV. C. Watershed management and protection.
D. Watershed resource inventories.
E. Vegetative mapping.
G. Surface water resource inventories.
H. Improved methods of water quantity monitoring.

V. A. Evaluation of irrigation scheduling, systems, and techniques.
C. Agricultural water utilization efficiency.
D. Irrigation systems and techniques improvements.

VI. Water conservation and preservation techniques.

A. Evaluation of phreatophyte removal.

VIII. B. Sediment reduction and control on watersheds and in lakes and reservoirs.
C. Waste water management: recycling, irrigation use, disposal.
D. Extent and prevention of ground water and surface water pollution from tailings ponds, mining operations, and minerals processing.
E. Assessment of biological contamination of water.
G. Evaluation of extent and prevention of thermal pollution of water.
I. Simple economic techniques for water quality monitoring.

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APPENDIX I

A and B

Major Hydrologic Research Topics for New Mexico

(as defined by Creel, 1974)

APPENDIX I

Section A
(Taken from Creel, 1974)

Water Quality

Community Sewage Treatment Facilities

Evaluation of Septic Tanks vs. Sewage Treatment in Rural and Small Communities

Community Water Supply Systems

Evaluation of methods of improving small community water supplies.

Water Quality Inventories

Base-line water quality inventories of chemical and biological quality of state water supplies.

Sediment Reduction and Control on Watersheds and in Lakes and Reservoirs

Salinity Reduction and Control

Disposal of Brackish (Brine) Water

Evaluation of Economic, Sociological, and Physical Impacts of the Use of Sewage Effluent for Irrigation

Clean Lake Studies because of Federal mandate

Salt Water Intrusion in Ground Water Aquifers, and Evaluation of Salt Accumulations

Irrigation Return Flow Studies

Waste Water Management: Recycling, Irrigation Use, Disposal

Animal Waste Disposal Effects on Water Quality

Drainage Characteristics and Movement of Minerals in Groundwater

Improved Methods of Water Quality Monitoring

Extent and Prevention of Ground and Surface Water Pollution from Tailing Ponds, Mining Operations, and Minerals Processing

Irrigation District Obligations and Relations to the Water Pollution Control Regulations

Assessment of Heavy Metal and Trace Element Contamination of Water

Assessment of Biological Contamination of Water

Evaluation of Agricultural Chemical Use on Water Quality

Evaluation of Extent and Prevention of Thermal Pollution of Water

Evaluation of Septic Tanks vs. Sewage Treatment in Highly Populated Areas

Movement of Chemical Substances in Surface and Groundwater Irrigation Return Flow

Simple Economic Techniques for Water Quality Monitoring

Obligations of Irrigation Systems Operated by Public or Private Organizations or Individuals and Their Relation to Water Pollution Control Regulations

Relation of Erosion and Sedimentation to Salinity in New Mexico Streams

Water Quantity

Watershed Management and Protection

Watershed Resource Inventories

Vegetative Mapping

Remote Sensing Applications to Watershed Management

Ground Water Resource Inventories

Surface Water Resource Inventories

Agricultural Water Utilization Efficiency

Urban and Rural Domestic, Public, Commercial and Industrial Water Requirements Inventories

De-Water Studies

Economic (and sociological implications) evaluations of completely depleting a groundwater aquifer in certain time frame.)

Evaporation Suppression Studies

Effects of Urban Uses of Water in Specific Growth Areas as compared to present uses of water

Evaluation of Phreatophyte Removal

Irrigation Systems and Techniques Improvement

Water Supply Alternatives for Municipal Uses

Evapotranspiration Rates of Agricultural Crops, Phreatophytes, and Other Plants, and Base-Line (Bare-Ground)

Irrigation System Design

Improved Methods of Water Quantity Monitoring

Water Infiltration Capacities in Relation to Basin Recharge

Water Evaporation Information

Evaluation of Water Requirements for Energy (Coal Gasification, Electrical Energy, Other)

Water Requirements for Surface Mined Areas Reclamation

Economic Feasibility of Supplemental Irrigation vs. Natural Rainfall for Reclamation and Land Use Conversions

Water in Relation to Land Use and Development

Evaluation of Water Importation Possibilities

Recreational Water Use Demands

Evaluation of Establishment of Minimum Pools in State Reservoirs

Evaluation of Water Transportation and Distribution Systems

Population Growth and Water Supply Relationships

Evaluation of Irrigation Scheduling, Systems and Techniques

Economic and Sociological Implications of Declining Ground-Water Levels

Desalting of Water for Agricultural, Municipal and Other Uses

Water Supply as It Relates to Land Use Planning

Evaluation of Lower Water Using Agricultural Crops

Development of New Economic Crops with Lower Consumptive Water Use

Water Conservation and Preservation Techniques

Evaluation of Irrigation Water Metering

Feasibility of Improving Ground Water Recharge from Surface Impoundments Such as Playa Lakes

Evaluation of Small Reservoirs for Small Irrigation Districts to Reduce Flood Runoff and Extend Irrigation Season

Utilization of Water Metering for Economy and Efficiency of Water Use

Water Information Dissemination

Improved Water Information Dissemination Techniques and Programs

Educational Programs on Water Conservation

Improved Information Dissemination of Activities and Knowledge of State and Federal Agencies

Coordination of Water Research Activities

Improving and Updating Knowledge of Hydraulics

Institutional

Indian Water-Rights

Community Water-Rights

Operation of the Prior Appropriation Doctrine as Applied to Ground Water

Relationship Between Groundwater Ownership, Use, and Value to Overlying Land Ownership, Use and Value

Determination of Economic and Social Values of Water Under Various Conditions, Projections, Constraints and Alternatives

Water Conservation and Preservation vs. Use

Economic, Sociological, Esthetic and Environmental Implications of Maintaining Agricultural Acreage at Present Level

Economic, Sociological and Esthetic Implications of Maintaining Subsistance Agriculture vs. Recreational Use of Water

Implications of Water in Natural Resource Development and Energy Production

Evaluation of and Determination of Recreational Values of Rivers, Lakes, and Channels, and Resevoirs

Criteria and Justification of Construction of (Water-Using) Recreational Oriented Structures

Environmental Resource Evaluations of River Basins

Flood Plain Evacuation and Relocation and Area Management

Evaluation of the Detrimental Effects of Recreational Use of Areas

Economic Evaluation of Basin Water Allocation Policies

Assessment of National Water Commission Report Implications to State

Economic, Sociological, Environmental and Esthetic Evaluation of Phreatophyte Areas

Recreational Boating Fee Establishment for State Lakes and Reservoirs

Economic, Sociological and Esthetic and Environmental Implications of Maintaining Various Leads of Irrigated Agricultural Acreages U.S. Population Growth and Industry Use of Water

Gaps in Baseline Environmental Resource Evaluation Information

APPENDIX I

Section B

Major Categories and Associated Subtopics

I. Improved Water Information Dissemination Techniques and Programs.

   A. Gaps in baseline environmental resource evaluation information.

II. Population Growth and Water Supply Relationships.

III. Ground Water Resource Inventories.

   A. Feasibility of improving groundwater recharge from surface impoundments, such as Playa Lakes.

   B. Water infiltration capacities in relation to basin recharge.

IV. Environmental Resource Evaluations of River Basins.

   A. Gaps in baseline environmental resource evaluation information.
   B. Evaluation of small reservoirs for small irrigation districts to reduce flood runoff and extend irrigation season.
   C. Watershed management and protection.
   D. Watershed resource inventories.
   E. Vegetative mapping.
   F. Remote sensing applications to watershed management.
   G. Surface water resource inventories.
   H. Improved methods of water quantity monitoring.
   I. Water infiltration capacities in relation to basin recharge.
   J. Relation of erosion and sedimentation to salinity in New Mexico streams.

V. Evaluation of Water Transportation and distribution Systems.

   A. Evaluation of irrigation scheduling, systems and techniques.
   B. Evaluation of small reservoirs for small irrigation districts to reduce flood runoff and extend irrigation season.
   C. Agricultural water utilization efficiency.
   D. Irrigation systems and techniques improvements.

E. Irrigation return flow studies.
F. Movement of chemical substances in surface and ground water irrigation return flow.

VI. Water Conservation and Preservation Techniques.

A. Evaluation of Phreatophyte Removal

VII. Water in Relation to Land Use and Development.

A. Water requirements for surface mined areas reclamation.
B. Evaluation of water importation possibilities.
C. Evapotranspiration rates of agricultural crops, phreatophytes and other plants, and baseline (Bare Ground).

VIII. Improved Methods of Water Quality Monitoring.

A. Baseline water quality inventories of chemical and biological quality of state water supply.
B. Sediment reduction and control on watersheds and in lakes and reservoirs.
C. Waste water management: recycling, irrigation use, disposal.
D. Extent and prevention of ground water and surface water pollution from tailings ponds, mining operations and minerals processing.
E. Assessment of biological contamination of water.
F. Evaluation of agricultural chemical use on water quality.
G. Evaluation of extent and prevention of thermal pollution of water.
H. Movement of chemical substances in surface and ground water irrigation return flow.
I. Simple economic techniques for water quality monitoring.

APPENDIX II

SELECTED BIBLIOGRAPHY

Note: The following abstracts have been put in standard format vis-a-vis the citation. The abstracts have been unaltered from the original as received from the computer printouts.

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ABROSIMOV, I.K., YU. M. KLEINER. 1973.

Moskovskoe Obshchestvo Ispytatelei Prirody (USSR). Geography Division. In: Landscape Indicators - New Techniques in Geology and Geography: Consultants Bureau, Division of Plenum Press, London and New York. p. 34-38. (Translated from Russian. Proceedings of Conference of Moscow Society of Naturalists, May 21-22, 1968. Moscow, Navka Press).

The landscape-indicator method of prospecting for and mapping shallow groundwater is becoming widely used in water-indicator investigations in the USSR. Vegetation is used as a direct indicator of depth and mineralization of shallow water. Relief and lithology of surface rocks are indirect indicators of water; thus, in arid regions, slightly indurated eolian deposits are the sites of lenses of fresh water, and these may be revealed by plant indicators in zones where such lenses discharge. Karst-forming processes are rather clearly indicated by vegetation. Sinks and canyon-like karst valleys, in addition to physiognomic expression in the landscape, are also marked by specific plant communities. Lineaments (straight segments of stream valleys, scarps, rectilinear shores, etc.) are most commonly geomorphic expressions of deep fractures, very well reflected in the landscape because of the discharge of groundwater along these fractures.

AMBARUCH, R. AND J.W. SIMMONS. 1973.

Application of Remote Sensing to Hydrology - Final Technical Report. IBM Electronics Systems Center, Huntsville, Alabama, 104 p. W74-07940

Data produced by remote observation from space and aircraft were tested for use in reducing the time and expense normally involved in predicting the hydrological behavior of an ungaged watershed. Such a capability can enhance effective planning for urban and industrial development, flood control, hydroelectric power, navigation, and water resources management. The continuous simulation model chosen for the study is the Kentucky Watershed Model (KWM). This model is based upon the Stanford Watershed Model IV, adapted and refined for application to this project. The area from which test watersheds are chosen for the study is the Tennessee River Valley, a major watershed of approximately 104,000 sq. kms. in the southeastern United States. This is a well-instrumented, throughly photographed and mapped area for which copious historical data

records are available. The remote sensing imagery used to determine watershed physical characteristics was actually aerial photographs, mostly at a scale of 1:24,000. The five validation runs produced simulated streamflows which correlated remarkably well with observed streamflow. Daily correlation coefficients ranged from 0.83 to 0.87; monthly, from 0.92 to 0.97. Many major storms were reasonably well matched with respect to peak flows and timing of peaks. For a multi-year open-loop simulation, this is adequate for most applications, and it strongly indicates the feasibility of using remotely sensed data to forcast the hydrologic performance of an ungaged watershed. (Knapp-USGS)

BARNES, J.C. 1973.

Evaluate the Application of ERTS-A Data for Detecting and Mapping Snow Cover. Environmental Research and Technology, Inc., Lexington, MA. 11 p. E73-10361.

The author has identified the following significant results. Analysis of ERTS-1 data covering the test sites in the western United States indicate that the MSS-4 and 5 spectral bands are the most useful for detecting and mapping snow cover. Of these two bands, the MSS-5 is the most consistently useful, as snow-covered areas in some MSS-4 images are nearly saturated causing some loss of detail. Snow can be readily detected and can be distinguished from clouds through a number of interpretive keys. At the ERTS-1 resolution, numerous terrestrial features not visible in lower resolution meteorological satelite data can be detected. In addition to various natural features, man-made features such as roads, electric power lines, cultivated fields, and timber cuts are visible. In two cases analyzed for the Salt-Verde Watershed in Arizona, good agreement is observed between the location of the snowline as mapped from the ERTS-1 data and as depicted on aerial snow survey charts compiled within a few days of the ERTS-1 passage. Results indicate that the snowline can be mapped in more detail from ERTS-1 imagery than can be achieved by current aerial survey methods.

BAUMGARDNER, M.F., S.J. KRISTOF, J.A. HENDERSON Jr. 1973.

Identification and Mapping of Soils, Vegetation, and Water Resources of Lynn County, Texas by Computer Analysis of ERTS MSS Data. Purdue University. Lafayette, Indiana Lab. for Applications of Remote Sensing. 11 p. N73-24411.

The results of the analysis and interpretation of ERTS multispectral data obtained over Lynn County, Texas are presented. The test site was chosen because it embodies a variety of problems associated with the development and management of agricultural resources in the Southern Great Plains. The utility of ERTS data in identifying, characterizing and mapping soils, vegetation, and water resources in this semiarid region is examined. Preliminary results from this study suggest that ERTS data may be used successfully in semiarid regions to accomplish the above tasks.

CASTRUCCIO, P.A., H.L. LOATS Jr. 1973.

Impact of Remote Sensing Upon the Planning, Management and Development of Water Resources. Summary of Computers and Computer Growth Trends for Hydrologic Modeling and the Input of ERTS Image Data Processing Load. Ecosystems International, Inc., Gambrills, MD. 51 p. N75-20802/5ST

An analysis of current computer usage by major water resources users was made to determine the trends of usage and costs for the principal hydrologic users/models. The laws and empirical relationships governing the growth of the data processing loads were described and applied to project the future data loads. Data loads for ERTS CCT image processing were computed and projected through the 1985 era. The analysis shows significant impact due to the utilization and processing of ERTS CCT's data.

CHADWICK, D. G. 1973.

Integrated Measurement of Soil Moisture by Use of Radio Waves. Utah Water Research Lab., Logan. 98 p. PB-227-242/5.

An integrated value of soil moisutre can be determined by measuring the attenuation of vertically-polarized surface radio waves that are propagated over the ground between a transmitting and receiving antenna. Soil moisture values in the root-zone region were measured over longitudinal distances typically ranging from 50 feet to 600 feet with good results. Integrated soil moisture measurements over greater distances are also possible. The received field strength of propagated radio surface waves closely matches theoretical calçulations. The measurement is easily made and does not disturb the soil. Dense, green vegetation, such as alfalfa or corn, causes errors in measurement accuracy. Less dense vegetation, such as range land, does not seriously affect measurement accuracy. The described equipment is portable and can be used by an unskilled operator.

CHANDLER, P.B., W.L. DOWDY, D.T. HODDER. 1970.

Study to Evaluate the Utility of Aerial Surveillance Methods in Water Quality Monitoring. North American Rockwell Corp., Downey, CA. Space Division. Prepared for California State Water Resources Control Board. 148 p. PB-202 405.

The reported project demonstrated the utility of aerial surveillance techniques in water quality management as inventory, monitoring, and enforcement tools. Primary emphasis was on determining those water quality factors amenable to measurement by remote sensing techniques and the most desirable methods of obtaining measurements. A survey of research and operational aerial surveillance programs was conducted. A limited-scale aerial surveillance/sea-truth demonstration with data interpretation and correlation of selected water quality factors was conducted. It was concluded that many important

factors could be detected using aerial surveillance techniques. A future large-scale undertaking utilizing the full spectrum of remote sensing equipment in a controlled scientific endeavor was scoped.

CHIKISHEV, A.G. 1968

Landscape-Indicator Investigations of Karst. Moskovskoe Obshchestvo Ispytatelei Prirody (USSR). Geographic Div. In: Landscape Indicators - New Techniques in Geology and Geography: Consultants Bureau. Div. of Plenum Press, London and New York. P. 48-63. 1973. (Translated from Russian. Proceedings of Conference of Moscow Society of Naturalists, May 1968. Moscow, Navka Press). W73-07845.

In multiple investigations of Karst by landscape indicators, aerial photography and direct aerial observation are of fundamental importance. The use of air photos and preliminary aerial flights over the region make it possible to obtain the most complete information concerning the extent of Karst development in the region. The morphological aspects of Karst forms, and the hydrological conditions of Karst formations without laborious surface work. In mountainous regions Karst in limestones that crop out at the surface is reliably recognized by a characteristic variegated-porous picture of the photo image and pitted microrelief, emphasized by the darker tone of vegetation associated with the low damper segments. Along with relief and hydrography, vegetation reacts sensitively to the physical and chemical properties of the rocks. The depth to which plants may indicate bedrock covered by unconsolidated deposits varies for different natural zones. The lithology may be indicated by plants in tundra regions to a depth of 1-2 m, in forest zones to a depth of 10 m, and in deserts to a depth of 20 m. (In relation to the principal types of Karst formation, plants are divided into calciphytes (confined to carbonate rocks), gypsophytes (on gypseous rocks), and halophytes (on halide rocks)). The contacts between carbonate rocks and other rock varieties may be drawn with great reliability. Stands of trees on carbonate rocks, because of the extreme dryness of the underlying rock and the harmful effect of calcium in excess, are normally thinner than in neighboring districts underlain by other rocks.

CLAPP, J.L. 1973.

On Multidisciplinary Research on the Application of Remote Sensing to Water Resources Problems. Wisconsin University, Madison, Institute for Environmental Studies. 77 p. N74-13102/0.

Research objectives during 1972-73 were to: (1) Ascertain the extent to which special aerial photography can be operationally used in monitoring water pollution parameters. (2) Ascertain the effectiveness of remote sensing in the investigation of nearshore mixing and coastal entrapment in large water bodies. (3) Develop an explicit relationship of the extent of the mixing zone in terms of the outfall, effluent and water body characteristics. (4) Develop and demonstrate the use of the remote sensing method as an effective legal implement through which administrative agencies and courts can not only investigate possible pollution sources but also legally prove the source of water pollution. (5) Evaluate the field potential of remote sensing techniques in monitoring algal blooms and aquatic macrophytes, and the use of these as indicators of lake eutrophication level. (6) Develop a remote sensing technique for the determination of the location and extent of hydrologically active source areas in a watershed.

COLCORD, J.E. 1975.

Landsat-I Imagery in Hydrologic Studies. Washington Univ., Seattle. Dept. of Civil Engineering. In: Papers from the fall convention, American Society of Photogrammetry, October 1975. Falls Church, VA. p. 413-436. W76-02163.

The study was done on the Nisqually River Basin situated generally to the southeast of Puget Sound in western Washington. Using Landsat-I images, it was possible to gather data on general geology, land use and vegetation parameters, groundwater sources, seasonal snow lines and snow pack, algae, and sediment patterns. Land use classifications for level 1 (urban and built-up) was compared to recent US Geological Survey Maps and the resulting data are presented in runoff change estimation for preliminary engineering design. For the study using Landsat-I imagery (1:1,000,000) in MSS Bands 4, 5, 6 and 7, the following were identified as items of concern: Watershed determination and related studies/river characteristics/land use characteristics/and atmospheric characteristics. The major problems encountered with imagery uses for engineering studies are: delay in obtaining coverage/cloud frequency expectation/vegetation cover/and shadow in vegetation and snow in areas of high relief and scale. However, the multi-data imagery is helpful in snow line variation and in changes in runoff prediction.

CRAWFORD, N.H., A.S. DONIGAN Jr. 1973.

Pesticide Transport and Runoff Model for Agricultural Lands. Hydrocomp, Inc., Palo Alto, CA. Environmental Protection Agency, Technology Series Report, December 1973. 211 p. W74-11920.

The development and testing of a mathematical model to simulate the loss of pesticides from agricultural lands are presented. The Pesticide Transport and Runoff (PTR) Model is composed of submodels concerned with hydrology, sediment loss, pesticide-soil interaction, and pesticide attenuation functions. The Model 'piggybacks' the applied pesticide onto the movement of water through the soil profile and the loss of water and

sediment from the land surface. The pesticide-soil interaction is based on the Freundlich adsorption-desorption isotherm. Attenuation functions of volatilization and degradation are provided but were not tested due to lack of data. Comparison of simulated and recorded runoff and sediment loss showed considerable agreement. Simulated pesticide loss agreed reasonably well with recorded values for those pesticides completely adsorbed on sediment particles. The Freundlich adsorption model did not accurately predict the division between the adsorbed and dissolved states for those pesticides which are transported by runoff and sediment loss. Recommendations for future work include further calibration and testing of the PTR Model, and additional development on the pesticide adsorption and attenuation functions. The regulation of pesticide releases to the environment is explored as a possible eventual use of the PTR Model.

DOUGLASS, R.W. 1970.

Application of Remote Sensing Techniques to Water Oriented Outdoor Recreation Planning. Geological Survey, Washington, D.C. Geographic Applications Program. Prepared by Association of American Geographers. January 1970. 20 p. PB-194 810.

The document is concerned with high altitude, small scale photography as a tool for evaluating potential water based recreation sites. Potential recreation sites adjacent to the proposed lake at the Tellico Project on the Little Tennessee River were evaluated. Aircraft took photographs at approximately 1:21,300 in October 1968. The images produced were infrared transparencies that were arranged on the roll to prevent stereoscopic interpretation. Success at this scale and flying height indicate merit in continuing with high elevation, samll-scale photography.

ELLYETT, C.D., D.A. PRATT. 1975.

A Review of the Potential Applications of Remote Sensing Techniques to Hydrogeological Studies in Australia. Newcastle Univ. (Australia). Dept. of Physics. Australian Water Resources Council, (Camberra), Technical Paper No. 13, 1975. W76-02534.

This review examined the relationship between remote sensing measurements and the physical properties of hydrogeological environments. Research into the hydrogeological applications of many of these remote sensing methods is still in its infancy and virtually no method can currently be considered a proven tool for hydrogeological investigations, as distinct from surface water studies. The visible and thermal infrared methods in combination will provide a powerful tool for the study of near surface soil moisture over large areas. The thermal infrared method has been successfully applied to the detection of groundwater discharge into bodies of open water, and in

certain circumstances can be used to estimate the discharge rate. Some physical property information relevant to hydrogeological environments can be obtained from Side Looking Airborne Radar (SLAR) surveys, although the cost of such surveys would usually be considered prohibitive. Recent advances with a monopulse radar system have shown considerable promise for the detection of shallow groundwater tables and the estimation of soil moisture content. The low frequency electromagnetic methods provide greater ground penetration than radar systems and are suitable for the investigation of near surface aquifers and recharge zones. The aeromagnetic method may be used indirectly in certain circumstances for the study of hydrogeological environments. (SIMS-ISWS).

ENGLAND, C.B. 1971.

Extension of Hydrologic Process Modeling to Total Watershed Modeling. Agricultural Research Services, Beltsville, MD. Hydrograph Lab. In: Biological Effects in the Hydrological Cycle, Proceedings of the Third International Seminar for Hydrology Professors. July 18-30, 1971. Purdue University, West Lafayette, Indiana.

In modeling the performance of watersheds, especially for agricultural research purposes, it is important to simulate not only the outflow hydrograph but also the internal hydrologic processes. This requires the use of comprehensive distributed-parameter models which permit consideration of storage distribution, paths, and rates of flow. One such model USDAHL-70 model of watershed hydrology, has been developed at the USDA Hydrograph Laboratory. The digital computer program of this model includes separate and distinct subroutines. One for each hydrologic process, such as percolation and infiltration, evapotranspiration, partitioning of watersheds into soil-landform zones by grouping units similar soil and land use, and cascading of flows from zone to zone. The model was applied to synthesize monthly flows for the watershed.

ENGLAND, C.B. 1973.

Watershed Models: Tools in Planning Land Management for Water and Pollution Control. Agricultural Research Service, Beltsville, MD. Hydrograph Lab. Journal of Soil and Water Conservation, (Vol. 28), p. 36-38. January-February 1973.

All phases of the hydrologic cycle are involved in the disposition of wastes on agricultural land. Infiltration, storage, movement of water in the soil, surface detention and runoff, evapo-transpiration, groundwater recharge and channel processes all influence the fate of any material applied to a soil. Because of the complex interdisciplinary nature of predicting watershed performance, comprehensive mathematical models have been developed in agricultural hydrology. Through manipulation of parameters controlling the prediction computations, quick and efficient evaluation of potential effects of management alternatives can be made, thus optimizing the design of control measures to achieve a specified result. These models can provide aid to understanding and predicting water movements within agricultural watersheds. Since they can be employed to determine the movement of dissolved or suspended pollutants, if they are constructed in such a way that land management effects are predictable, they can become a useful tool in pollution control planning.

FLEMING, G. 1968.

The Stanford Sediment Model I:Translation. Strathclyde Univ. Glasgow, Scotland. Bulletin International Association Scientific Hydrol. Vol. 13. No. 2. pp 108-125. June 1968. W68-00834.

A sediment transport model for digital computer and a program translated into 1900 algol, a programming system used in Europe, are described. The original model and program were developed by Negev at Stanford. Results from the use of the translated program have been checked against the original by running the same data for the Napa River in both/they are in complete agreement. The model considers the entire watershed and an attempt is made to simulate the erosion-deposition processes for the watershed by distinguishing between 2 main sources of sediment - the land surface and the stream system. The effects of splash erosion, overland flow, rill erosion, and gullies are added to the stream's wash load, interload, and bed load. (Knapp-USGS).

FORESTRY REMOTE SENSING LAB. 1970.

Analysis of Remote Sensing Data for Evaluation of Vegetation Resources. California Univ., Berkeley. Prepared in Cooperation with Dept. of Agric. Forest Serv. 30 Sept. 70, 176 p. N73-2236.

Research has centered around: (1) completion of a study on the use of remote sensing techniques as an aid to multiple use management; (2) determination of the information transfer at various image resolution levels for wildland areas; and (3) determination of the value of small scale multiband, multidate photography for the analysis of vegetation resources. In addition, a substantial effort was made to upgrade the automatic image classification and spectral signature acquisition capabilities of the laboratory. It was found that: (1) Remote sensing techniques should be useful in multiple use management to provide a first-cut analysis of an area. (2) Imagery with 400-500 feet ground resolvable distance (GRD), such as that expected from ERTS-1, should allow discriminations to be made between woody vegetation, grassland and water bodies with approximately 80% accuracy. (3) Barley and wheat acreages in Maricopa County, Arizona could be estimated with acceptable accuracies using small scale multiband, multidate photography.

Sampling errors for acreages of wheat, barley, small grains (wheat and barley combined), and all cropland were 13%, 11%, 8% and 3% respectively.

FOSTER, K.E., P.F. MACKEY, C.D. BONHAM. 1972.

Natural Resource Inventory for Urban Planning Utilizing Remote Sensing Techniques. Arizona Univ., Tucson. Office of Arid Lands Studies. October 1972. 18 p. N73-20436.

Remote sensing techniques were applied to the lower Pantano Wash area to acquire data for planning an ecological balance between the expanding Tucson metropolitan area and its environment. The types and distribution of vegetation are discussed along with the hydrologic aspects of the Wash.

FOSTER, K.E., J.D. JOHNSON. 1973.

Research for Applications of Remote Sensing to State and Local Governments (ARSIG), Arizona University, Tucson. Office of Arid Land Studies. Feb. 73. 199 p.

Remote sensing and its application to problems confronted by local and state planners are reported. The added dimension of remote sensing as a data gathering tool has been explored identifying pertinent land use factors associated with urban growth such as soil associations, soil capability, vegetation distribution, and flood prone areas. Remote sensing within rural agricultural setting has also been utilized to determine irrigation runoff volumes, cropping patterns, and land use. A variety of data sources including U-2 70mm multispectral black and white photography, RB-57 9-inch color IR, HyAC panoramic color IR and ERTS-1 imagery have been used over selected areas of Arizona including Tucson, Arizona (NASA Test Site 30) and the Sulphur Springs Valley.

GILLILAND, B.E. 1969.

Water Resource Pollutant Identification by Digital Computer Analysis of Remote Infrared Sensor Spectral Intensities. Clemson Univ., S.C. Dept. of Electrical Engineering. In: Record of the 1969 Institute of Electrical and Electronics Engineers Systems Science and Cybernetics Conference. October 1969, Philadelphia, Penn: The Institute of Electrical and Electronic Engineers Catalog No. 69C37-SSC. P 64-69. 1969. W72-00305.

Digital computer analysis of remotely sensed spectral radiance in a select set of wavelength bands in the middle infrared region was used to identify pollutant substances in water bodies. Qualitative and quantitative analysis techniques were explored, with applications in surveillance and monitoring of water quality. Extended to potential automatic control of waste water discharge. Pollution events can potentially be identified and monitored on-line in an essentially real-time

operation using multiband remote infrared radiation sensors coupled with a digital computer. Identification of pollutants results from a successful comparison of the multiband spectral radiance information incident on the sensor system from an unknown source to that of predetermined and computer stored spectral signature. The digital computer eliminated problems associated with complex logic circuitry and permits extension to more sophisticated pattern recognition strategies as needed. (Woodard-USGS)

GOETZ, A.F.H., F.C. BILLINGSLEY, D. ELSTON, I. LUCCHITTA. 1973.

Preliminary Geologic Investigations in the Colorado Plateau Using Enhanced ERTS Images. Jet Propulsion Lab., Pasadena, CA. In: Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1: Vol. I - Technical Presentations. Sect. A, National Aeronautics and Space Admin. Rept. NASA Sp -327. p 403-411. 1973. W74-01708.

Bulk and computer enhanced frames of the Verde Valley region of central Arizona, an area which has been well mapped, were analyzed for structural information and rock unit identification. Most major rock units in areas of sparse ground cover are identifiable on enhanced false-color composites. Regional structural patterns are strikingly visible on the ERTS images. New features were identified which will aid in the search for groundwater near Flagstaff, Sedona, and Stewart Ranch.

GOLDMAN, C.R. 1974.

Eutrophication of Lake Tahoe Emphasizing Water Quality. California Univ., Davis. Institute of Ecology. Pacific Northwest Environmental Research Lab., Corvallis, Oreg. Dec. 74. 428p. PB-240 318/6ST.

A 4½ year study on the rate and factors affecting the cultural eutrophication of oligotrophic Lake Tahoe is reported. Primary productivity has increased alarmingly with a steady shift in the seasonal maximum from early spring to late summer. Productivity increased 25.6% from 1968 to 1971. Using the 1959-1960 data from earlier studies, the increase to 1971 was 51%. Diatoms dominate the phytoplankton population and the maximum zone of phytoplankton photosynthesis may be as deep as 50-75m. The extent of winter mixing is important in the nutrient budget of the lake and bacteria associated with stream-borne nutrients facilitate nutrient regeneration. The littoral zone, although extremely important visually to the lake, contributes only 10% of the total primary production. Great variability in fertility of the lake has been demonstrated by synoptic studies and aerial remote sensing. Highest productivity is found in the lake near tributaries which drain disturbed land. Nutrients associated with road building, housing and lumbering are major causes of eutrophication in Tahoe.

HALLIDAY, R.A. 1973.

Water Survey of Canada: Application for Use of ERTS-A for Retransmission of Water Resources Data. Department of the Environment, Ottawa (Ontario). Applied Hydrology Div. March 1973. 10 p. E73-10469.

The author has identified the following significant results. Nine sites in isolated regions in Canada have been selected for installation of ERTS data collection platforms. Seven platforms were installed in 1972, one of which did not operate. The six operating platforms transmitted over 7000 water level readings from stream gauging stations. This data is available on a near real time basis through the Canada Center for Remote Sensing and is used for river flow forecasting. The practicability of using satellite retransmission as a means of obtaining data from remote areas has been demonstrated.

HAMDAN, A.S., D.D. MEREDITH. 1974.

Network Analysis of Conjunctively Operated Ground Water-Surface Water Systems. Illinois Univ., Urbana. Dept. of Civil Engineering. January 1974. 75 p. PB231 204.

The concept of network models is introduced and a general network model for a multiple purpose, multiple unit water resource system is developed. The 'out-of-kilter' algorithm is then presented as a solution technique for network flow problems. A model for preliminary screening of alternatives for water supply from conjunctive use of ground water and surface water in the Kaskaskia River Basin in Illinois is presented and analyzed. The results from the analysis demonstrate how the network procedures can be used to determine optimum investment plans, to test policy constraints, and to develop policies for future development and future constraints.

HANKS, R.J., J.C. ANDERSON, L.G. KING, S.W. CHILDS, J.R. CANNON. 1974.

An Evaluation of Farm Irrigation Practices as a Means to Control the Water Quality of Return Flow. Utah State Univ., Logan. Utah Agricultural Experiment Station, Logan, Research Report No. 19. July 1974. 48 p. OWRR-A-018-UTAH(1). 14-31-0001-4045. W74-11681.

A physical and economic model has been devised to evaluate irrigation practices as related to irrigation return flow. The physical model requires data of soil water properties, irrigation rates and amounts, potential evapotranspiration and plant rooting properties. Output data include salt and water flow into the water table and relative transpiration. The economic model requires data on cost of irrigation, value of crop, cost of production etc. Output data include net revenue and shadow price as a function of salt outflow. The model predicts that net revenue increases as salt flow increases and that the shadow price (the increase in revenue per unit increase in salt outflow) falls off rapidly as salt outflow increases. It would appear that reasonable water management practices could be achieved that reduce salt outflow on the farm at about a cost of $1 per ton.

HIGER, A.L., A.E. COKER, E.H. CORDES, R.H. ROGERS. 1976.

Water Management Model in Florida from ERTS-1 Data. Geological Survey, Miami, Florida. Final Contract Report, 1975.

A prototype data acquisition and dissemination network, installed and operated by the US Geological Survey, is a viable approach for providing the near real-time data needed to solve hydrologic problems confronting the nearly 2.5 million residents of southern Florida. Water-stage and rainfall data from ground stations are transmitted from the Everglades via Landsat, previously known as ERTS (Earth Resources Technology Satellite), the NASA tracking stations, and the US Geological Survey to the users in less than 2 hours. A significant improvement over conventional techniques requiring up to 2 months. Landsat imagery significantly enhances the utility of the ground station measurements. Water stage (depth) is correlated with water-surface areas from the imagery to obtain water stage-volume relations in near real time for management decisions concerning the distribution of water to the people, fauna and flora of southern Florida.

HUGHES, W.C. 1970.

Economic Feasibility of Increasing Pecos Basin Water Supplies Through Reduction of Evaporation and Evapotranspiration. New Mexico Univ., Albuquerque. Dept. of Economics.

A hydrologic model was developed for the Pecos River Basin in New Mexico to estimate the additional water that could be obtained by vegetation treatment in the forested headwater areas. By removing phreatophytes in the lower river valley, and by applying monolayer films on the major reservoirs in the Pecos Valley. The cost and benefits attributable to the increase in water supplies estimated by the hydrologic model were analyzed to determine the economic feasibility of such a program. Results of this analysis were that removal of timber from the forested headwater region of the Pecos watershed would increase the water yield by about 15%, but was currently unfeasible because the recreational value of the forest far exceeded the value of the additional water. The results also indicated that the annual water gain of 70,000 acre-feet from the eradication of phreatophytes in the Pecos Valley justified the cost of their removal, and that suppression of evaporation on reservoirs during late summer and fall was feasible in the Pecos Valley and would yield approximately 4,000 acre-feet of water annually. (Creel, New Mexico).

IDSO, S.B., R.D. JACKSON, R.J. REGINATO. 1975.

Estimating Evaporation: A Technique Adaptable to Remote Sensing. Science. Vol. 189. Sept. 1975, pp 991-992.

A procedure is presented for calculating 24-hour totals of evaporation from wet and drying soils. Its application requires a knowledge of the daily solar radiation and the maximum and minimum air temperatures (standard Weather Service measurements), moist surface albedo (readily estimated or obtainable from a one-time measurement), and maximum and minimum surface temperatures (obtainable from surface or airborne sensors). Tests of the technique on a bare field of Avondale loam at Phoenix, Arizona, have shown it to be independent of season.

INGLIS, M.H. 1975.

A Quick Look at Surface Water Area Measurement Methods for Southeastern New Mexico. Technology Application Center in cooperation with Bureau of Land Management. Santa Fe, NM 1975. 9 p. (unpublished)

The surface areas for several southeastern New Mexico ponds and lakes were estimated using Landsat images for three different dates. Both visual interpretation and automatic image enhancement were used to make acreage estimates. Results indicate that density slicing techniques can give area measurements accurate to within ± 10 acres.

INSTITUTE FOR ENVIRONMENTAL STUDIES. 1972.

On Multidisciplinary Research on the Application of Remote Sensing to Water Resources Problems. Wisconsin Univ., Madison. 1972. 86 p.

This research is directed toward development of a practical, operational remote sensing water quality monitoring system. To accomplish this, five fundamental aspects of the problem have been under investigation during the past three years. These are: (1) development of practical and economical methods of obtaining, handling and analyzing remote sensing data; (2) determination of the correlation between remote sensed imagery and actual water quality parameters; (3) determination of the optimum technique for monitoring specific water pollution parameters and for evaluating the reliability with which this can be accomplished; (4) determination of the extent of masking due to depth of penetration, bottom effects, film development effects, and angle falloff, and development of techniques to eliminate or minimize them; and (5) development of operational procedures which might be employed by a municipal, state or federal agency for the application of remote sensing to water quality monitoring, including space-generated data.

INTERNATIONAL BUSINESS MACHINES CORP. 1974.

A Study of Remote Sensing as Applied to Regional and Small Watersheds. Vol. 2: Supporting Technical Details. 28 June 1974. 442 p. N74-30833/9SL.

The Stanford Watershed Model, the Kentucky Watershed Model and OPSET program, and the NASA-IBM system for simulation and analysis of watersheds are described in terms of their applications to the study of remote sensing of water resources. Specific calibration processes and input and output parameters that are instrumental in the simulations are explained for the following kinds of data: (1) hourly precipitation data; (2) daily discharge data; (3) flood hydrographs; (4) temperature and evaporation data; and (5) snowmelt data arrays. The Sensitivity Analysis Task, which provides a method for evaluation of any of the separate simulation runs in the form of performance indices, is also reported. The method is defined and a summary of results is given which indicates the values obtained in the simulation runs performed for Town Creek, Alabama; Alamosa Creek, Colorado; and Pearl River, Louisiana. The results are shown in tabular and plot graph form. For Vol. 1, see N74-27813.

JANZA, F.J. 1969.

Electromagnetic Sensor Correlation Study. Ryan Electronic and Space Systems, San Diego, California. January 1969. 150 p. PB-183 414.

Correlation studies between electromagnetic remote sensor outputs and hydrological signature of the terrain such as soil moisture, snow cover and depth, and water areas show positive correspondences. Multisensor direct and cross correlations, as compared to single sensor correlations, are shown to strongly increase the confidence level of the hydrological information.

KABANOVA, K.S. 1970.

Distribution of a Hydrologic Network in Irrigated and Drained Areas. Transl. from Trudy Gos Gidro Instituta, No. 164. p. 56-63. 1968. Soviet Hydrology: Selected Papers, Issue No. 6, p. 594-600. 1968. W70-07198.

Placement of runoff stations along the length of a river must allow determination of runoff in individual reaches. Variation in water discharge along the river course can result from natural or artificial modifications of the environments. The distribution of hydrologic stations along the Zeravshan River, USSR is described. Large water quantities from this river are used for irrigation. Distribution of a hydrologic network in a large drainage basin must consider: (1) use of all possible stations with long series of observations; (2) determination of runoff; (3) study of water regime in reaches above and below dams and other hydraulic structures; (4) water balance determination in reservoir areas based on hydrometric data. An analysis of the existing hydrologic network in the Pripyat' River basin showed that the number of stations should be increased by 40%.

KALININ, G.P. 1974.

Hydrological Basis for Forecasting and Calculating Runoff by Space Images of the Earth's Surface. Kanner (Leo) Associates, Redwood, California. Translated from Gidrologicheskiye Osnovy Prognoza I Rascheta Stoka Po Aerokosmicheskim Snimkam Zemnoy Poverkhnosti, Unpublished manuscript, Academy of Sciences, Moscow (USSR), 53 p. 1974. NASW-2481. N74-25889.

Procedures were outlined for applying generally accepted hydrological equations to determine runoff from parameters that can be derived from satellite or aerial photography. Some of these parameters are the area of coverage of the surface with water, the surface area of the river network, and the soil moisture content. Some American studies of the use of remote sensing for runoff prediction were described. Further problems in the investigation of processes of formation of runoff by use of aerial and space photographs were listed. (Sims-ISWS)

KELL, N.G. 1972.

Application of Aerial Methods in Groundwater Studies. Indian National Scientific Documentation Center, New Delhi, 1971. 287 p. (TT68-50638 and TT70-57236/originally published by Izdatel'Stvo Akademii Nauk SSSR Moskva, 1962, Leningrad.) W72-120023.

The use of aerial photography in the search for groundwater was based on photographic surveys made by the laboratory of aerial surveying of the USSR Academy of Sciences in 1958-59 in desert, semidesert, and forest zones of the USSR. The areas photographed were the Turkmen Republic, the northern plains of the Sub-Caspian lowlands between the Volga and Ural Rivers, and northwestern regions of the RSFSR, including the Leningrad, Pskov, Novgorod and Kalinin oblasts, and parts of the Estonian SSR. The fundamental purpose of the surveys was to locate and evaluate sources of groundwater on the basis of landscape features identifiable with or indicative of the occurrence of groundwater. The results demonstrate the practicality of direct aerial observation in delineating and interpreting the surface extent of various lithologic units and their water-yielding properties.

LANDGREBE, D.A. 1974.

A Study of the Utilization of ERTS-1 Data from the Wabash River Basin. Purdue Univ., Lafayette, Ind. Lab. for Applications of Remote Sensing. January 1974. 52 p. E74-10321.

The author has identified the following significant results. The most significant results were obtained in the water resources research, urban land use mapping, and soil association mapping projects. ERTS-1 data was used to classify water bodies to determine acreages and high agreement was obtained with USGS figures. Quantitative evaluation was achieved of urban land use classifications from ERTS-1 data and an overall test accuracy of 90.3% was observed. ERTS-1 data classifications of soil test sites were compared with soil association maps scaled to match the computer produced map and good agreement was observed. In some cases the ERTS-1 results proved to be more accurate than the soil association map.

LIGON, J.T., D.B. STAFFORD. 1974.

Correlation of Hydrologic Model Parameters with Changing Land Use as Determined from Aerial Photographs. Clemson Univ., S.C. Dept. of Agricultural Engineering. South Carolina Water Resources Research Institute, Clemson Report No. 50, December 1974. 75 p. W75-04448.

Results are described of a research project in which the effects of progressive land use changes in watersheds on the hydrologic response of the water sheds were investigated. The study examined two watersheds in the Piedmont region of South Carolina. The North Tyger River near Spartanburg was selected for study because it was believed to be typical of watersheds which have experienced significant changes in agricultural land use practices. The Reedy River near Greenville was selected as being typical of watersheds in which rural land is being converted rapidly to urban land use. The distribution of land use in each watershed was determined at six intervals over the past 30 years from measurements on aerial photographs. A computer program for the Kentucky version of the Stanford Watershed Model was used to simulate streamflow in the two watersheds. A comparison of simulated and recorded streamflow was used to optimize model parameters so that reasonable agreement between simulated and recorded streamflow was obtained. Correlation of the optimized model parameters and watershed land use was the technique used to examine the relationship between watershed hydrologic response and land use changes. The watershed model parameter, basic maximum infiltration rate, was found to increase significantly with the percentage of the watershed in forest and pasture and to decrease significantly with the percentage of the watershed which consisted of impervious area and residential area. The other three watershed model parameters studied were not significantly correlated with watershed land use.

LIND, A.O. 1973.

Survey of Lake Flooding from ERTS-1: Lake Champlain. Vermont Univ., Burlington. Remote Sensing Lab. June 73. 11 p. B73-10771.

The author has identified the following significant results. ERTS-1 imagery showing seasonal lake-level conditions in Lake Champlain can be used to assess shoreline change and flooding extent. MSS bands 6 and 7 provide maximum land-water contrasts and are the most useful for shoreline location. Shoreline changes observed between ERTS coverages of October 10 (low water) and April 7 and 25 (high water) are readily apparent and enlargement of specific scenes by a factor of four provides data which can be transferred to a map base. The unique synoptic view provided by ERTS-1 will make it possible to map shoreline positions occurring at a specific lake stage. Due to present government concerns over abnormally high lake levels, resource management questions have been raised regarding the extent, nature, and occurrence of inundation magnitude of shoreline change, and lake volume change.

LINDGREN, D.T. 1971.

Color Infrared (CIR) Photography: A Tool for Environmental Analysis. Dartmouth College, Hanover, NH. Dept. of Geography. August 1971. 42 p. PB-204 472.

Research carried out under NASA auspices suggests that in the future remote sensors may play an important role in monitoring our environment. One medium, color infrared photography, appears to have immediate utility. Its capability to identify, measure the acreage of, and monitor the health of agricultural and woodland resources has been demonstrated, as has its capability to identify the sources and extent of certain types of water pollution. CIR is also beginning to demonstrate considerable potential as a tool for urban analysis. The great value of CIR is that it can provide these data quickly and inexpensively, and for that reason will be preferred to more complex multispectral systems by budget-conscious administrators.

VAN LOPIK, J.R., A.E. PRESSMAN, R.L. LUDLUM. 1968.

Mapping Pollution with Infrared. Photogrammetric Engineering, Vol. 34, No. 6. p. 561. June 1968.

The 8-14 micron band is optimal for most aerial infrared surveys because energy emitted by the earth's surface is at a maximum and atmospheric absorption is at a minimum. An aerial infrared study at Galveston Bay, Texas, is discussed, and pictures are shown which clearly demonstrate the effectiveness of aerial infrared photography.

VAN LOPIK, J.R., G.S. RAMBIE, A.E. PRESSMAN. 1968.

Pollution Surveillance by Non-Contact Infrared Techniques. Journal of the Water Pollution Control Federation, Vol. 40, No. 3, p. 425. 1968.

This paper concerns the use of airborne infrared mapping systems in the measurement and delineation of thermal pollution of water and theoretical aspects of non-contact determination of pollutant type, concentration, and distribution. Discussions are focused on the 4-14 micron portion of the infrared spectrum. Specific applications discussed are the capability of rapidly spotting discharge points and surface thermal diffusion patterns such as cold water drainage into a large body of water, and heated effluent discharged by industry into a large body of water. Several photographs are shown in which the thermal differences in the water are quite apparent. Although non-contact infrared techniques determine the temperature of a surface layer only tens of microns in thickness, accuracies of ± 1 or 2 degrees centigrade can be made readily and accuracies of ± 0.2 degree centigrade can be achieved with precision techniques.

MCCOY, R.M. 1967.

An Evaluation of Radar Imagery as a Tool for Drainage Basin Analysis. PhD. Dissertation, Department of Geography, Univ. of Kansas, 112 p. 1967. N69-11953.

Radar images offer an untested, but highly promising, tool for drainage basin analysis. The large coverage and the abundance of landform detail make radar especially suited for areal reconnaissance studies. This present study is an intensive analysis of drainage basins on a K-band radar imaging system, plus a cursory look at two other radar systems as a means of comparison. The objective is to test the capabilities and limitations of radar imagery for quantitative drainage basin analysis. For convenience, this objective is approached through three separate, though interrelated, phases. 1. To determine means of converting radar image terrain data to a topographic map equivalent. 2. To determine the extent to which radar images can be analyzed within existing geomorphic techniques. 3. To examine some procedures for automatic measurement of drainage basin parameters. The procedures were planned to give accurate results with a minimum of operator bias. Each of the basins selected on radar imagery was also examined on USGS 7½ minute topographic quadrangles. This scale map (1:24,000) is accepted for purposes of this report as a consistent presentation of terrain. Imagery was interpreted using a constant amount of enlargement, and a consistent philosophy of map interpretation was maintained. The same methods of stream ordering, counting, measuring, and data handling were applied to map and radar drainage displays.

Preliminary analysis of drainage basins on AN/APQ-69 and a synthetic aperture radar shows that first and second-order streams may be missing entirely on those systems. The K-band radar imagery, however, shows a substantial number of first-order streams, and a correlation and regression analysis was used to determine the actual relationship between radar data and topographic map data. Equations by which radar data can be converted to the equivalent topographic map value were developed for drainage areas, stream numbers, stream lengths, basin perimeters, bifurcation ratio, average length ratio and circularity ratio. The result of the analysis is that drainage area, basin perimeter, bifurcation ratio, average length ratio and circularity ratio can be measured from the imagery with little difference from the map-derived values. This attests to a similar relationship among drainage parameters on both radar imagery and topographic maps. Stream numbers and stream lengths obtained from radar imagery must be converted to map values by an appropriate equation. Such conversion equations are necessitated by losses in low-order stream details on the radar image.

Monoscopic radar images were used in this study to derive terrain slope angles. Nomograms were developed by which the terrain slope can be derived from measurements of slope lengths and depression angles using two different radar views of the same slope. The mean regional slope was the same using map data or radar data on 35 sampled slopes.

MEALOR, W.T. Jr., T.W. PINSON, D.L. WERTZ, C.M. HOSKIN, D.C. WILLIAMS. 1972.

Remote Sensing Study of Land Use and Sedimentation in the Ross Barnett Reservoir, Jackson, Mississippi. University of Southern Mississippi, Hattiesburg. 97 p. N73-18396.

This multi-year study is aimed at focusing on the recognition of sediment and other effluents in a selected area of the Ross Barnett Reservoir. The principal objectives are the determination of land use types, effect of land use on erosion, and the correlation of sediment with land use in the area. The I2S multi-band imagery was employed in conjunction with ground truth data for both water and land use studies. The selected test site contains approximately forty square miles including forest, open land, and water in addition to residential and recreational areas.

MEIER, M.F. 1973.

Evaluate ERTS Imagery for Mapping and Detection of Changes of Snowcover on Land and on Glaciers. Geological Survey, Tacoma, Wash. February 1973. 3 p. E73-10379.

The author has identified the following significant results. The percentage of snow cover area on specific drainage basins was measured from ERTS-1 imagery by video density slicing with a repeat-ability of 4 percent of the snow covered area. Data from ERTS-1 images of the melt season snow cover in the Thunder Creek drainage basin in the North Cascades were combined with existing hydrologic and meteorologic observations to enable calculations of the time distribution of the water stored in this mountain snowpack. Similar data could be used for frequent

updating of expected inflow to reservoirs. Equivalent snowline altitudes were determined from area measurements. Snowline altitudes were also determined by combining enlarged ERTS-1 images with maps. ERTS-1 imagery was also successfully used to measure glacier accumulation area ratios for a small test basin.

MEIER, M.F., R.H. ALEXANDER, W.J. CAMPBELL. 1966.

Multispectral Sensing Tests at South Cascade Glacier, Washington. Proceedings, Fourth Symposium on Remote Sensing of the Environment, Report No. 4864-11-X, Willow Run Laboratories of the Institute of Science and Technology, The University of Michigan, Ann Arbor. April. pp. 145-159. 1966.

Airborne remote sensing tests were carried out at South Cascade Glacier, Washington, as part of a program to determine the potential of obtaining glaciological data from earth-orbiting spacecraft. The sensors employed were: 9-lens multispectral camera, sampling selected frequencies in the visible and photographic infrared; cartographic cameras with panchromatic, color, and color infrared film; a thermal infrared scanning radiometer; profiling radiometers at 4 frequencies of passive microwave radiation; side-looking radar; and a scatterometer for measuring radar reflectivity. Correlative meteorological and photometric measurements were made on the ground, and detailed glaciological information was available from past studies. Orbiting sensors might be used to solve some important glaciological problems by obtaining simultaneous, spatially distributed data related to energy balances, mass budgets, snow cover changes, and crevasse fields.

MILLER, R.R. 1973.

An Introduction to Computer Information Systems in Distribution. In Computer Uses in Water Systems: Conference Papers, A Water Research Association Conference, University of Reading, England, P. 265-274. September 1973. W74-12122.

Various computer techniques for recording, retrieving and presenting information concerning water supply systems and networks, in both the specific and the broadest sense, are introduced. Tabular and cartographic techniques are dealt with, including the digitization of Ordnance Survey maps. Examples of particular applications already used in urban planning systems, including line printer maps using letter intensity and overprinting, are considered. The paper concludes with a look at other more advanced graphical techniques. Information regarding a distribution system and the other parameters affecting water supply must be easily summarized, digested and updated; the first and largest phase of these ventures is information collecting. As this information becomes more generally available, the techniques discribed will form a basis of systems for its presentation to all interested parties.

MITSCH, W.J. 1973.

Remote Sensing of Water Quality: A State of the Art Report. Florida Univ., Gainesville. Water Resources Research Center. May 1973. 17 p. PB-223 503/4.

Remote sensing, or the carrying out of aerial or space surveys of the earth's surface, is finding several applications in the fields of water quality and water resource management. It offers a means of obtaining large amounts of data, but its value is in the expansion of data in the spatial, temporal and spectral modes. The most valuable techniques presently are photography, infrared scanning and multispectral scanning. Aircraft applications include the measuring of the distribution of various waste discharges into water bodies and the study of aquatic plant growth and benthic communities. The ERTS (Earth Resources Technology Satellite) program of the U.S. Dept. of the Interior is investigating satellite applications of monitoring the earth's resources. The water resource applications are less obvious than those of the aircraft and concern environmental indicators on a much larger scale. However, the satellite offers the enhancement of data in the temporal mode with periodic remote sensing of most of the earth's surface.

MOLLARD, J.D. 1970.

Photo-Interpretation Studies in the Location of Prairie Groundwater Supplies. Mollard (J.D.) and Associates Ltd., Regina, (Saskatchewan). Canadian Geotechnical Journal. Vol. 7, No. 2. p. 127-135. May 1970. W71-12391.

Photo-interpretation studies were applied to hydrogeological investigations in the prairie provinces of western Canada. Most of these studies involved the search for previously unknown commercial sources of groundwater in southern Saskatchewan and Alberta. Performance records reported cover the 13-year period from 1956 to 1969. Interpretation of hydrogeological environments was 90% successful using conventional black-and-white aerial photography. Follow-up field data are available on 127 projects, which include 84 groundwater development investigations, pump testing, data analysis and evaluation of safe yield. Airphoto interpretation techniques proved helpful in correctly identifying commercial sources of groundwater in approximately 7 out of 10 projects. About half of the water sources were required for urban use and about one-quarter were required for a variety of industrial uses. Also, roughly half of the studies involved finding 45.5 to 272.8 liters/min and roughly half involved finding 272.8 to 9092 liters/min. Less frequently, the groundwater studies dealt with regional mapping of the surficial and bedrock hydrogeology, with setting up monitoring systems for the detection and surveillance of groundwater contamination, and with locating small groundwater supplies.

MOODY, D.W., T. MADDOCK, III. 1973.

A Planning Model for Preliminary Network Design. Geological Survey, Washington, D.C. In: Proceedings (Vol. III), International Symposium on Uncertainties in Hydrologic and Water Resource Systems, University of Arizona, Tucson. December 1972. p 1039-1069. W73-14173.

Some of the uncertainty associated with forecasting future water demands and with estimating water supply available for regional project development can be reduced by investing in data collection programs. A water resources information system seeks to provide planners with a sufficient amount of data to minimize the expected opportunity loss. The questions asked are: What kinds of data should be collected? When should they be collected? How much should be spent to reduce the uncertainty in the water resource planning process? Since the true values of the model parameters are uncertain, statistical methods are necessary to determine the relative importance of each parameter to the planning process. Presented is a planning model which provides the vehicle for developing a preliminary design for a data collection network. The model utilizes mixed-integer programming to identify a minimum-cost set of water resources projects and to determine the sequence of their construction. The model has parameters related to the expected values of hydrologic and economic factors, and the optimum design's sensitivity to variations in these factors establishes the shape of an opportunity-loss surface, e.g., the difference between the values of the objective function using 'true' parameter values and the estimated parameter values.

MOORE, G.K., M. DEUTSCH. 1975.

ERTS Imagery for Groundwater Investigations. Geological Survey, Bay Saint Louis, Miss. Gulf Coast Hydroscience Center. Ground Water Vol. 13. No. 2. p. 214-226. March-April 1975. W75-07208.

ERTS Imagery offers an opportunity to apply moderately high-resolution satellite data to the nationwide study of water resources. This imagery is both a tool and a form of basic data. The main advantage of its use is to reduce the need for field work. In addition, broad regional features may be seen easily on ERTS imagery, whereas they would be difficult or impossible to see on the ground or on low-altitude aerial photographs. Some present and potential uses of ERTS imagery are to locate new aquifers, to study aquifer recharge and discharge, to estimate groundwater pumpage for irrigation, to predict the location and type of aquifer management problems, and to locate and monitor strip mines which commonly are sources for acid mine drainage. In many cases, boundaries which are gradational on the ground appear to be sharp on ERTS imagery. Initial results indicate that the accuracy of maps produced from ERTS imagery is adequate for many purposes.

MOREY, R.M. AND W.S. BARRINGTON Jr. 1972.

Feasibility Study of Electromagnetic Subsurface Profiling. Geophysical Survey Systems, Inc., North Billerica, MA. October 1972. 76 p. PB-213 892/0.

A study was made of a unique radar system which produces a continuous profile of subsurface conditions showing depth and location of geological formations and buried utilities. Information is obtained by sending electromagnetic pulses into the earth and then receiving the reflected pulses from interfaces and objects. The unit travels at 3 mph, and can detect interfaces directly below it to depths of 10 feet in clay and 25 feet in sand. Depth of penetration is governed by conductivity and dielectric constant. Water content influences these soil parameters; an increase in water content decreases penetration. The penetrability of the soil determines the maximum depth at which pipes can be detected. A break in the pipe can be detected by the saturated soil around the break. Limits of penetration have not been reached; work is being done to determine empirical standards of system performance on a wide variety of soils. Since better information yields better cost estimates for designing sewage collection systems, the advantages of the radar system are apparent.

NATIONAL ACADEMY OF SCIENCES. 1974.

More Water for Arid Lands, Promising Technologies and Research Opportunities. Washington, D.C. Advisory Committee on Technology Innovation. Agency for International Development, Washington, D.C. 1974. 161 p. PB-239 472/4ST.

Little known but promising technologies for the use and conservation of scarce water supplies in arid areas are the subject of this report. Not a technical handbook, it aims to draw the attention of agricultural and community officials and researchers to opportunities for development projects with probable high social value. Each technology is presented in a separate chapter and arranged under the following topics: methods, advantages, limitations, stage of development, needed research and development, selected readings (a short list of reviews and general articles) and contacts (a list of individuals or organizations the panelists know to be involved in relevant research).

NATIONAL FIELD INVESTIGATIONS CENTER-DENVER, COLORADO. 1972.

Remote Sensing Study - Las Vegas Wash Basin, Las Vegas, Nevada. August 1972. 58 p. PB-229 561/6.

The aerial reconnaissance program reports were designed to fulfill the following objectives: Establish the presence of and discharge patterns for the pollutant seepage; establish the presence of industrial/municipal wastes entering the Wash; locate and document all locations where groundwater (sub-surface) is surfacing; and locate and document the actual channel (water flow) path.

NEFEDOV, K.E., T.A. POPOVA. 1975.

Deciphering of Groundwater from Aerial Photographs. NASA TT F-681, 1972. 191 p. Translation of Deshifrirovanie Gruntovykh Vod Do Aerofotosnimkam, Gidrometeologicheskoe Izd., Leningrad. 1969. W75- 11882.

The use of aerial photographs in groundwater studies is discussed. The principles of groundwater photo interpretation, aerial photo sampling and extrapolation of aerial photo indexes are described. A technique for medium-scale mapping of groundwater in areas of deficient precipitation is presented. A number of landscape elements and morphological units are considered in the estimation of groundwater conditions.

NETTLES, M.E., D.B. STAFFORD. 1974.

Determining Land Use Changes in Watersheds by Aerial Photographic Measurements. Clemson Univ., S.C. Water Resources Research Inst. Office of Water Research and Technology, Washington, D.C. Clemson Univ., S.C. Dept. of Civil Engineering.

Techniques are described for using aerial photographs to investigate land use changes in watersheds. Land use changes in two watersheds in western South Carolina were examined. The North Tyger River watershed near Spartanburg, S.C., has experienced significant changes in agricultural land use over the past 26 years. The Reedy River watershed, within which most of the city of Greenville, SC, is located, has experienced rapid urbanization over the past 27 years. Six sets of existing aerial photographs taken at approximately five-year intervals were used to delineate, classify, code, and measure the areas of various land use classes in the two watersheds. The land use classes employed were those that had different runoff characteristics.

PAULSON, R.W. 1973.

Near Real Time Water Resources Data for River Basin Management. Geological Survey, Harrisburg, PA. January 1973. 39 p. E73-10451.

The author has identified the following significant results. Twenty Data Collection Platforms (DCP) are being field installed on USGS water resources stations in the Delaware River Basin. DCP's have been successfully installed and are operating well on five stream gaging stations, three observation wells, and one water quality monitor in the basin. DCP's have been installed at nine additional water quality monitors, and work is progressing on interfacing the platforms to the monitors. ERTS-1 relayed water resources data from the platforms are being provided in near real time, by the Goddard Space Flight Center, to the Pennsylvania District, Water Resources Division, U.S. Geological Survey. On a daily basis, the data are computer processed by the Survey and provided to the Delaware River Basin Commission. Each daily summary contains data that were relayed during 4 or 5 of the 15 orbits made by the ERTS-1

during the previous day. Water resources parameters relayed by the platforms include dissolved oxygen concentrations, temperture, pH, specific conductance, well level, and stream gage height, which is used to compute stream flow for the daily summary.

POE, G.A., A.T. EDGERTON. 1971.

Determination of Soil Moisture Content with Airborne Microwave Radiometry. Aerojet-General Corp., El Monte, CA. Microwave Div. September 1971. 61 p. COM-72-10430.

An analysis of airborne microwave brightness temperature measurements of agricultural soils in the Phoenix Valley, Arizona, on February 25 and March 1, 1971, was performed through comparisons with extensive soil moisture measurements. A comparison of results obtained from presently available theory and measured data at 1.42, 4.99, 19.35, 37 and 94 GHz is presented. Computation of correlation coefficients for measured brightness temperatures and measured soil moisture contents are also given. These comparisons reveal that the 1.42 and 4.99 GHz measured brightness temperatures consistently responded to measured soil moisture changes along the flight lines. Several reasons were advanced to explain the lack of correlation at the higher frequencies but none could be determined to be more valid than the others.

POUQUET, J. 1969.

Possibilities for Remote Detection of Water in Arid and Subarid Lands Derived From Satellite Measurements in the Atmospheric Window 3.5-4.2um. National Aeronautics and Space Administration. Greenbelt, MD. Goddard Space Flight Center. International Conference on Arid Lands in a Changing World. Arizona University, Tucson, June 3-13, 1969.

The purpose of this work was to survey water resources and assess agricultural possibilities in arid and subarid lands. Detection was either of subsurface water through its direct thermal effect or the soil moisture storage capacity. Daytime infrared radiations were almost useless because the scanned areas were too large,the eastern temperatures were too high, the western too low. But, nighttime infrared values proved most useful. (Soil moisture moves toward the cooler profile, at night the cool surface. It carries stored daytime warmth with it to the surface). Most useful were grid print maps of ground equivalent black body temperatures derived from nimbus radiometer measurements in the 3.5-4.2 mu range. Several examples from Africa and North America are presented. By locating areas appearing warmer than they should be, preselection of promising areas for field exploration was made, which from the ground could take years. It is speculated that infrared sensing will become one of the principle media used for the systematic survey of arid land resources.

PREWETT, O.E., D.R. LYZENGA, F.C. POLCYN, W.L. BROWN. 1973.

Techniques for Measuring Light Absorption, Scattering, and Particle Concentrations in Water. Environmental Research Inst. of Michigan, Ann Arbor. April 1973. 37 p. AD-759 668.

The purpose of the research reported was to investigate the usefulness of multispectral remote sensing techniques in determining the concentration of suspended solids in aquatic environments. For the research, aerial photography and multispectral scanner imagery was used to record the upwelling radiation at various locations on the surface of the water. Procedures for determining the concentrations of suspended solids are explored. Two techniques are discussed: The first applies to bodies of water that are shallow and fairly clear; The second applies to bodies of water that are deep or very turbid. The first technique is a direct outgrowth of earlier water-depth studies and, when the necessary ground-truth data are available, can also be used to determine water depth or the scattering and adsorption coefficients of the lake. The second has the advantage of requiring less ground truth data for interpretation of the remote measurements. Both techniques are feasible within certain operational constraints. Both give values of the concentration of suspended solids, relative to the concentration at a fixed point, for every location in a body of water for which multispectral data are avaialble.

RAGAN, R.M., T.J. JACKSON. 1975.

Use of Satellite Data in Urban Hydrologic Models. Maryland Univ., College Park. Dept. of Civil Engineering. Journal of the Hydraulics Division, American Society of Civil Engineers, Vol. 101, No. HY12, Proceedings Paper 11790. p 1469-1475. December 1975. W76-03748.

The study investigated the use of computer-aided analysis of Landsat multispectral data in estimating percentage of imperviousness and associated land uses needed in urban hydrologic modeling. An interactive computer was used to delineate seven land use classifications in the 132 square mile Maryland portion of the Anacostia River Basin from Landsat data. The land use distributions compared favorably with those of an earlier study which obtained the same information through analysis of aerial photographs having a scale of 1:4,800. The Landsat data was used to estimate the basin imperviousness as 25.1% while the aerial photographic study had given 23.5% comparisons between the photographic and Landsat imperviousness estimates were made for subareas within the Anacostia Basin as small as 0.14 square miles. Approximately 94 man-days were required to complete the land use analysis using the aerial photographs while less than 4 man-days were required to accomplish similar tasks using the Landsat data. (Lardner-ISWS)

RANGO, A. 1975.

Applications of Remote Sensing to Watershed Management. National Aeronautics and Space Administration. Goddard Space Flight Center, Greenbelt, MD. April 1975. Conf-Presented for Presentation at Symp. On Watershed Management, AM. Soc. of Civil Engr., Logan, Utah. August 1975. N75-20472/1ST.

Aircraft and satellite remote sensing systems which are capable of contributing to watershed management are described and include: the multispectral scanner subsystem on LANDSAT and the basic multispectral camera array flown on high altitude aircraft such as the U-2. Various aspects of watershed management investigated by remote sensing systems are discussed. Major areas included are: snow mapping, surface water inventories, flood management, hydrologic land use monitoring, and watershed modeling. It is indicated that technological advances in remote sensing of hydrological data must be coupled with an expansion of awareness and training in remote sensing techniques of the watershed management community.

REEVES, C.C. 1973.

Dynamics of Playa Lakes in the Texas High Plains. In: Third Earth Resources Technology Satellite Symposium, Goddard Space Flight Center, Washington, D.C. 1973. pp. 1041-1970. E74-10257.

Three small playa lake basins on the Texas High Plains were originally selected as ERTS-1 test sites to attempt correlation of ERTS-1 imagery with the water balance ecosystem and geology/morphology of the lake basins. Two of the test sites were instrumented with water level recorders, infiltrometers, tensiometers, evaporation pans, totalizing aneometers, weighing rain gauges, and continuous recording microbarograph and hygro-thermographs. However, when initial imagery (under maximum usable magnification) showed that resolution was not adequate for the monitoring of water fluctuations of the small lakes, the 5-mile long large Double Lakes playa complex was instrumented as an alternate test site.

During the period July 1972-August 1973, the Double Lakes playas went from an initial flooded condition (July, 1972 pass) to a partially dry condition (south playa dry, north playa wet, June 19, 1973 pass) to a total dry condition (July 6) to a flooded condition (July 24) to a partial dry condition (August 11). This sequence is portrayed by 16 mm time-lapse film loops constructed from ERTS-1 MSS imagery.

Color composites using an electronic density profile have been particularly useful for distinguishing the exact water area from the muddy areas of the Double Lakes playas, and for determining the salt crust areas. Color composites also portray gradations in water transparency, due to depth fluctuations, suspended sediment or algae, much better than the single MSS bands.

Analysis of Bands 6 and 7 of ERTS-1 MSS imagery, using photographic enlargement and a 32-color density slicer with zoom magnification, shows that lake basins as small as 200 m in diameter (± 10 acres) can be reliably classified as being "wet" or "dry", thus supplying the methodology for a rapid, periodic census of surface water. A cost/benefit analysis reveals that the use of MSS imagery for such a census results in a 66 to 200-fold cost reduction when compared to the costs of using other conventional methods. Thus, even the poorest of the arid countries of the world can afford to monitor their ephemeral lakes, enhancing the predictability of extended drought conditions.

REMOTE SENSING CENTER, TEXAS A & M, COLLEGE STATION. 1975.

Remote Sensing Applied to Crop Disease Control, Urban Planning, and Monitoring Aquatic Plants, Oil Spills, Rangelands, and Soil Moisture. Feb. 1975. N75-20799/3ST.

The application of remote sensing techniques to land management, urban planning, agriculture, oceanography, and environmental monitoring is discussed. The results of various projects are presented along with cost effective considerations.

ROACH, J.T., J.W. KELLEY. 1974.

Application of the LUNR Inventory System for Water Resources Planning and Management in the Susquehanna River Basin. Cornell Univ., Ithaca, NY. Water Resources and Marine Sciences Center. April 1974. PB-233 841/6.

A study is made of the Land Use and Natural Resources inventory (LUNR) to New York State to demonstrate its application and management in the Susquehanna River Basin. The feasibility of combining in one data bank information needed for comprehensive water resources planning and management is explored. LUNR is a computer-based system of data storage and retrieval; it accomodates point, area and linear information which is identified, located and stored according to a geographic referencing system. Much information is obtained from remote sensing, but the system is very flexible. It is held that what occurs on the land in a river basin has an impact upon the water resources of that basin. The development, characteristics and intricacies of the LUNR system are described. First an overview and chronology are presented; data sources, base maps, scale, geographic referencing, information classification, and more are evaluated in detail. Next, examples of LUNR applications in the Susquehanna River Basin are considered.

RODDA, J.C., W.B. LANGBEIN, A.G. KOVZEL, D.R. DAWDY, K. SZESTAY. 1970.

Hydrological Network Design Needs, Problems and Approaches. Meteorological Organization Report No. 12, 1969. W-70 06550.

Network design enters into most aspects of hydrology; consequently, it is a topic which merits considerable attention. Lack of necessary attention results from difficulties in demonstrating the value of scientific design, problems of defining and classifying hydrological networks, and several other factors, including the absence of clear and concise objectives. Methods of design apply the concepts of regionalization, mapping and systems analysis, but the most sound design criteria are economic ones. There are no relevant economic data from networks. Some countries possess networks or plans for them which can serve as models for others. It is evident, however, that approaches to design are likely to enter a new phase of development in the near future, with the routine use of artificial satellites, automatic weather stations and computers for all aspects of data processing and analysis. This report is concerned with these and other matters pertinent to hydrological network design. It seeks to present the topic critically and cautiously as a reminder that much has still to be accomplished.

ROOT, R.R., L.D. MILLER. 1971.

Identification of Urban Watershed Units Using Remote Multispectral Sensing. Colorado State Univ., Fort Collins. Dept. of Watershed Sciences. June 1971. PB-209 639.

The dynamic nature of urbanizing watersheds is documented by analysis of thirteen small watersheds in the Denver suburbs for the percent area of ten surface materials using aerial photographs at five to ten year intervals (concrete, asphalt, rooftop, gravel, lawn, natural, agricultural, forested, bare soil, and water). The results clearly show the changes in impervious areas in these watersheds as a function of year and time of year. A method is outlined whereby remote multispectral imagery can be used to map these surface characteristics which in turn can be related to surface hydrologic units and used as input into a watershed simulation model.

RUFF, J.F. 1973.

A Feasibility Study of Using Remotely Sensed Data for Water Resource Models. Colorado State Univ., Fort Collins. February 1973. N73-23479.

Remotely sensed data were collected to demonstrate the feasibility of applying the results to water resource problems. Photographs of the Wolf Creek watershed in southwestern Colorado were collected over a one year period. Cloud top temperatures were measured using a radiometer. Thermal imagery of the Wolf Creek Pass área was obtained during one pre-dawn flight. Remote sensing studies of water resource problems for user agencies were also conducted. The results indicated that: (1) remote sensing techniques could be used to assist in the solution of water resource problems; (2) photogrammetric determination of snow depths is feasible; (3) changes in turbidity or suspended material concentration can be observed; and (4) surface turbulence can be related to bed scour; and (5) therml

effluents into rivers can be monitored.

RUPPERT, R.W., G.S. CLAUSEN. 1974.

Interbasin Transfer or Migration: An Economic Analysis of Two Responses to Ground Water Depletion. Kansas Water Resources Research Inst., Manhattan. W74 02223.

An area which depends upon ground water mining for a substantial proportion of its income faces three alternatives as its groundwater becomes depleted: 1) it can develop more water through alternative sources of supply as improved natural recharge, importation and artificial recharge, and waste water reuse; 2) it can transfer water use to less consumptive, higher-yield applications such as high-yield crops or manufacturing processes; 3) it can incur reductions in income and in population because of migration. An economic model which can be used to compare, from society's point of view, the first alternative and the third as responses to ground water depletion was studied. Should an area depleting its groundwater be encouraged to develop interbasin transfer of water or should it be encouraged to promote migration. In order to fully assess the nature of the costs of constructing or of abandoning facilities such as public buildings and roads and private factories or farm houses, a model of just the area would not be adequate. In order to study society's point of view it is necessary to imbed the model of the area within a model that takes into account the economic consequences of migration on the receiving area. Several conceptual models are developed that include migration, interbasin transfer and ground water depletion. Some of the theoretical implications of the models are interpreted as they relate to the formulation of ground water resource pricing schemes. Some of the implications of the research findings for local ground water management districts are discussed. The research methods being employed to develop projections of water requirements for the state of Kansas are called into question.

SALOMONSON, V.V. 1975.

Water Resources. National Aeronautics and Space Administration, Greenbelt, MD. Goddard Space Flight Center. In: Third Earth Resources Technology Satellite Symposium. Vol. III, Discipline Summary Reports, Washington, DC. December 1973. W75-07501.

The synoptic coverage of ERTS imagery permits fairly easy identification of basin extent and broad physiographic features such as drainage area, stream network character, land use and water coverage. It is relatively easy to identify snow by using ERTS-1 MSS bands 4 and 5. Glaciers are readily observed in the ERTS imagery. Recognizable glacial features include cirques, terminal moraines and crevassed areas. Surging glaciers can easily be distinguished from their characteristic wiggly folded moraines. Surface water is one of the most easily delineated parameters in the hydrologic cycle. Flood plain features such as natural and arfificial levee systems, upland boundaries, vegetation and soil differences. Flood alleviation measures, and land use and agricultural patterns are easily identified through tonal differences on ERTS-1 color composites. Indications of water quality can be observed in a limited manner through the use of ERTS-1 imagery in bands 4 and 5. Areas covered by wetlands can be measured by a variety of techniques. The presence of irrigation methods is best identified in the arid and semiarid regions of the United States with ERTS-1. Since groundwater or subsurface water cannot be seen directly from ERTS imagery, its presence must be inferred from indentification of surface features that are generally correlated with or are an indication of subsurface water. Relative variations of soil moisture in unvegetated or bare-soil areas can be seen.

SCARBROUGH, L., R.E. KIDD. 1972.

Evaluation of Techniques for Selecting Sites for Induced Infiltration Along the Alabama River. Geological Survey of Alabama, University. PB-220 961/7.

The study includes the application of photogeologic, geophysical and auger test-drilling methods in the flood plain of the Alabama River to locate and define deposits that would be good shallow aquifers having definite potential for hydraulic connection to the river. Aerial photographs were studies to assist in locating abandoned river channels and other areas in which shallow aquifers might exist. Prospective areas were then delineated, and geophysical studies and an auger test drilling program were implemented. Refraction seismic and electrical resistivity methods were used to attempt to locate sand and/or gravel deposits. Electrical resistivity became the primary geophysical method used when experience indicated that sand and gravel deposits were more resistive than the associated clay and silt deposits. (Modified author abstract)

SCHUMANN, H.H. 1972.

Applications of ERTS-A Data Collection System (DCS) in the Arizona Regional Ecological Test Site (ARETS). Geological Survey, Phoenix, Ariz. Water Resources Div. December 1972. E73-10332.

The author has identified the following significant results. Preliminary analysis of DCS data from the USGS Verde River Stream flow measuring site indicates the DCS system is furnishing high quality data more frequently than had been expected. During the 43-day period between Nov. 3 and Dec. 15, 1972, 552 DCS transmissions were received during 193 data passes. The amount of data received far exceeded the single high quality transmission per 12-hour period expected from the DCS system. The digital-parallel ERTS-1 data has furnished sufficient to accurately compute mean daily gage heights. These in turn, are used to compute average daily streamflow

rates during periods of stable or slowly changing flow conditions. The digital-parallel data has also furnished useful information during peak flow periods. However, the aerial-digital DCS capability, currently under development for transmitting streamflow data, should provide data of greater utility for determining times of flood peaks.

SERS, S.W. 1972.

Remote Sensing in Hydrology a Survey of Applications with Selected Bibliography and Abstracts. Texas A & M Univ., College Station. Remote Sensing Center. October 1971. N72-21357.

Remote infrared sensing as a water exploration technique is demonstrated. Various applications are described, demonstrating that infrared sensors can locate aquifers, geothermal water, water trapped by faults, springs and water in desert regions. The potentiality of airborne IR sensors as a water prospecting tool is considered. Also included is a selected bibliography with abstracts concentrating on those publications which will better acquaint the hydrologist with investigations using thermal remote sensors as applied to water exploration.

SNIEDOVICH, M., C.C. KISIEL, L. DUCKSTEIN, D.R. DAVIS. 1973.

Worth of Hydrologic Data for Short-Term Forecasts of Floods. Arizona Univ., Tucson, Dept. of Hydrology and Water Resources. July 1973. COM-73-11773/1.

A methodology is developed for the evaluation of the worth of the hydrologic data for short-term forecasts of floods. The effectiveness of the forecasts is measured in terms of the entire system under consideration - that is the flood plain, rather than solely in hydrologic terms such as the mean error of forecast. Both the actual and potential worth of the forecasts are studied with emphasis on the effects of warning time, forecast error, response of the population, and hydrometric network on the end product of the system - that is, the social and economic improvement of the flood plain. An adequate evaluation, especially concerning the potential worth of the hydrologic data, requires a multi-disciplinary study involving hydrologists, economists, sociologists, psychologists and flood plain authorities. In the light of continuous improvement in the scientific and technologic aspects involved in the forecasting system there is a need for a continuous reevaluation of the forecasting system as a potential alternative in flood control projects especially as a complementary alternative to the classical ones such as zoning, and structures.

SONDEREGGER, J.L. 1970.

Hydrology of Limestone Terranes: Photogeologic Investigations. Geological Survey of Alabama, University. 1970. PB-198 043.

Panchromatic, color, and infrared films were used to locate fracture traces as an aid to the interpretation of the occurrence and movement of groundwater in a limestone area in Alabama. Air photography using color and infrared films resulted in greater interpreter confidence and showed correlation with geologic structure. Wells drilled along fracture traces yielded substantially more water than the average of the randomly located wells. The thickness of the residuum had no noticeable control over the fracture-trace concentration. Previous models explaining the relationship between fracture tracers and solution activity dealt with a single homogeneous limestone aquifer. In this area, two limestone aguifers separated by an aquiclude produce two different lithologic units on which solutional features that are reflected by fracture traces are developed.

TISDALE, E.W. 1973.

Application of Remote Sensing in the Study of Vegetation and Soils in Idaho. Idaho Univ., Moscow, Coll. of Forestry, Wildlife and Range Sciences. May 1973. E73-10512.

The author has identified the following significant results. Comparison of ERTS-1 imagery and USGS 1:250,000 scale maps of study areas with known ground points revealed significant map errors. These errors were sufficient to render impractical the projection of ERTS-1 imagery directly onto maps of the area. Marked differences were found in the delineation of ground features by different MSS bands. Generally, Band 4 was least useful, while Band 5 proved valuable for indicating patterns of native vegetation, cultivated areas - both dry and irrigated, lava fields, drainage basins, and deep bodies of water. Band 6 was better for land forms and drainages and for shallow bodies of water than Band 5 but inferior for indicating patterns in native vegetation and most types of cultivated land. Band 7 was best of all for indicating lava flows, water bodies, and landform features. Use of an additive color viewer projector aided greatly in separation of images. A combination of Band 5 and 7 with appropriate color filters proved best for separating most types of native vegetation and cultivated crops. Landform features and water bodies also showed well with this combination. The addition of Band 4 imagery to these further enhanced the identification of semi-dormant vegetation.

TSCHANTZ, B.A. 1973.

Strip-Mined Watershed Hydrologic Data Acquisition Study. Tennessee Univ., Knoxville. Water Resources Research Center. August 1973. PB-223 558/8.

Remotely sensed aerial photography of two small strip-mined east Tennessee watersheds was used as a means for obtaining land use information essential to econometric and hydrologic

studies and for reclamation practice surveillance. 1:12,000 scale maps were produced for both watersheds from three color IR photographic flights. Other available high altitude photography and thermal imagery data were used to help map strip mine disturbed areas. Excellent photographic coverage and quality permitted approximately 5,041 acres of watershed, representing 847 acres of disturbed bench, slope, and slide areas to be mapped for each mission at a cost of less than 10 cents/acre. The study demonstrated the usefulness of using low altitude IR photography for identifying, mapping and measuring strip-mine disturbance areas.

TSCHANTZ, B.A., J.D. WOMACK, J.M. PROCHASKA, H.P. DESELM, C.C. AMUNDSEN. 1972.

Remote Sensor Utilization for Environmental System Studies. Volume I. Tennessee Univ. Knoxville.Air Force Cambridge Research Labs., L.G. Hanscom Field, MA. December 1972. AD-786 484/6ST.

The research involved the use of photography and thermal imagery as tools for quickly retrieving relevant information from expansive and complex environs using aerial platforms such as aircraft, satellites, and towers. Volume I summarizes efforts in the disciplines of water resources, planning, botany and ecology, agriculture, and electrical engineering. Remote sensing application studies include thermal and water quality effects in streams and lakes; urban and regional land use change detection; prediction of landscape (site and cover) parameters; identification of agricultural plant species; detection of plant disease; identification of agricultural soil series; evaluation of soil moisture conditions; and development of remote sensing data processing techniques.

VEZIROGLU, T.M., S.S. LEE. 1974.

Application of Remote Sensing for Prediction and Detection of Thermal Pollution. Miami Univ., Coral Gables, Florida. Clean Energy Research Inst. October 1974. N75-10572/6ST.

The first phase is described of a three year project for the development of a mathematical model for predicting thermal pollution by use of remote sensing measurements. A rigid-lid model was developed, and results were obtained for different wind conditions at Biscayne Bay in South Florida. The design of the measurement system was completed, and instruments needed for the first stage of experiment were acquired, tested, and calibrated. A preliminary research flight was conducted.

VEZIROGLU, T.M., S.S. LEE. 1973.

Feasibility of Remote Sensing for Detecting Thermal Pollution. Part 1: Feasibility Study. Part 2: Implementation Plan. Miami Univ., Coral Gables, Fla. Dept. of Mechanical and Industrial Engineering. December 1973. N75-15199/3ST.

A feasibility study for the development of a three-dimensional generalized, predictive, analytical model involving remote sensing, in-situ measurements, and an active system to remotely measure turbidity is presented. An implementation plan for the development of the three-dimensional model and for the application of remote sensing of temperature and turbidity measurements is outlined.

VILLEMONTE, J.R., J.A. HOOPES, D.S. WU, T.M. LILLESAND. 1973.

Remote Sensing in the Mixing Zone. Wisconsin Univ., Madison. Inst. for Environmental Studies. August 1973. Submitted for Publication Sponsored in Part by Dept. of Natural Resources. Conf-Presented at Awra Intern. Symp. On Remote Sensing of Water Resources, Burlington, Ontario. 1973. N74-19041/4.

Characteristics of dispersion and diffusion as the mechanisms by which pollutants are transported in natural river courses were studied with the view of providing additional data for the establishment of water quality guidelines and effluent outfall design protocols. Work has been divided into four basic categories which are directed at the basic goal of developing relationships which will permit the estimation of the nature and extent of the mixing zone as a function of those variables which characterize the outfall structure, the effluent, and the river, as well as climatological conditions. The four basic categories of effort are: (1) the development of mathematical models; (2) laboratory studies of physical models; (3) field surveys involving ground and aerial sensing; and (4) correlation between aerial photographic imagery and mixing zone characteristics.

VOGEL, T.C., M.J. LYNCH, A.O. LIND, R.W. BIRNIE. 1972.

A Matrix Evaluation of Remote Sensor Capabilities for Military Geographic Information. Martin Co. Orlando Florida. Materials Research Lab. July 1972. AD-751 192.

The work is an initial attempt to evaluate 20 selected remote sensor types for their ability to obtain data on specific natural and cultural terrain components (81 selected MGI elements). The evaluations were made at three levels according to the complexity of the MGI element and the level of experience required from the interpreter. The MGI elements were categorized into four major divisions: (1) Drainage and Water, (2) Vegetation, (3) Landforms and Surficial Materials, and (4) Cultural and Industrial-Economics. The problems associated with detection of each MGI element, recommended interpretation techniques and the references pertinent to each evaluation are presented.

WARD, R.C. 1973.

Data Acquisition Systems in Water Quality Management. Colorado State Univ., Fort Collins. Socioeconomic environmental studies series. May 1973. PB-222 622/3.

The role of routine water quality surveillance was investigated, including a delineation of the objectives of a state water quality program based upon the state and federal laws. Seven specific objectives are listed under the two general objectives of prevention and abatement: planning, research, aid programs, technical assistance, regulation, enforcement, and data collection, processing, and dissemination. Each objective was broken down into the general activities required for its accomplishment and the data needed for each activity were identified. A survey of systems for grab sampling, automatic monitoring, and remote sensing was performed, each data acquisition technique being analyzed for capabilities, reliability, and cost. A procedure was developed for designing a state water quality surveillance program responsive to objectives. Financial and manpower constraints are considered.

WATER RESOURCES CENTER, WISCONSIN UNIV., MADISON. 1970.

Proceedings of the National Symposium on Data and Instrumentation for Water Quality Management at Wisconsin Univ., Madison. December 1970. PB-203 150.

The central theme of the Symposium was to assess the benefits offered by advanced data collection, analysis and display systems toward the enhancement of the nation's environment. Under this framework, the Symposium considered case studies where advanced systems were in operation and experience has been gained, and explored the results of recent research on several topics.

WHITE, M.E. (in preparation)

Volumetric Measurements and Seasonal Variation of Selected New Mexico Lakes. Thesis in progress, Geography Department, University of New Mexico, Albuquerque.

Landsat 1, Band 7 imagery was analyzed using visual interpretation, electronic planimeters, and density slicing techniques. Results so far indicate that while data from these area measuring methods correlate highly with field data, the amount of error prohibits the use of the estimated acreages for any monitoring programs.

WHITE, P.E. 1973.

Water Quality Parameter Measurement Using Spectral Signatures. Cincinnati Univ., Ohio. Remote Sensing Center. May 1973. N73-25141.

Regression analysis is applied to the problem of measuring water quality parameters from remote sensing spectral signature data. The equations necessary to perform regression analysis are presented and methods of testing the strength and reliability of a regression are described. An efficient algorithm for selecting an optimal subset of the independent variables available for a regression is also presented.

WIEGAND, C.L. 1973.

Reflectance of Vegetation, Soil, and Water. Agricultural Research Service, Weslaco, Texas. February 1973. E73-10408.

The author has identified the following significant results. The ability to read the 24-channel MSS CCT tapes, select specified agricultural land use areas from the CCT, and perform multivariate statistical and pattern recognition analyses has been demonstrated. The 5 optimum channels chosen for classifying an agricultural scene were, in the order of their selection, the far red visible, short reflective IR, visible blue, thermal infrared, and ultraviolet portions of the electromagnetic spectrum, respectively. Although chosen by a training set containing only vegetal categories, the optimum 4 channels discriminated pavement, water, bare soil, and building roofs, as well as the vegetal categories. Among the vegetal categories, sugar cane and cotton had distinctive signatures that distinguished them from grass and citrus. Acreages estimated spectrally by the computer for the test scene were acceptably close to acreages estimated from aerial photographs for cotton, sugar cane and water. Many nonfarmable land resolution elements representing drainage ditch, field road, and highway right-of-way as well as farm headquarters area fell into the grass, bare soil plus weeds, and citrus categories, and lessened the accuracy of the farmable acreage estimates in these categories. The expertise developed using the 24-channel data will be applied to the ERTS-1 data.

WILLIAMS, L. O. 1970.

Evaluation of Remote Sensor Images, Asheville Basin Area, North Carolina. Tennessee Univ., Knoxville. December 1970. Prepared in cooperation with East Tennessee State Univ., Johnson City.

Isopleth mapping, computation of Pierson's Correlation Coefficient and multiple linear regression analysis have been employed to analyze the system: water-vegetation-soil-rock-topography in a 50 mile long, 12 mile wide area centered on Asheville, North Carolina. Comparison of data suggests that analysis of the 100 random samples give results which are comparable to isopleth mapping of 196 sample sites for variables which have relative abundance and which have relatively contrasting properties of weathering, erodibility and water retention. These variables are clay and silt in soils, quartz in soils and bedrock, and muscovite in bedrock, and they appear to be dependent on a unique combination of independent variables. Accordingly it appears that lowlands (Case A) will be more likely to have clay rich soils, with relatively longer channel lengths per square mile, and to have soils which have low color values and relatively more soil moisture. The subsurface is likely to have abundant muscovite or biotite in both soils and bedrock and garnet will be associated.

WILLIAMS, R.S., Jr. 1972.

Terrestrial Remote Sensing: Applications of Thermal Infrared Scanners to the Geological Sciences (IV). Air Force Cambridge Research Labs., L.G. Hanscom Field, MA. January 1973. Pub. in ISA Transducer Compendium, Part 3, Instrument Society of America, Pittsburgh, PA. p 219-236. 1972. AD-756 353.

Airborne thermal infrared scanning radiometers are being increasingly applied to the study of geologic phenomena by geologists. Successful aerial thermographic surveys require the combined knowledge of a geologist, an electronics engineer and a pilot/navigator. Characteristics of the environment (terrestrial surface and atmosphere), limitations of airborne scanning radiometers and stability of aircraft place constraints on the usefulness of the thermograph for geologic investigations. Field observations are mandatory for the accurate correlation of tonal variations on a thermograph with the geologic phenomena under study. Presently known geologic applications of aerial thermography include geothermal areas, volcanoes, and several hydrogeologic phenomena, including groundwater discharge into surface waters, surface current flow, and outfall and surface movements of pollution which has a thermal component.

WIMBERLY, E.T. 1975.

Satellite Relay and Processing of Hydrologic Data in South Florida. Geological Survey, Tallahassee, Fla. Water Resources Div. National Aeronautics and Space Administration, Washington, D.C. July 1975. PB-244 784/5ST.

Management of water in south Florida requires current hydrologic data on water levels and rainfall. This need is being met by a data processing system which provides near-real-time data from remote areas. The flow of data is from data-collection platforms at field sites via Landsat-1 satellite to the National Aeronautics and Space Administration's (NASA) ground-receiving stations to the NASA Data Processing Facility at Goddard Space Flight Center to the Miami office of the US Geological Survey to data users. The process requires only a few hours, and current data are provided to water management agencies in several different forms. The system has proven to be dependable.

WOFFINDEN, D.S., A.D. KARTCHNER. 1968.

Water Quality Telemetry. Utah Water Research Lab., Logan. August 1968. PB-215 284.

The primary objective of the project is to demonstrate the feasibility of telemetering, by radio transmission, several water quality parameters from remote, battery operated, monitoring stations to a central receiving station. A secondary objective of the project is to show the economic feasibility of establishing and maintaining a remote, battery-operated field station.

APPENDIX III

Major Investigative Topics
and Associated Selected References

I. Improved Water Information Dissemination Techniques and Programs.

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II. Population Growth and Water Supply Relationships

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