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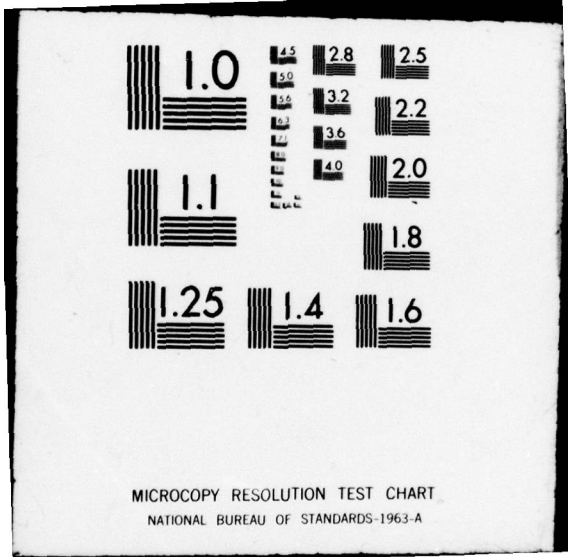
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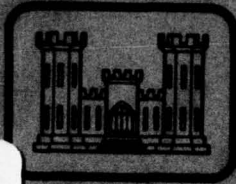
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TECHNICAL REPORT EL-79-2

PROCEEDINGS OF THE MILITARY
HYDROLOGY WORKSHOP, 17-19 MAY 1978
VICKSBURG, MISSISSIPPI

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May 1979
Final Report

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20. ABSTRACT (Continued).

CONI → groups were then formed to address four specific areas of hydrology:
(a) streamflow, (b) soil moisture, (c) meteorology, and (d) water supply.
Each group developed a research plan which identified short-term capability
update requirements and long-term technology advancement requirements.
Synopsis of the research plans were presented during the final general session. ↗

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PREFACE

A Military Hydrology Workshop cosponsored by the U. S. Army Research Office (ARO) and the U. S. Army Engineer Waterways Experiment Station (WES) was held at the WES on 17-19 May 1978. This report was published under Department of the Army Project No. 4A762719AT40, "Mobility, Soils, and Weapons Effects Technology," Task Area A-3, "Geoscience Techniques and Methodologies," Work Unit 009, "Hydrology Support for Military Operations," sponsored by the Assistant Chief of Engineers, Office, Chief of Engineers (OCE). Mr. Richard Barnard was the Technical Monitor for OCE.

Papers were presented by the following: CPT R. L. Marx, Department of the Army, 139th Engineer Detachment; Dr. Ray K. Linsley, Hydrocomp; Dr. John L. Vogel, Illinois State Water Survey; Dr. Robert A. Clark, National Weather Service; Dr. Victor I. Myers, South Dakota State University; Dr. Cornelius H. M. van Bavel, Texas A&M University; Mr. Ronald M. Cionco, USA Electronics Command Atmospheric Sciences Laboratory; Mr. C. Sherman Grazier, USA Engineer School; Mr. R. Theodore Hurr, U. S. Geological Survey; Mr. Arlen D. Feldman, USA Hydrologic Engineering Center; MAJ John Allen, USA Logistic Center; Dr. Steve J. Mock, ARO; Dr. Daniel D. Evans, University of Arizona; and Mr. W. E. Grabau, MAJ R. H. Gillespie, Dr. L. E. Link, Mr. J. K. Stoll, and Mr. W. A. Thomas, all of WES.

The presentations by WES personnel were prepared under the general supervision of Dr. John Harrison, Chief, Environmental Laboratory (EL), Mr. Grabau, Special Assistant, EL, and Mr. Bob O. Benn, Chief, Environmental Systems Division (ESD), EL. Dr. Mock was responsible for the ARO participation in the workshop. Dr. Wesley P. James, WES, was responsible for the overall coordination and management of the workshop.

COL J. L. Cannon, CE, was Director of WES at the time of the workshop and during preparation of this report. Mr. F. R. Brown was Technical Director.

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ATTENDEES

MILITARY HYDROLOGY WORKSHOP

U. S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

17-19 May 1978

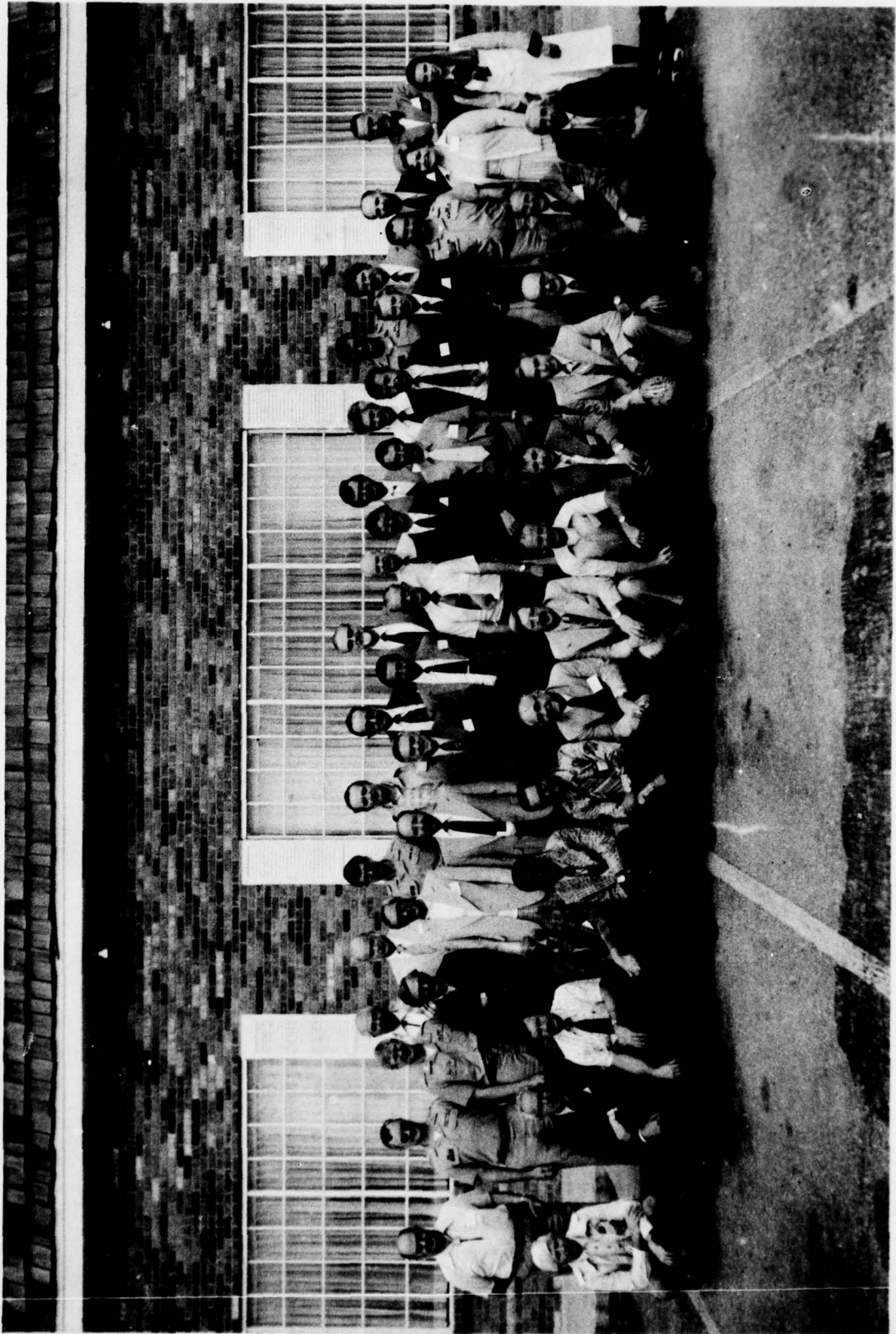
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ATTENDEES
MILITARY HYDROLOGY WORKSHOP

U. S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

17-19 May 1978

First row, from left to right: Dr. Cornelius van Bavel; Dr. Gert Aron;
Dr. Steve Mock; Dr. Kevin Carey; Soronadi Nnaji; R. T. Hurr; Dr. George Huebner;
Dr. John Vogel; Dr. Pat Gannon; Dr. Jimmy Williams; Dr. L. E. Link;
Dr. A. O. Poulain; Dr. Wesley P. James; W. G. Shockley.

Second row, from left to right: C. Sherman Grazier; MAJ John Allen;
CPT Bob Marx; Dr. Tom Schmugge; Dr. Robert M. Ragan; Dr. Ray O. Jackson;
Dr. Robert A. Clark; Ray K. Linsley; Dr. Marvin D. Kays; Arlen D. Feldman;
Thomas L. Engdahl; Theodore C. Vogel; Jerry R. Luniden; MAJ Alan C. Smith;
Halley Jo Ragsdale; Donna C. King.

Third row, from left to right: Dr. E. S. Simpson; Dr. D. D. Evans; LT E. D. Smith;
P. S. Eagleson; Dr. Victor Myers; R. H. Barnard; Walt Duncan; W. A. Thomas;
J. G. Collins; MAJ R. H. Gillespie; J. W. Labadie; R. M. Cionco; and W. E. Grabau.

AGENDA

MILITARY HYDROLOGY WORKSHOP

U. S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

17-19 May 1978

Wednesday, 17 May 1978

General Session, Military Hydrology Requirements

W. P. James, Chairman

0800	Registration and name tags	
0830	Welcome and WES briefing	LTC D. A. Hughes, WES
0905	Workshop organization and ground rules	W. G. Shockley, WES
0920	Definition and Overview of Military Hydrology	L. E. Link, WES
0940	Battlefield Hydrology Requirements	S. Mock, ARO
1000	Break	
1020	The Need for Soil Moisture in Mobility	MAJ R. H. Gillespie, WES
1040	Stream Crossing Requirements	J. K. Stoll, WES
1100	Water Supply Requirements	W. E. Grabau, WES
1120	Impulse Flood Waves	W. A. Thomas, WES
1140	The Army's Operational Capabilities	CPT R. L. Marx, 319th Engr. Det
1200	Lunch	

General Session, State of the Art

L. E. Link, Chairman

1300	Measurement and Forecasting of Streamflow	Arten Feldman, HEC
1320	The National Weather Service River and Flood Programs	Robert Clark, NWS
1330	Advanced Concepts for Hydrologic Models	Ray Linsley, Hydrocomp
1340	Soil Moisture Monitoring and Forecasting	Dan Evans, University of Arizona
1400	State of the Art in Soil Moisture Modeling	Cornelius van Bavel, Texas A&M University
1410	Results of the January 1978 NASA-USDA Soil Moisture Workshop	Victor Myers, SDSU

AGENDA (Continued)

- | | | |
|------|---|--|
| 1420 | Open discussion | |
| 1440 | Break | |
| 1500 | Summary of Existing Capabilities for Measuring and Forecasting Selected Weather Variables | Ron Cionco, Atmospheric Sciences Laboratory |
| 1520 | Meteorological Research in the National Weather Service | Robert Clark, NWS |
| 1530 | Radar Rainfall Over an Urban Region | John Vogel, ISWS |
| 1540 | Water Supply and Distribution | MAJ John Allen, U. S. Army Logistics Center |
| 1600 | Groundwater Investigations | R. T. Hurr, USGS |
| 1610 | Location of Sursurface Water Sources | C. Sherman Grazier, U. S. Army Engineer School |
| 1620 | Open discussion | |
| 1630 | Adjourn | |
| 1800 | No-Host Social Hour (Ramada Inn) | |

Thursday, 18 May 1978

Discussion Groups, Research Requirements

S. Mock, Chairman

- 0830 General Session - Instruction for discussion groups.
(The desired product from each discussion group is a list of identified research needs. Each research item on the list should include a brief statement of justification, description of the required research, and priority ranking.)
- 0900 Group discussions
- 1015 Break
- 1035 Group discussions - continued
- 1200 Buffet lunch
- 1300 Group discussions - continued
- 1515 Tour of Waterways Experiment Station (discussion leaders to summarize results of session)
- 2030 "Return to the River," a musical extravaganza at the Vicksburg Auditorium - see attachment (optional)

PROCEEDINGS OF THE MILITARY HYDROLOGY WORKSHOP

17-19 MAY 1978, VICKSBURG, MISSISSIPPI

INTRODUCTION

The military Hydrology Workshop was held at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, 17 to 19 May 1978. In order to keep the workshop to a manageable size, attendance was by invitation. The Army Research Office (ARO) provided financial support for travel of non-Army attendees. Participants were selected to provide a wide range of organizational representation and technical expertise. Attendees included 50 hydrologic experts representing 11 Army offices or laboratories, 6 other Federal agencies, 9 universities, 1 State agency, and a private engineering firm. A list of attendees is given on pages 4 through 8.

The objective of the research effort in military hydrology is to develop an improved hydrological capability for the Armed Forces. The purpose of the workshop was to identify research needs in the following four areas: (a) streamflow monitoring and forecasting, (b) soil moisture monitoring and forecasting, (c) meteorological monitoring and forecasting, and (d) water supply. The results of the workshop will be used to formulate a research plan that will specify both short-term research required to adapt existing hydrologic technology to military application and long-term research required to develop advanced hydrologic technology.

The workshop agenda is given on pages 11 through 13. The first morning of the workshop was devoted to a general session on military hydrology requirements where speakers identified the type of hydrologic information required and defined constraints associated with military operations.

A general state-of-the-art session was held Wednesday afternoon. In this session, three reports completed for WES by the Hydrologic Engineering Center (HEC), the University of Arizona, and the Atmospheric

Sciences Laboratory were presented. In addition, nine speakers representing organizations with extensive hydrologic experience discussed their activities and views on research needs. A summary of each of the presentations is included herein.

The second day of the workshop was devoted to group discussions in each of the four technical areas listed above. Each group was charged with the responsibility to identify both short-term capability update research requirements and long-term technology advancement research requirements. Attendees could participate in more than one group discussion. Synopses of the discussions were presented by the discussion leaders at a general session Friday morning and are included within.

DEFINITION AND OVERVIEW OF MILITARY HYDROLOGY

by

L. E. Link*

Military hydrology is a specialized field of hydrology that deals with the effects of surface and subsurface water on planning and conducting military operations. It involves attributes such as streamflow quantities, current velocities, potential flood characteristics, channel and lake-bed geometries, soil moisture accumulation, groundwater availability, and water quality. Some examples of hydrologic data needs for selected military operations include:

- a. Stream discharge and stage measurements and forecasts for gap crossings.
- b. Stream velocity and stage measurements and forecasts for bridging.
- c. Soil moisture measurements and forecasts for mobility.
- d. Meteorological forecasts in support of all combat operations to ensure force survivability and readiness under the most hazardous conditions.

Joint regulation AR 115-21 and AFT 105-10 of May 1977 assigns responsibilities for providing hydrologic information. The Chief of Engineers has the responsibility for performing all research and development activities and providing support of operational elements in the Continental United States (CONUS) and other territories of the United States. Under the authority of this regulation, the Waterways Experiment Station (WES) was directed to initiate a study to develop an improved hydrologic capability for the Armed Forces. Almost immediately we found that there was a pressing need to adapt the most recent technology available. This is because only one Army unit (319th Engineer Detachment in New Kensington, Pennsylvania) has a Table of Organization and Equipment (TOE) of terrain-hydrology, and its existing measuring and forecasting procedures are outmoded. Thus, the WES study was

* U. S. Army Engineer Waterways Experiment Station.

designed to take advantage of recent developments in data processing, hydroscience technology, and remote sensing to provide a short-term update in Army hydrologic capability. This will be based on adaptation of existing technology and a long-term advancement in capability through technological advances.

Our efforts to date have been to: identify hydrologic data requirements for the Army, the Air Force, and the Navy; to determine current Army capabilities; define available state-of-the-art technology; assess research needs; and develop a detailed plan of research. These efforts are outlined in a draft report entitled "Military Hydrology Status and Research Requirements." This report summarizes the results of support efforts by the U. S. Army Hydrologic Engineering Center, the U. S. Army Electronics Command Atmospheric Sciences Laboratory, the University of Arizona, the 319th Engineer Detachment, and in-house efforts by the WES. It was prepared as a "strawman" for this workshop to help focus our attention on specific military hydrology data requirements and to stimulate ideas for achieving a final plan of research that will provide the capabilities needed by the Army to meet both short- and long-term data needs. It is envisioned that research will be needed in many diverse areas; thus, we are looking not only for ideas, but assistance in executing those ideas, as well. Keep this in mind as we continue with the workshop.

BATTLEFIELD HYDROLOGY REQUIREMENTS

by

Steve Mock*

I would like to address what I see as the fundamental and by far the most difficult problem in military hydrology; namely, the capability of predicting hydrologic conditions on the mesoscale, some few hours ahead of and under battlefield conditions. Under certain conditions this capability could give a commander an immense tactical advantage, whether on offense or defense.

Consider, for example, a commander who has a forecast in hand stating that all streams up to third order in size in a particular sector will be flowing at bankful stage 4 hours hence and that low-lying areas will have some flooding, or will be fully saturated and impassable to both wheeled and tracked vehicles. I leave it to your imagination to decide what a skilled commander could do possessing such information.

What is required to have such a capability?

1. An accurate forecast or "nowcast" of weather: rainfall amounts and location.
2. A knowledge of present soil moisture condition.
3. A knowledge of present streamflow conditions.
4. A model which, given the predicted rainfall, can forecast stream conditions and resulting soil moisture regimes.

None of the streams are gaged or have previous records available. What do we need to accomplish this? We need the means to measure the various model inputs, i.e., wind, rainfall, soil moisture. But I think the models must come first; establish their capability and validity, and the others will follow.

* U. S. Army Research Office, Research Triangle Park, North Carolina.

THE NEED FOR SOIL MOISTURE DATA TO ASSESS MOBILITY

by

MAJ R. H. Gillespie*

The classic key to success in ground combat is the ability to shoot, move, and communicate. All three elements are extremely important, and a commander ignores one only at his peril. However, I would like to do just that and address only the ability to move or "...git thar fustest with the mostest..." To do this, a commander must know where and how fast he can move his units, and where and how fast enemy units can move.

Current Army doctrine states that the problem facing the Army is to win the first land battle. This battle is envisioned as being of very short duration, probably lasting only one or two weeks. It will be characterized by very intensive combat between rapidly moving armored and mechanized forces. Some guidelines for the solution of the problem are realistic training, employment of weapons and crews to the best effect, correct assessment of the dynamics of modern battle, and continued reassessment in pace with the ever-changing nature of the modern battlefield.

Those solution elements which involve ground mobility assessment include early identification of enemy thrusts, rapid massing of combat power at points of our selection, rapid placement of effective obstacles, frequent rapid lateral shifting of combat forces, and continuous superior use of combat, combat support, and logistical support resources. All of these elements involve a proper assessment of ground mobility.

Any system to evaluate mobility must consider the interaction of vehicles, drivers, and the terrain. The parameters for vehicles and drivers are fairly easy to quantify, but the same cannot be said of terrain. Terrain characterization requires a quantitative description of the surface composition and geometry, the vegetation, and the hydrology. All of these may vary with weather and seasonal changes.

These are some of the features which must be considered. We have time-stable features, features which vary with season, and features which

* U. S. Army Engineer Waterways Experiment Station.

vary with current and recent weather. One of the most important features which affect a vehicle's ability to traverse a given piece of terrain is the soil strength. In fact, if the soil strength at a particular time for a particular area on the ground is known, a fairly accurate prediction of a vehicle's mobility there can be made. However, soil strength varies with the weather and season due to the changes in moisture content. Therefore, any system for assessing mobility must be able to measure or predict moisture content and from that make a determination of soil strength.

Hopefully, this workshop will help to define research objectives which will better enable us to determine or predict soil moisture. This will help to place in the hands of our commanders a decisionmaking tool which will give them a distinct advantage in analyzing courses of action and may in fact act as a force multiplier. That saying of Ben Franklin's in Poor Richard's Almanac, "For want of a nail..." could well be modified to "For want of moisture content, the battle was lost."

STREAM CROSSING REQUIREMENTS

by
J. K. Stoll*

Does the U. S. Army have requirements for stream crossings? The answer is unequivocally yes!

Imagine if we had excavated a steep-sided, wide, deep moat around this building and filled it with muddy Mississippi River water. Further, each of you would have been required to be here promptly at 0830 this morning to convene the workshop. The moat, or gap, to use the military jargon, would have been an effective barrier, certainly to your vehicle. How would you have solved the problem of getting to this room on time?

The combat soldier on the forward edge of the battlefield has had this same problem throughout history. Gaps are the most significant obstacles an advancing army encounters. This is because of their frequency and severity and the subsequent time delays incurred.

Some things have been done to help the soldier with his problem. Vehicles have been designed to:

- a. Swim.
- b. Ford shallow.
- c. Ford deep (vehicle submerges and crosses on the stream channel bottom).

Further, rafting and bridging equipment has been designed and used. As examples, 55 bridges were built across the Rhine River in World War II, and 1,482 tactical bridges were built by U. S. forces during the Italy campaign of World War II. Our Army cannot be a totally effective fighting force without the means to maintain mobility across gaps.

Figures 1 and 2 present tactical gap-crossing results for a study of tracked and wheeled vehicles, respectively, for a study area in West Germany. As shown, four of the five wheeled vehicles tested were unable to cross more than 60 percent of the gaps encountered. Similar results were obtained for another area tested, also in West Germany. Wheeled

* U. S. Army Engineer Waterways Experiment Station.

PERCENT OF CROSSINGS GO - ALL STAGES, WEST GERMANY STUDY AREA
TRACKED VEHICLES

VEHICLE	EUROPEAN WATERWAYS AREA			
	<u>BOTTOM CROSSING</u>	<u>BANK CLEARANCES</u>	<u>EGRESS TRACTION</u>	<u>ALL THREE FACTORS GO</u>
M548E1 (D)	99	39	69	32
M113A1 (S)	99	46	60	38
M551 (S)	99	43	78	37
XM723 (S)	99	92	81	80
M60A1	95	48	78	38
FIVE-VEHICLE AVERAGE	98	54	73	45

Figure 1. Gap-crossing data for tracked vehicles in
a West Germany study area

PERCENT OF CROSSINGS GO - ALL STAGES, WEST GERMANY STUDY AREA
WHEELED STUDY VEHICLES

VEHICLE	VEHICLE AS-IS			
	BOTTOM CROSSING	BANK CLEARANCES	EGRESS TRACTION	ALL THREE FACTORS GO
M151A2	85	0	2	0
M861	89	0	0	0
M561*	95	18	1	0
M35A2	92	26	5	1
M813	92	10	1	0
M656*	96	29	6	2
M520E1*	96	35	8	4
M127E1	92	26	0	0
M818/M125	92	10	4	0
TD901	96	36	1	1

* SWIMMER AS-IS

Figure 2. Gap-crossing data for wheeled vehicles in a West Germany study area

vehicles performed very poorly; less than 1 percent of the tests being successful. It should be noted, though, that for an area studied in the Middle East, nearly all wheeled vehicles tested were able to cross more than 90 percent of gaps encountered. This indicates that performance is highly dependent on the operational environment, in this case gap characteristics.

A commander of a combat unit arriving at a gap must somehow cross it. If he is not confident that his vehicles can cross either by swimming or fording, what are his alternatives? He may use assault bridging equipment assigned to the unit or call in an engineer bridge company.

I indicated earlier how important bridging was during World War II. It was just as important in Korea and Vietnam. And not only is it important to us but also to the enemy because he can adjust his tactics on the basis of his knowledge of our bridging assets. If the enemy knows you have an 18-m armored vehicle launched bridge, he will tend to defend gaps greater than 16 m in width (a 1-m set back distance is required on each bank). For gaps greater than 16 m, you will be required to use a bridge that must be constructed, a time-consuming process and one associated with high vulnerability to men and equipment.

Two operations simulation models that WES is particularly proud of are the Army Mobility model for use in evaluating the performance of tracked and wheeled vehicles and the STAFFGAP (Simulated Terrain and Force For Gaps) for use in evaluating bridging equipment. All environmental-materiel interaction models require adequate input data, and the gap-crossing module of the Army Mobility model and the STAFFGAP model are not exceptions. They require detailed information on the geometric and hydrologic characteristics of gaps as shown in Figure 3. These data are needed on magnetic tape or disk storage for direct input to the computer to interact with the vehicles or bridging equipment, as the case may be, and obtain the output measures of effectiveness.

Output from the models can be tailored to the needs of the equipment designer, the procurement specialist, or the military strategist and tactician. But irrespective of the user, the worth of the model computations is most dependent on the quality of the gap input data.

GAP DATA

GEOMETRY AND HYDROLOGY

GAP WIDTH
CURRENT VELOCITY
BANK ANGLE - RIGHT
BANK ANGLE - LEFT
BANK HEIGHT - RIGHT
BANK HEIGHT - LEFT
WATER WIDTH
DEPTH
WATER DEPTH
BOTTOM WIDTH

VEGETATION AND SOIL STRENGTH

VEGETATION BANK WIDTH LEFT
STEM DIAMETER AND DENSITY UNIT
VEGETATION BANK WIDTH RIGHT
STEM DIAMETER AND DENSITY UNIT
CONE INDEX TOP LEFT BANK
CONE INDEX INTERFACE LEFT
CONE INDEX STREAM BED
CONE INDEX INTERFACE RIGHT
CONE INDEX TOP RIGHT BANK
SOIL TYPE CODE

Figure 3. Gap data requirements
for the Army Mobility and STAFF-
GAP models

WATER SUPPLY REQUIREMENTS

by

W. E. Grabau*

Among the responsibilities of the military hydrologist is that of providing water supplies for the Armed Forces. In general, the task consists of six major steps, as illustrated in Figure 1. However, for the purposes of this workshop, the scope has been restricted in two ways.

First, we are concerned only with the Army in the field and not with permanent military installations in the U. S. or overseas. The assumption is that the provision of water supplies for such installations will closely resemble the procedures followed to provide municipal and/or industrial water supplies. All of the normal civil sector apparatus of hydrologic, hydraulic, and civil engineering will be invoked.

Second, we are concerned only with steps 1-3 in Figure 1. The assumption is that the design and construction of pumping systems, storage tanks, and treatment plants are the provinces of civil engineers, and not those of the hydrologist. To be sure, the border dividing the interests and concerns of those whose role it is to locate suitable water sources and those charged with acquiring, treating, and distributing water is very tenuous. Obviously, the nature of the potential supply constrains the acquisition and treatment systems, and the availability of acquisition and treatment machinery to some degree controls the specifications of suitable sources. However, despite such obvious interaction, there is a reasonably clearly understood separation of functions between those who seek water and those who manipulate it, once found. It is this distinction that we wish to emphasize. We want to confine our concerns in this workshop to those of finding and assessing potential water supplies.

The first problem area (Figure 1) is specifying the need. In order to do his job properly, the military hydrologist must have a clear idea of both the quantities and qualities needed and the time period over which the need will exist. Examples are numerous. It is easy to imagine

* U. S. Army Engineer Waterways Experiment Station.

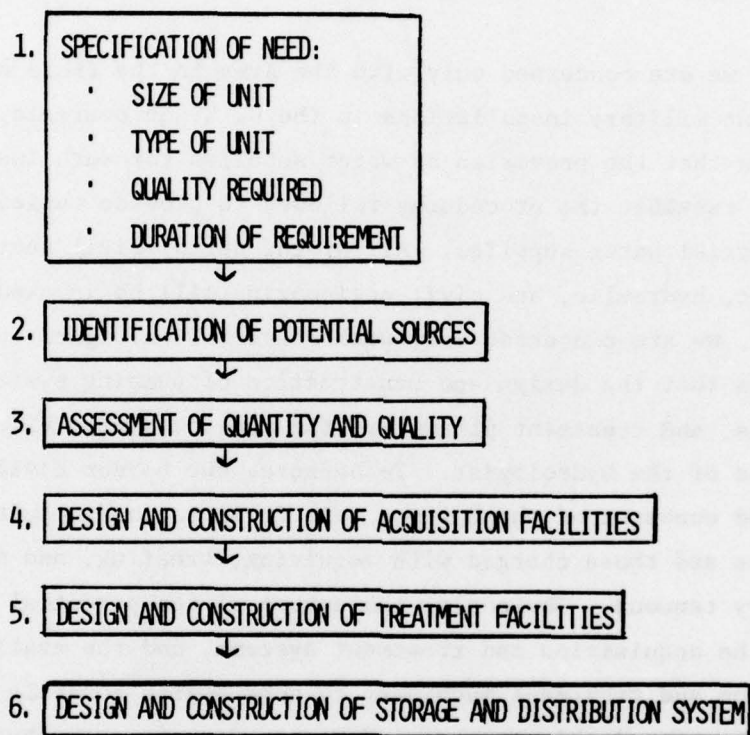


Figure 1. Idealized diagram of procedure for obtaining water supplies

a source of water quantitatively adequate for drinking and cooking, but quite inadequate for sanitary and other purposes. It is equally easy to imagine sources qualitatively adequate for laundries and vehicle wash racks, but unsuitable for human consumption.

The implication is that the military hydrologist needs a rapid and reliable way of determining the probable water requirements of a military force. It is clear that water requirements, both quality and quantity, must be related to such elements as manpower, equipment types and amounts, mission, and climatic regime of the theater of operations. The general procedure is obvious: the military hydrologist first establishes the kinds and amounts of water that are required and then uses information to guide him in his search for appropriate sources. Thus, the first requirement is for an analytical procedure that will reliably establish water requirements for any given size and composition of force for any part of the world, for any season of the year, and for any length of operation.

The second problem area (Figure 1) is related to the location and identification of potential sources of water. This is an extraordinarily complex area of concern; in the civil sector, individuals devote a lifetime of study to this matter and, even so, may concentrate on only one aspect of the problem. The military hydrologist cannot afford this luxury; he must somehow be given procedures that work quickly and with reasonably good prospects of success, but which require a minimum of specialized training.

In this regard, it is important to recall that water is obtained in four basic categories of situations: surface water (such as streams, canals, and lakes), soil water (stored in or passing through surface and unconsolidated materials), groundwater (stored in or passing through subsurface and consolidated materials), and meteoric water (harvested from rain, snow, or fog). Each has its special problems and potentials. For example, placing dependence upon a surface stream may lead to disaster unless the hydrologist can be quite sure of the reliability of the flow; thus, harvesting water from surface streams requires the capability to make reasonably quick and reliable runoff predictions and forecasts.

There are clearly two major areas of concern. The first is the problem posed by the long training period which has been traditionally required to produce a competent hydrologist. In this context, a competent hydrologist is one who can practice effectively in all four areas: surface, soil, ground, and meteoric waters. The second main problem area concerns what might be called the hardware of exploration. There are many tools of water exploration, ranging from current velocity meters to well-drilling gear to airborne magnetometers to satellite images. Unfortunately, for all practical purposes, none of them have been adapted to the special requirements of the military hydrologist. The existing gear is too heavy, or too bulky, or too fragile, or too time-consuming, or something.

The conclusion is that we need vastly improved methods of exploring for water. That includes methods of training hydrologists, with a dramatically reduced period of training, and much better exploration instruments and procedures. Only in this way can we envision a capability for finding and assessing adequate water supplies within the very short time frames that are implied by modern military concepts.

The third problem area is that of assessment. To some degree the problem of assessing both quantity and quality, but especially quantity, is a function of step 2 in Figure 1. That is, the location and identification of a suitable source implies that the source has been evaluated in terms of quality and quantity. However, that is not always true. Water standing in the bottom of an open-shaft farm well is certainly a potential source, but special techniques are required to determine how much water can be extracted and what its quality will be. Thus, estimation of quantity implies that the military hydrologist has access to both procedures and instruments of specialized kinds. While such items are widely available in the civil community, they are often not well suited to military situations. The instruments tend to be heavy and bulky and the procedures are slow.

Essentially similar conditions pertain to the matter of assessment of water quality. While excellent information can be obtained with civil sector equipment and procedures, the necessary gear for chemical

and biological assessments tends to be too bulky, too easily damaged, and too complicated for successful military use. Thus, it seems likely that both improved instruments and procedures will be required.

IMPULSE FLOOD WAVES

by

W. A. Thomas*

The following aspects of impulse flood wave analysis are pertinent to military hydrology requirements:

- a. Development of the flood wave. The size of breach and rate of development are pertinent structural determinations in analyzing impulse flood waves. These are considered as "given information" in this topic.
- b. Size of flood waves. Reservoir volume and head on the breach at the time of failure determine the size flood wave that will develop from a specified breach. Size is pertinent for estimating the depth of flooding, duration of flooding, and potential impact on transportation, communication, and industrial facilities in the study area.
- c. Movement of the flood wave. The flood wave depth decreases with distance downstream from the breached dam unless the valley is very steep. It is important to know how far the wave must travel before it becomes ineffective as a hydraulic force or barrier. Time of arrival of the front of the wave, time of arrival of the peak, and duration of flooding are pertinent.
- d. Ground wetting. Will enough water seep into the ground to cause problems with the movement of wheel or track equipment?
- e. Analytical requirements.
 - (1) Existing: Military Hydrology Bulletins 9 and 10 present current methodology.
 - (2) Needed: The complexity of the problem suggests that two levels of sophistication are appropriate for analysis:
 - (a) Simple approach, for a first approximation, which utilizes existing map and area intelligence and quickly assesses the order of magnitude of a potential hazard.
 - (b) Analytical approach which accounts for physical processes involved, the complexities of topography and multiple structures, and the initial state of the ground and flow conditions in the study area.

* U. S. Army Engineer Waterways Experiment Station.

THE ARMY'S OPERATIONAL CAPABILITIES

by

CPT R. L. Marx*

In answer to the question "What is the Army's operational capabilities in hydrology?", I would classify it as limited or extremely limited.

The 319th Engineer Detachment completed a self-assessment of the unit in August of 1977. The assessment was made primarily by 1LT David Rose.

Presently, there are two types of units in the Army charged with the hydrology responsibility: the terrain-hydro detachment and the terrain detachment. Within the Army, excluding the National Guard, there are a total of eight terrain units. Only one, the 319th Engineer Detachment (Reserve) in New Kensington, Pennsylvania, near Pittsburgh, is charged specifically with the hydrology mission. There are three other terrain detachments in the reserve system and four in the active Army (one in Hawaii, one in Europe, and two in CONUS).

The mission of all terrain units, including the 319th, is to collect, interpret, analyze, produce, and disseminate military geographic intelligence (Figure 1). This mission statement was prepared to show the mission of all terrain units. Presently, only the 319th Engineer Detachment is charged with the portion of the statement "and provide consultant services" in military geology and hydrology.

This is not to say that these capabilities would not be required of other terrain detachments, but the chances of those units completing the tasks charged to a hydrology detachment and outlined in the draft report are very unlikely.

Under the new Table of Organization and Equipment (TOE) for terrain units, all units will be organized in the same manner and will have the same mission. In the most recent draft copy of FM 5-146 Engineering Topographic Units, the one aspect stressed is the response time of the terrain unit. The terrain unit is to "respond to 50 percent of all inquiries within 4 hours and the remainder including those requiring graphic presentation within 48 hours."

* Department of the Army, 319th Engineer Detachment (Terrain).

TERRAIN DETACHMENT MISSION

**TO COLLECT, INTERPRET, ANALYZE, PRODUCE,
AND DISSEMINATE MILITARY GEOGRAPHIC
INTELLIGENCE**

THIS ENTAILS THE FOLLOWING CAPABILITIES:

- 1. COLLECTION**
- 2. PREDICTIONS AND ANALYSES OF THE EFFECTS
OF TERRAIN FACTORS ON MILITARY OPERATIONS**
- 3. PREPARATION OF PRODUCTS (OVERPRINTED
MAPS, OVERLAYS TO STANDARD MAPS, SPECIAL
GRAPHIC) AND TEXTUAL OR VERBAL OUTPUT**
- 4. PROVIDING CONSULTANT SERVICES**

Figure 1. Terrain detachment mission

I can't blame you for laughing because we know how long it takes to apply the existing hydrology models such as HEC 1 and HEC 2. We better start now if we are to be able to answer the questions that may be asked.

The 319th Engineer Detachment (Terrain-Hydrology) is a Theater Army level terrain detachment and is presently authorized 22 people. The authorized equipment is limited. When our unit is sent out, we have a carpenter's tool kit, some drafting equipment, and a photo interpretation kit (Figure 2). Somehow we are to get the job done.

The majority of the unit's experience has been in the area of river-crossing tasks, but specifically we have completed a special flood hazard report for the Corp's Pittsburgh District Office and special reconnaissance reports for the Corp's Baltimore District Office.

To accomplish any of our missions, it has been necessary to beg, borrow, or steal equipment to get the job done. By utilizing the resources of the Corps Offices, post engineers, engineering units at a post, and the Defense Mapping School, we have managed.

Being a Reserve rather than Active Duty Unit, the time available for training is limited to one weekend a month plus a two-week summer

MAJOR ITEMS OF EQUIPMENT*
TO&E 5-336H AND 5-540H TERRAIN TEAMS

1. **TERRAIN TEAM THEATER ARMY AND TERRAIN TEAMS CORPS**
 - A. **HYDROLOGIC SURVEY SET**
 - B. **METEOROLOGIC SURVEY SET**
 - C. **SURVEY SET**
 - D. **SOIL TRAFFICABILITY TEST SET**
 - E. **PHOTO INTERPRETATION KIT**
 - F. **TEST SET SOIL**
 - G. **REFLECTING PROJECTOR**
 - H. **REPRODUCTION SET DIAZO**
 - I. **DRAFTING SET**
2. **DIVISION TERRAIN TEAM**
 - A. **PHOTO INTERPRETATION KIT**

*NOT INCLUDING ORDNANCE, QUARTERMASTER, AND OTHER COMMON ISSUE EQUIPMENT

Figure 2. Major items of equipment

camp, so we must rely on the civilian education and training of existing and new personnel.

Earlier I briefly mentioned the new TOE. The Army is going to a new TOE 5-5401J and a new version of 5-540H series for terrain units. As shown in Figure 3, the number of people is increased to 25. This increase in personnel may seem to be an asset, but the total experience level of the terrain unit is decreased. Also under the revisions, the equipment available to the terrain detachment is more in line with its needs to collect data, but are not what is required to do a complete job.

The new emphasis within the Army is the matching of a terrain unit with an existing unit to support the intelligence (G-2) effort at all levels of command (Figures 4 and 5). The support will provide information as part of the Intelligence Preparation of the Battlefield (IPB). This is not tomorrow, but today; and part of the requirement is for hydrology information and the establishment of a data base.

A typical, yet classic question a commander asks of the terrain unit is "What happens if I blow this dam?" Honestly, no one in our unit

PERSONNEL STRENGTH TO&E 5-336H AND 5-540H TERRAIN TEAMS

ENGINEER TOPOGRAPHIC BATTALION (THEATER ARMY)

	MAJ	CPT	LT	EM	TOTAL
1 TERRAIN TEAM THEATER ARMY	1	4	2	18	25
3 TERRAIN TEAMS (CORPS)	3	12	6	54	75
12 TERRAIN TEAM (DIVISION)		12		48	60
TOTALS	4	28	8	120	160

Figure 3. Personnel strength

THE TOPOGRAPHIC COMMUNITY: Command, Control, and Technical Coordinating Relationships

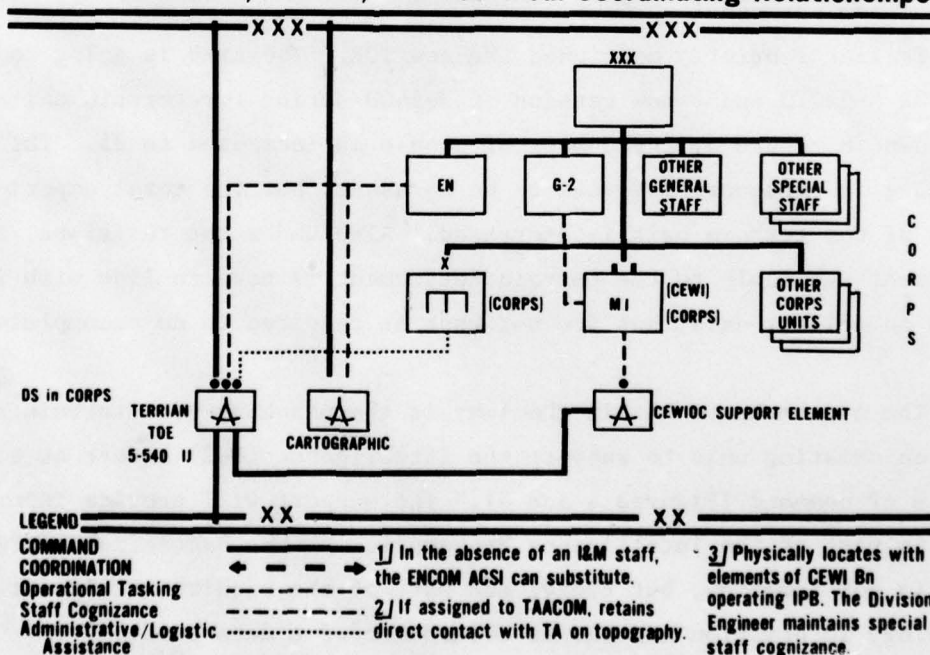


Figure 4. Topographic community

hydrologists, computer access, and a data base.

It is a sad state of readiness, but that is why we are here--to decide where we are going and how to get there.

MEASUREMENT AND FORECASTING OF STREAMFLOW

by

Arlen Feldman*

The Hydrologic Engineering Center (HEC) undertook a research project for the Waterways Experiment Station (WES) in an effort to improve the hydrologic forecasting capabilities of the military. The HEC project described and evaluated the existing methods for measuring and forecasting discharge in a river, with special attention given to techniques based upon remotely sensed inputs. The results of this study were transmitted to WES in a report entitled "Measurement and Forecasting of Streamflow by Remote Means" by Arthur F. Pabst and Robert J. Cermak, August 1977. The following paragraphs give brief highlights of that report.

Measurement of streamflow, forecasting of streamflow, and research directions are the three main sections of the report. Original development or validation of measurement or forecasting procedures was not conducted; rather, a state-of-the-art evaluation was made. Extensive references are given for the techniques presented.

In the measurement of streamflow, three main attributes were considered: water depth, water velocity, and discharge. The measurements were to be made by either completely remote means or by semiremote means where some part of the measuring device comes in physical contact with the stream.

Water depth measurements by remote means can be made by multispectral scanners of water color, optical measurement of the velocity and length of waves, and laser signal reflections. The laser device appears to be the most promising for stream depth analysis. A semiremote means for measuring water depth is that of dropping a pressure-sensing device into the stream. The water pressure is converted to depth and transmitted to a receiving station.

* USA Hydrologic Engineering Center, Davis, California.

Water velocity measurement by remote means can be accomplished through time-lapse photography tracking natural objects floating in the stream. Semiremote methods include time-lapse photography of artificial targets floating in the stream; observation of tracers dispersing in the stream; dropping objects into the stream that sink to the bottom and then resurface, yielding a depth integrated velocity; and optical, acoustical, and electromagnetic measuring devices. Because the velocity gradients vary with depth, care must be taken in the interpretation of the measurements.

Fewer methods are available to measure discharge. The study did not include any completely remote means for this measurement. It is conceivable that remote measurement of velocity and stream width together with regional geomorphologic data for stream cross sections could be used to estimate discharge. Semiremote methods for discharge measurement involve the dispersion of tracers and the observation of water surface elevations upstream and downstream of known structures in the river.

Streamflow forecasting involves a knowledge of how a watershed responds to moisture inputs together with a prognosis of future rainfall/snowmelt inputs. The paper presents a review of current practices with emphasis on general characteristics and differences. An evaluation of these procedures is made with respect to their compatibility with remotely sensed data. Tables of forecast model input data and remote measurement of required data are given. Various levels of sophistication of forecast models are discussed with respect to the type of data available. In general, several adequate hydrologic forecasting methods are now available. Thus, no new model development is recommended. A special adaptation of existing techniques to available remote and field data and operational capabilities would be of a high priority.

Two levels of research recommendations were made: a major \$1 million development effort and an intermediate-scale effort. Both research programs would be divided into three phases: acquisition of data, model specifications, and forecast generation. The large-scale effort involves the development of new, automated linkages between remote sensor outputs and the hydrologic forecast model. The smaller scale

effort would make maximum use of existing techniques for data handling and forecast model application.

THE NATIONAL WEATHER SERVICE RIVER AND FLOOD PROGRAM

by

Robert A. Clark*

The National Weather Service (NWS) is charged with the responsibility of real-time forecasting of streamflow on the major rivers in the United States. Currently forecasts are issued daily for 2500 river points. In order to prepare these forecasts, data are collected from approximately 7500 stations: 2500 streamflow and 5000 rainfall.

One of the primary problems associated with river forecasting is that illustrated by Figure 1, in which the forecasts of maximum peak were escalated for a period of approximately 2 days due to continued rainfall. In particular, it should be noted that the actual crest was accurately forecast only 24 hr in advance, and that was after most of the rainfall had occurred.

Figure 2 illustrates the relationship between warning time and flood damage reduction. Although this was derived for a specific area in Pennsylvania, it illustrates that with longer warning times, it is possible in some instances to reduce flood damages by as much as 30 to 40 percent. From this graph it is apparent that as the warning time decreases, the reduction in damages also decreases. An area of primary current concern is that of introducing accurate quantitative precipitation forecasts (QPF's) into the forecast procedure. Considerable effort is being made in the NWS at this time to provide improved QPF's and to utilize such forecasts in river and flood forecasting programs.

The NWS river forecast procedures have evolved primarily from an index-based system developed in the 1940's to account for soil moisture (antecedent precipitation index) to a procedure in which detailed conceptual models are being used. Among the conceptual models being used extensively are the Sacramento Model and a modified form of the Stanford Watershed Model. Both of these models account for both upper

* National Weather Service, Silver Springs, Maryland.

W. BR. SUSQUEHANNA RIVER AT WILLIAMSPORT, PA.

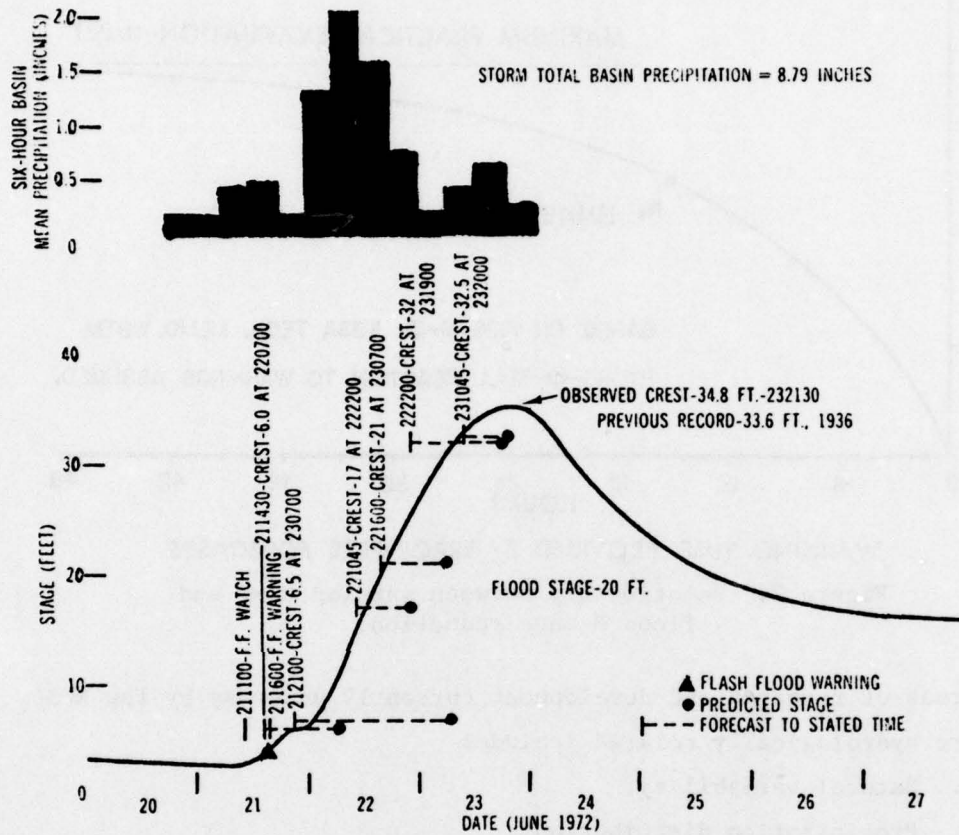
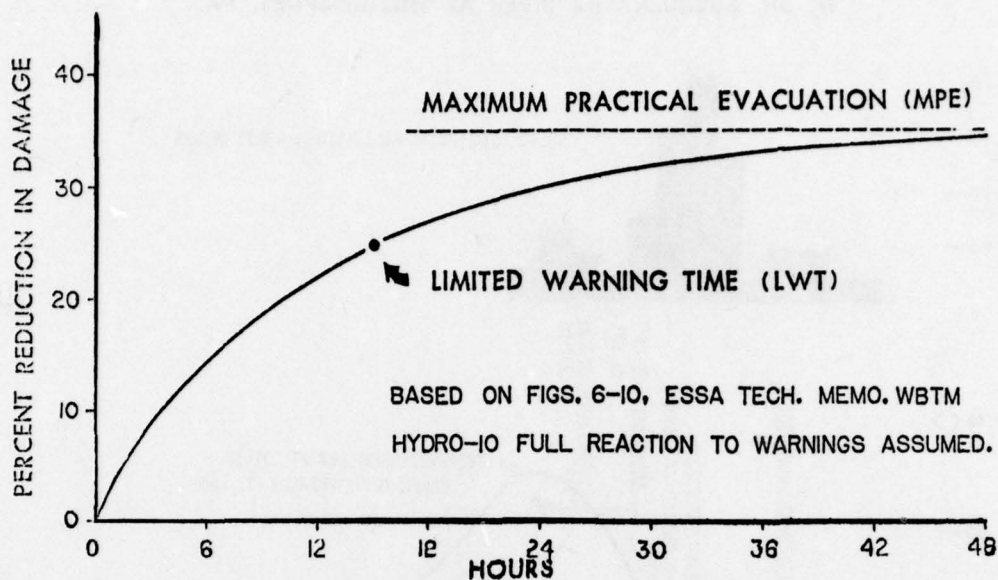


Figure 1. Forecast during Hurricane Agnes for West Branch Susquehanna River at Williamsport, Pa.

and lower zone soil moisture and attempt to depict the actual processes by which moisture falls on the earth's surface, passes either through or over the soil mantle, and back into the streamflow system. In addition to a rather complex soil moisture accounting, the current NWS River Forecast System (NWSRFS) includes such models as snow accumulation and ablation, reservoir operation, extended streamflow prediction, river routing, and dynamic wave routing and a dam break model. Implementation of the models in the NWSRFS has been progressing rapidly within recent years, with these models currently calibrated for approximately 10 percent (more than 300,000 square miles) of the United States. In general, the results from these new models have been encouraging.



WARNING TIME PROVIDED BY ERROR-FREE FORECASTS

Figure 2. Relationship between warning time and flood damage reduction

Areas of research and development currently underway by the NWS that are hydrologically related include:

- a. Natural variability.
- b. Precipitation distribution.
- c. Network design.
- d. Flash floods.
- e. Improved meteorological forecasts: precipitation, temperature.
- f. Evapotranspiration.
- g. Uncertainty.
- h. Interrelationships of the hydrologic cycle.
- i. Extended meteorological forecasts.
- j. Climatic models.
- k. Design floods for hydraulic projects.
- l. Effects of man.

There are, of course, other significant areas of research and development in other components of the National Oceanic and Atmospheric Administration, such as satellite data applications in the

National Environmental Satellite Service.

Recently, the NWS has gone operational in the application of remote sensing of passive gamma radiation for estimating snow water equivalent. This technique, which involves an aircraft overflight at approximately 500 ft, offers real potential for collecting large amounts of data over vast areas within a short period of time.

ADVANCED CONCEPTS FOR HYDROLOGIC MODELS

by

Ray K. Linsley*

Ten minutes is a short time to undertake a discussion of hydrologic models. To achieve this, I propose to consider only the continuous type water-balance models. I think this type of model will prove most reliable for the computation of runoff. In addition, it offers the possibility of computing other information of possible value to the military, such as soil moisture and depth and extent of snow.

There must be at least two dozen different continuous models currently available. Most of these models contain quite similar logic, which is not surprising considering that they all attempt to simulate the same basic hydrologic process. Excluding those models which are programmed to use long computational intervals or have very much oversimplified algorithms, all perform in much the same fashion and yield very similar answers which are generally data limited. With adequate input data these models will generally simulate flows with an accuracy that is equivalent to that of conventional stream gaging.

In constructing a model, we begin with an understanding of the natural hydrologic cycle which we convert to a conceptualized description and then to a set of mathematical algorithms which describe the conceptual cycle and are reasonably practical to solve with a digital computer. There are inevitably errors in the model, i.e., the algorithms do not describe the hydrologic process perfectly. But when the model is tested, we find that it is difficult to diagnose these model errors or to show that small variations in the model structure have much effect on the answer. This seems to result from the fact that the model errors are typically submerged by the data "errors." I use the word "error" to describe actual errors in the rainfall or evaporation inputs or in the streamflow data against which the model output is checked. I also include in this error the consequences of too few stations to adequately describe rainfall patterns over the watershed. In addition to model and

* Hydrocomp, Palo Alto, California.

data errors, some error in the final output may result from imperfect choice of parameter values used to adjust the model to the watershed. If the parameters are determined by calibration against observed data, parameter error should be relatively small. If they are estimated on the basis of judgment, parameter errors can be very large.

At the present time, one can say that existing models which are complete in their description of the hydrologic cycle and which are properly calibrated to a specific watershed will produce results which are about as accurate as the available data will allow. Except for special problems for which most models are not designed, one must expect that improvements in existing models will come slowly and will be relatively small. New algorithms for special problems, such as frozen ground or the seepage from influent stream channels, can be written and added to existing programs. When the special problem is a dominating factor for a watershed, significant improvement may result. For most watersheds the new algorithms will have little effect. Other refinements which seem attractive may prove less so when tested. Multiple soil strata for soil moisture computation seems desirable and logical, but if these computations are averaged over rather large segments of a watershed for which the soil moisture is surely not uniform, do they really improve the answer? Probably not. A distributed parameter approach is attractive, but if rainfall is known at only three points within the watershed, is anything gained by using, say, 100 grids with different parameters for each? Certainly not if the parameters must be estimated because measured data are not available. It may be noted also that the change from three segments to 100 segments is bought at the cost of a thirtyfold increase in computer time and labor to input the parameters!

I believe that we will not make any major improvements in models until we have some test watersheds which are thoroughly instrumented so that testing can be done on data sets which are essentially free of "error," so that model error can be recognized. For any watershed we will find that reduction in model error does little to enhance simulation. For watersheds with special problems, model deficiencies may be more evident. All in all, the most obvious improvements in simulation await

significant breakthrough in data collection and evaluation and possibly a new generation of ultra-high-speed computers.

One may suppose that a major problem in military applications of simulation will be data acquisition. Tests of the value of various remote sensing techniques as data sources for simulation will be important. Simulation requires three general types of input data: (a) hydro-meteorological data, (b) physical watershed data (area, slopes, vegetal cover, etc.), and (c) parameters defining infiltration, soil moisture capacity, etc. Others will discuss the acquisition of hydrometeorological data. Physical watershed data are relatively easily obtained by remote sensing. The third type data will be especially critical for military operations since opportunities for model calibration may be limited. This indicates the desirability of research relating measurable soil properties (type, depth, measured infiltration, etc.) to model parameters. The use of characteristics evident from remote sensing data to derive parameters will be especially important. An alternative approach would be to secure data in advance from prospective theaters of operation and perform calibrations under favorable conditions.

Another area of possible interest lies in improved programming of simulation models for ease in use. Research in this area might go so far as to explore the practicality of a dedicated minicomputer fully programmed and ready to run as soon as parameters and data are input. It might be possible to accomplish this with a remarkably small piece of hardware and thus have equipment that could be easily moved, be available to those who needed to ask questions, and would not be tied up by other work when it is needed most. Interactive programs that prompt the user as to the next piece of input or the next step would be useful in ensuring relatively rapid solutions of problems with minimum error.

Finally, of course, there is a real need for training of personnel who will be using simulation models. In a very real sense, simulation requires a higher order of professional competence than some more conventional methods. Without adequate training, a simulation user may encounter some very rough going in application--he or she may literally be overwhelmed by the considerable volumes of output. Without

professional competence, errors resulting from incorrect inputs or other causes may go undetected.

Curiously, simulation has, in one sense, changed very little. Skilled practitioners and adequate data have always been the key to effective hydrologic analysis and these remain the key to effective simulation. Models allow us to be more logical and hence more accurate.

SOIL MOISTURE MONITORING AND FORECASTING

by

Daniel D. Evans*

The soil-water system is made up of such a complexity of factors that accurate characterization of a particular system seems almost impossible, especially at the microscopic level. Fortunately, soil moisture content is a straightforward concept: simply the amount of water in a given volume (or weight) of soil. However, in the measurement and forecasting of soil moisture, one must be aware of the complexities as they may influence the results.

Different measurement techniques yield results with different units or they pertain to different water properties. As a quick review, the usual ways of expressing moisture content are:

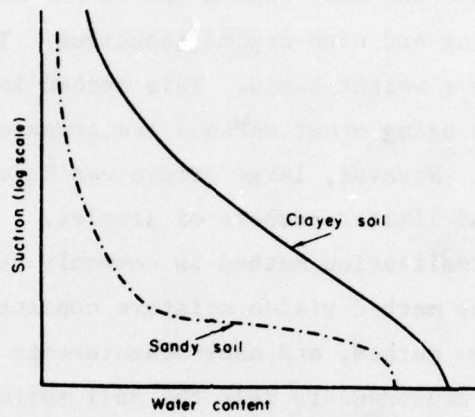
- a. Percent by weight.
- b. Percent by volume.
- c. Equivalent depth of water in a specified depth of soil.
- d. Percent of saturation.
- e. Percent of field capacity.

To convert from volume basis to weight basis or vice versa requires an estimate of the bulk density of the soil.

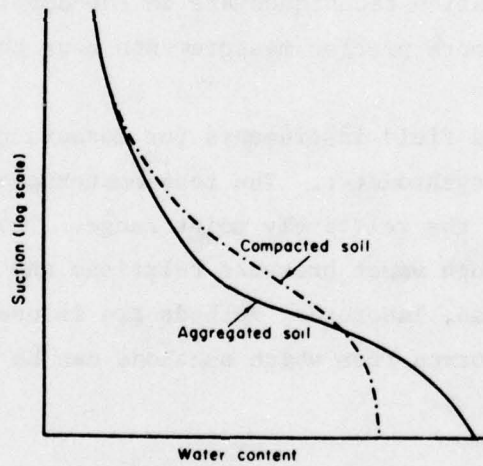
Involved in several of the measurement techniques is the concept of soil suction (or soil water potential). Soil suction relates to the potential energy associated with the soil moisture. Moisture in a dry soil has a lower potential energy than a wet soil, but the sign is often changed for soil suction so a higher positive number applies to a dry rather than a wet soil.

Typical suction versus moisture content curves are shown in Figure 1. In some cases it may be convenient to measure one variable and infer the other through a moisture characteristic curve for the soil or through an appropriate calibration curve.

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a. Effect of texture on soil water retention



b. Effect of aggregation on soil water retention

Figure 1. Suction versus moisture content curves

Ground Methods of Measurement

Soil moisture content

Perhaps the oldest and most common method for determining water content is the sampling and oven-drying technique. The results are normally expressed on a weight basis. This method is often taken as a standard, and results using other methods are compared to those obtained by the drying method. However, large errors can be encountered due to spatial variations and limited numbers of samples.

The neutron thermalization method is commonly used to assess soil moisture content. The method yields moisture content on a volume basis. It is a nondestructive method, and many measurements can be taken at the same site. However, measurements near the soil surface may be questionable. Equipment is available commercially, but calibration for a particular soil may be necessary.

Gamma ray attenuation techniques are in the developmental stage. They show promise of more precise measurements near the soil surface.

Soil suction

Two commonly used field instruments for measuring soil suction are the tensiometer and psychrometer. The tensiometer measures suction directly, but only in the relatively moist range. The psychrometer measures suction through vapor pressure relations and is most applicable in the dry range. Also, laboratory methods are in use to obtain moisture characteristic curves from which suctions can be inferred from soil moisture content.

Remote Methods of Measurement

Results obtained by various researchers indicate that soil moisture differences at or near the soil surface can be detected remotely by utilizing several different spectral bands. However, results to date are for isolated locations under restricted environmental conditions. No one method has been sufficiently tested to ensure successful application in a new area without first obtaining ground measurements.

Visible and near infrared

Reflectance in the visible and near infrared is influenced by soil moisture content and other properties such as particle size, organic matter content, surface roughness, angle of incidence, and look angle. Examples of the effects of moisture content and time of day on the albedo of bare soil are shown in Figure 2. The albedo for dry soil is about 0.30, while that for a wet soil is about 0.15. On some days, there was a pronounced change during the day due to drying of the soil surface. Zenith angle effects can be corrected.

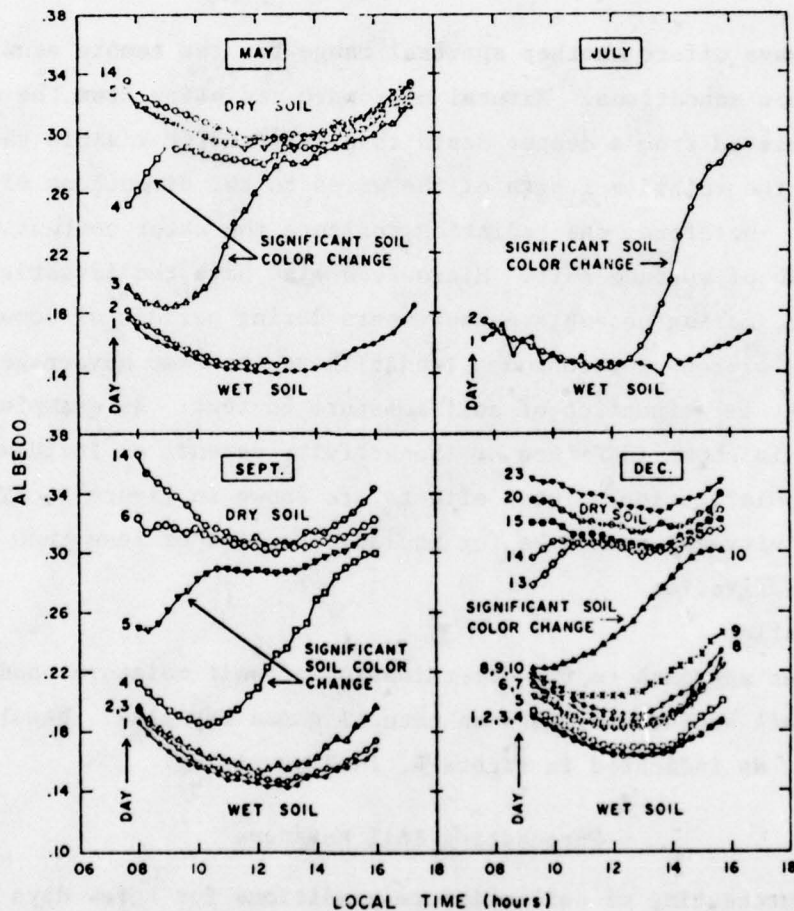


Figure 2. Diurnal variations of albedo for specified days after irrigation of a smooth bare Avondale loam soil in May, July, September, and December 1973 at Phoenix, Arizona (Munsell color notation supplied for this soil by the Soil Conservation Service is 10YR 5/3 when dry and 10YR 3/3 when wet. Source: Idso et al. 1975a)

Thermal infrared

Temperature at the soil surface is a function of soil water, due both to evaporative cooling and differences in heat diffusivity. The amplitude of the diurnal surface temperature cycle is also a function of surface soil moisture content. This effect is shown in Figure 3. When the average water content is plotted against the amplitude, a nearly straight line results. The slope of the line would certainly depend upon the soil. However, when the amplitude is plotted against suction, differences among soils appear to be less.

Microwave

Microwave offers another spectral range for the remote sensing of soil moisture conditions. Natural microwave radiation from the soil (passive) is emitted from a deeper depth than infrared or visible radiation because of the relative length of the waves to the dimensions of the soil particles. Therefore, the radiation reflects the water content of a thicker slab of surface soil. Microwaves also have the advantage of cloud penetration, making possible measurements during periods of cloud cover.

Active microwave techniques (radar) have the same advantages. The reflectivity is a function of soil moisture content. An example of field data is shown in Figure 4. Sensitivity depends on incidence angle and polarization. These effects are shown in Figure 5. The greatest sensitivity appears to be for incidence angles of less than 10° and with HH polarization.

Gamma radiation

Another approach to the determination of soil moisture conditions near the soil surface is based on natural gamma ray flux. Results are scant, but, as indicated in Figure 6, look promising.

Forecasting Soil Moisture

The forecasting of soil moisture conditions for a few days or a few weeks is a desirable objective. However, even if the moisture content is measured by remote means at a given time, forecasting of conditions is limited when considered in the light of existing methodologies. Future soil moisture conditions will depend on initial

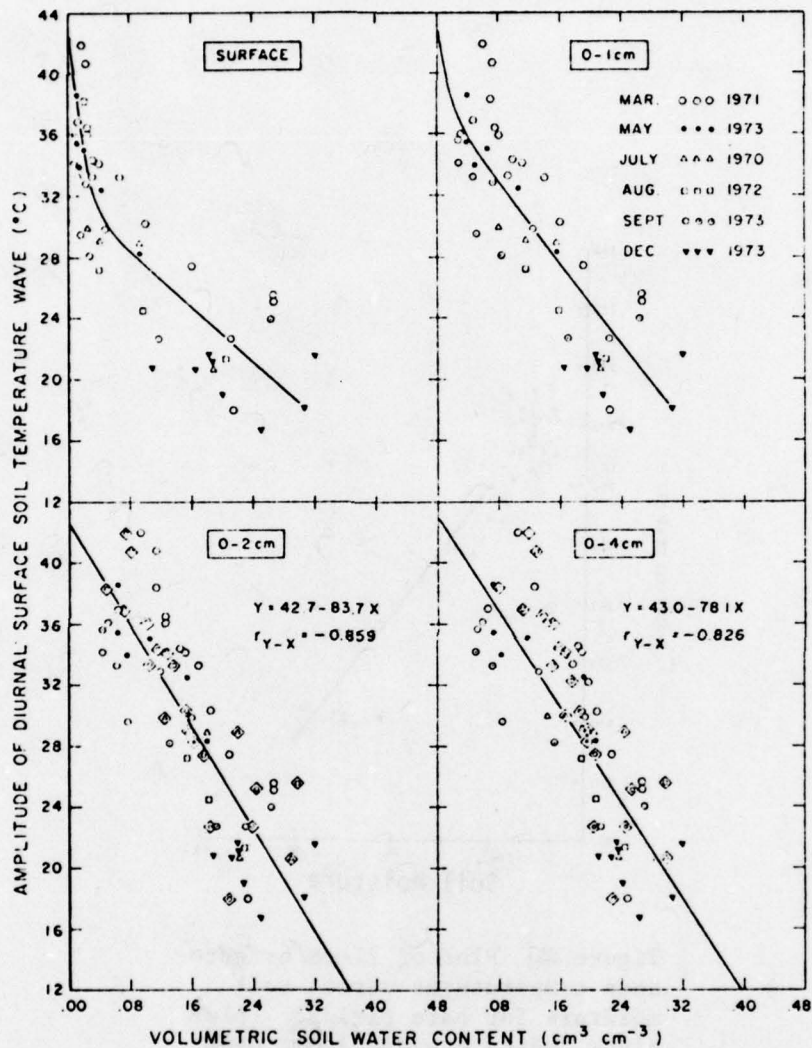


Figure 3. Amplitude of the diurnal surface soil temperature wave on clear day-night periods versus the mean daylight volumetric soil water content of four different depth intervals. (The points enclosed by diamonds represent volumetric water contents obtained by direct gravimetric sampling of the soil, while all remaining points represent volumetric water contents obtained by the albedo assessment technique of Idso et al. 1975a. Source: Idso et al. 1975b)

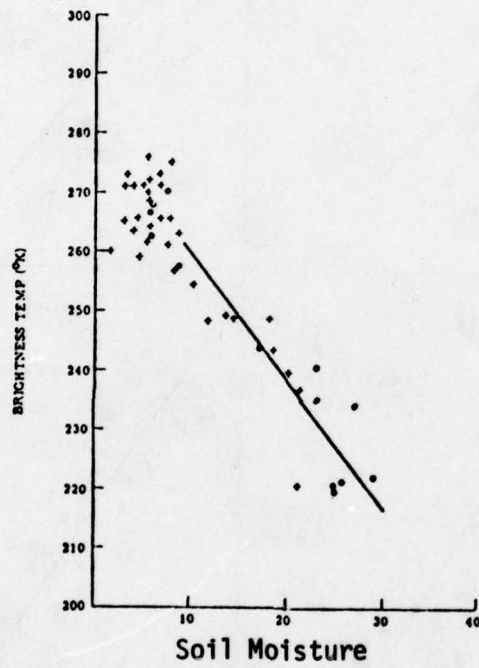


Figure 4. Plot of 21-cm brightness temperatures versus soil moisture for bare fields. (plus signs indicate sandy loam; open circles indicate clay loam. Source: Schmugge et al. 1974)

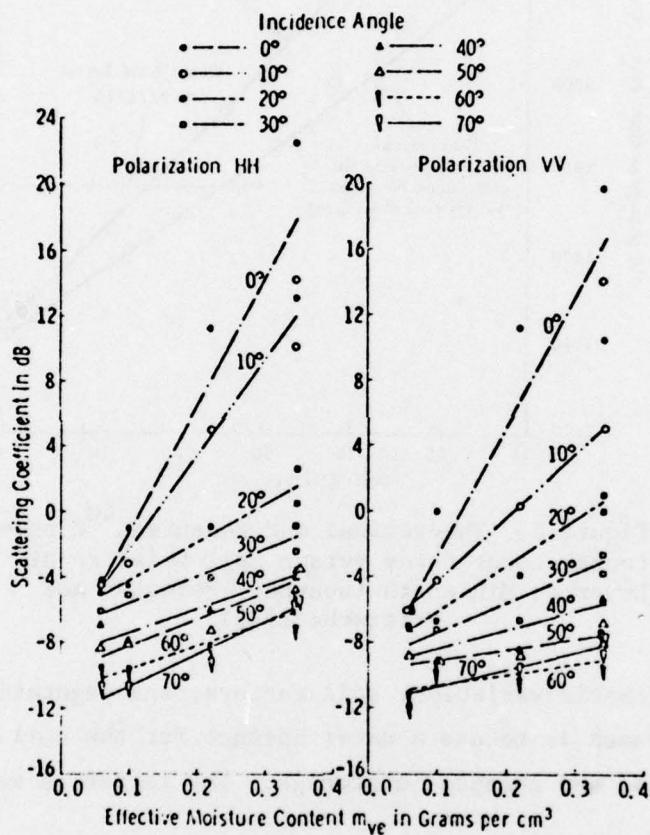


Figure 5. Scattering coefficient as a function of effective moisture content. (Frequency = 7.1 GHz. Source: Ulaby 1974)

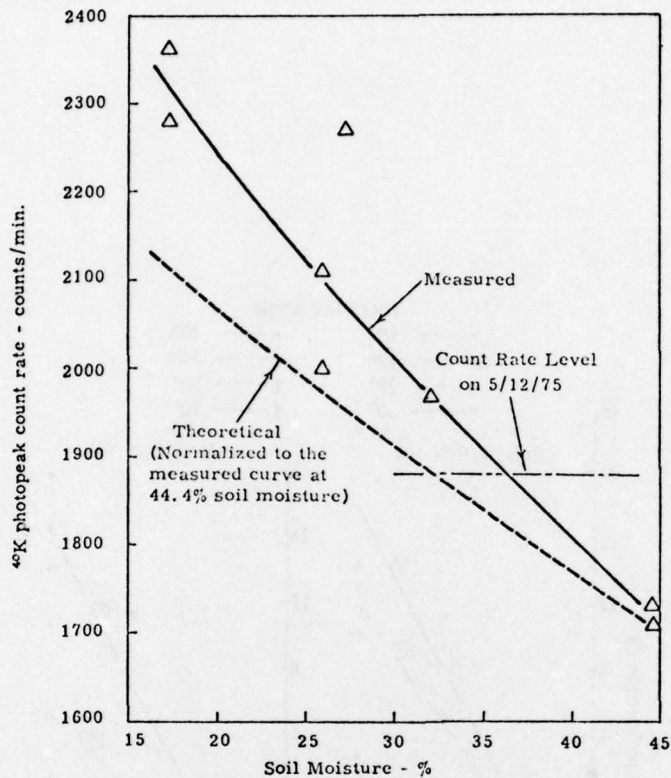


Figure 6. Theoretical and measured ^{40}K photopeak count rates versus soil moisture at Luverne, Minnesota (source: Feimster and Fritzsche 1975)

conditions, climatic variables, soil factors, and vegetative cover. The usual approach is to use a water balance for the soil that includes inputs, outputs, and changes in storage. The latter is what is to be forecast.

Several approaches have been proposed for predicting or forecasting soil moisture conditions. The first requirement is an accurate estimate of initial soil moisture conditions. The second is an assessment of effective precipitation. The third is a method for predicting evapotranspiration (ET).

Precipitation forecasting is being covered in a separate report, but it is doubtful if effective precipitation can be adequately forecast as a component of a meaningful budget. Therefore, the analysis

may be made by initially assuming zero precipitation and then adding measured precipitation as it occurs.

Several equations have been proposed for predicting ET, especially potential ET. These approaches, given a set of initial conditions and a projection of climatic conditions, may yield a suitable estimate of ET, which can then be used to project soil moisture conditions.

Deep seepage of water may be a significant component of a soil water budget. Deep seepage would depend on initial conditions and soil profile characteristics. Profile characteristics may be obtained from soil survey reports, if available.

Forecasting soil moisture conditions may require an unsaturated flow model coupled to the water balance model. Forecasting success will depend upon several factors.

Summary

In summary, several methods are available for ground measurement of soil moisture, but spatial variability may require numerous measurements for an adequate assessment. Several remote sensing techniques appear promising, but further research is necessary before any of them can be considered operational. Forecasting soil moisture conditions requires an assessment of initial conditions and an estimate of several environmental factors during the forecast period.

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STATE OF THE ART IN SOIL MOISTURE MODELING

by

Cornelius H. M. van Bavel*

A soil moisture model is, generally, a numerical method to estimate the current or future values of soil moisture content as a function of time, depth, and location within a given land area. Electrical or other physical analogs are only rarely employed for soil moisture estimation, as contrasted to the case of groundwater modeling. Thus, the model consists of a collection of algorithms that transform current or forecast input to current or future output. Generally, this is done by numerical approximation using digital computers.

It is also possible to use historical input data and develop estimates of past soil moisture conditions, with the aim of developing a climatology or recurrence probability of soil moisture status.

Soil moisture modeling has two distinct main objectives in relation to logistic decisionmaking. One is to assess trafficability of land surfaces, which requires a rather detailed picture of the moisture content, and the other is to assess runoff and river flow as a result of rainstorms. In this case, soil moisture is important but is only one of several unknowns that must be estimated.

Historically, there has been no significant effort to model soil moisture for the purpose of predicting trafficability. But, this statement should be verified by a careful review of the world literature. Earlier work in this area by WES consisted of a multiple regression model, and its usefulness does not appear to be adequate. It remains to be seen if significant improvements can be made by adapting results obtained in other applicable areas.

In contrast, surface hydrology has long been concerned with the role of soil moisture, originally in the form of an empirical antecedent precipitation index (API) and, more recently, by introducing into hydrologic or watershed models subroutines for estimating soil moisture. Generally, these submodels have not been experimentally tested, but their usefulness for direct forecasts of soil moisture should be explored just the same.

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Finally, with the evident importance of soil moisture for crop production, the literature of soil science and agronomy of the last 25 years contains many proposals for establishing the recurrence values of soil moisture conditions and real-time estimates to be used in yield forecasting, irrigation scheduling, and other objectives. There has been no significant effort to apply these results to the related problem of trafficability and runoff estimation.

Besides the API method, there are two alternative approaches to the problem. One approach, which is based on the assumption that the root zone of the soil can be viewed as a reservoir of essentially static capacity, is to pursue a simple bookkeeping or accounting method of the total amount of water in that reservoir. The problem is the adequate determination of the effective precipitation, the evapotranspiration losses, and the soil storage capacity.

It is easy to identify several drastic and arbitrary simplifications in this approach; its practicality is evident; and its potential has by no means been exhausted. It remains the principle of current irrigation advisory services, and it is, essentially, the soil moisture subroutine of most hydrologic models. Over the short term, its usefulness in trafficability and local streamflow forecasting methods should be seriously explored and tested.

The second approach, which has constituted the frontier of research for a decade or so, is one in which the distribution of water within the soil profile is calculated and its dynamic nature is recognized. Obviously, these are layered models in one or more dimensions. They account for the unique role of the soil surface layer and for the action of root systems and the state of the water. Also, they are often driven by actual weather variables, rather than by assumed or mean values of evapotranspiration.

Such comprehensive models require a great deal of knowledge on the part of the user. They also are demanding of computing time and of soil and vegetation parameters that may not always be available. On the other hand, it may well be that useful forecasts of trafficability cannot be made without such dynamic heterogeneous soil models. A

long-term effort is needed to compare the apparent merit of the different proposals that have been made in this area, to formulate the simplest possible approach, and to assess whether it is an improvement over simple accounting models.

In either case, the reliability of a model depends on its correct initialization. Since the error of approximation accumulates, it is necessary to have periodic audits, if the simulation proceeds over a period of many days. In that case, therefore, a comparison of a measurable output of a soil moisture model and its predicted value are indispensable. Two potential candidate factors are the surface moisture content and the temperature of the soil and/or the vegetal surface.

At this time it is not certain that we can routinely, remotely, and accurately establish these two parameters. It is plausible, however, that over the short term this will be accomplished.

Soil moisture modeling can utilize rather crude estimates of radiation, temperature, humidity, windspeed, soil properties, and vegetal cover and still remain on track. The critical input is actual rainfall, both its amount and distribution. This statement applies equally to historical, current, and forecast data.

Thus, there is little justification in pressing soil moisture modeling beyond the current or foreseeable state of the art of rainfall measurement. It also implies that research, development, demonstration, and training in the areas of hydrology, hydrometeorology, and soil science must be closely coordinated.

Measurement is the test of any theory. Soil moisture models are theoretical and idealized. There is a great lack of experimental demonstration to test the degree of realism and to assess the comparative merit of various soil moisture models. Good field experiments require considerable dedication, money, expertise, time, and patience. No one who is primarily interested in practical and simple applications should be misled as to the amount of work that still remains undone in this area.

RESULTS OF THE JANUARY 1978 NASA-USDA SOIL
MOISTURE WORKSHOP, BELTSVILLE, MARYLAND

by
Victor I. Myers*

Significant progress has been made in the development of remote sensing techniques for estimating soil moisture, and some useful applications for soil moisture information have been demonstrated. However, there is an array of questions that must be answered before an operational program is appropriate. A substantial research-oriented program is justified. Following is a summary of recommendations made by participants in the NASA-USDA workshop concerning future research and development. These recommendations represent a consensus but not unanimous agreement.

- a. Visible, reflective infrared (IR), thermal IR, and active and passive microwave techniques should be fully considered in a research and development program. At the present time, no single technique appears advantageous over others for the total range of applications. For specific applications one or more of the techniques may be preferred.
- b. A research program should investigate sampling depth sensitivity, soil moisture profile dynamics, and effects of soil type, surface roughness, and vegetation.
- c. Use of present meteorological satellites should be more fully explored, particularly for thermal and reflective applications.
- d. Major attention should be given to assessing moisture profiles using modeling techniques that use meteorological data and can frequently be fine tuned with remote sensing inputs.
- e. Research should be oriented around broad resource areas (water resources and hydrology, agriculture, climatology). Examination of resource requirements is more likely to provide insight into sensor and platform design than is a narrower approach of considering a single sensor and its potential.

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- f. Attention should be given to application of remote sensing for estimating precipitation. For many applications, precipitation is as important as soil moisture.
- g. The capability for rapid turnaround and dissemination of data must be developed. Most users will require soil moisture information within 48 hours of its acquisition. Dissemination should be to the largest logical audience of users in formats of their choosing.
- h. Data should be provided to users, upon request, for those limited programs where present capabilities for detecting soil moisture are useful.
- i. Since users are concerned with the interactions of soil moisture with their resource interests, careful consideration should be given to evaluating phenomena related to soil moisture (runoff, infiltration, yield, crop-water stress, etc.).
- j. Future agriculture/water resource satellites having thermal IR sensors should have a midday equator crossing time. An early morning overpass time reduces significantly the potential of using thermal IR in soil moisture studies.
- k. Better coordination should be established between groups within the remote sensing community, especially between government, university, and industry.

A soil moisture program should be established to address the recommendations of the Soil Moisture Workshop. The overall objective of this program should be to implement a research and development program that will lead to the capability of estimating soil moisture from measurements made in space.

Specific objectives of this program should be to:

- a. Define the physical parameters involved and evaluate the interaction between electromagnetic energy, soil moisture, and associated factors.
- b. Compare and evaluate measurement systems and techniques for measuring and estimating soil moisture.

- c. Begin consideration of data handling and distribution procedures adaptable to users in water resource management, agriculture, and climate.
- d. Establish a working group to coordinate the research and development program and obtain user input.

To meet the objectives of the soil moisture program, the following five year (1979-1984) research and development plan is recommended:

- a. Conduct comprehensive controlled experiments at three to five locations in the U. S. under variable conditions of climate, soils, crops, topography, etc. Suggested locations include arid southwest/west, southern Great Plains, northern Great Plains, midwest, southeast. The research should include:
 - (1) Multispectral (visible, IR, passive and active microwave) sensors.
 - (2) Study of sampling depth, vegetation effects, roughness effects, soil moisture profile dynamics, time rate of change effects, and resolution requirements.
 - (3) Development and improvement of models.
 - (4) Test of transferability of models and algorithms between sites.
 - (5) Evaluation of phenomena related to soil moisture (precipitation, yield, crop-water stress, plant-water content, etc.).
- b. Conduct research at ground, aircraft, and spacecraft altitudes.
 - (1) Utilize ground and truck-mounted sensors.
 - (2) Utilize contract aircraft making repeat visits to the selected sites.
 - (3) Utilize existing and planned NASA and NOAA orbital systems (Landsat C and D, Seasat, GOES, HCMM, Tiros-N, Shuttle, etc.).
- c. NASA should initiate preliminary planning of a first-generation soil moisture/water resources satellite.
 - (1) Five to seven years may be required to put the satellite into operation.

- (2) A single satellite oriented toward soil moisture and water resources will lead to more orderly research and development efforts.
- (3) A single satellite will facilitate dissemination of data to users.

SUMMARY OF EXISTING CAPABILITIES FOR MEASURING
AND FORECASTING SELECTED WEATHER VARIABLES

by
Ronald M. Cionco*

Introduction

The objective of this paper is to summarize in a very general way the numerous capabilities for measuring and forecasting precipitation, cloud cover and height, and profiles of temperature, humidity, and wind. Due to the short time frame involved in our study, we have emphasized methodologies and techniques that rely upon the collection of meteorological data by remote means and also upon numerical predictive models that are operational. We, in fact, concentrated more on precipitation than on the other variables mentioned and limited our search to the period from 1970 to early 1977.

I do not intend to present an all-inclusive treatment of the subject matter here or even to cover the subject matter as extensively as in our report.** Many worthwhile measurement methods and forecasting techniques, including some very recent developments, have not been cited due to the limited scope of this review. However, the more successful methods, techniques, and equipment were addressed in the report.

Precipitation, clouds, temperature, humidity, and wind can significantly affect military tactical procedures such as performance of electro-optical weapons systems; transport and diffusion of obscuration materials, toxic and incapacitating chemical agents, and pollutants in the atmosphere; and maneuverability of aircraft.

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** Monahan, H. H. and Cionco, R. M., "An Evaluation of Existing Capabilities for the Measurement and Forecasting of Selected Weather Variables," July 1977, Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico.

These weather variables also present hydrologic implications to military operations (i.e., vehicular trafficability) to the extent that each variable influences soil moisture, water supply, and streamflow. A high percentage of the variation in water runoff from a given region is caused by variations in the intensity, duration, and location of rainstorms. As for snow, accumulation is a problem because it is so difficult to quantify; even when snow accumulation is known, the rate of melting assumes major importance with solar insolation becoming a significant factor, probably even more so than temperature. Humidity is really significant only when it is near the low end of its range, where dehydration is rapid enough to be troublesome. Wind velocity coupled with low humidity effectively increases the rate of evapotranspiration.

Therefore, the measurement and prediction of weather variables are of extreme importance to the Army decisionmakers in tactical planning and operations. To repeat, these weather changes can seriously affect weapons systems, target acquisition, battlefield surveillance systems, dispersion of smoke and chemicals, and selection of air and ground mobility tactics.

Measurement Capabilities

Remote sensing methods are those involving the collection of data by systems not in direct contact with the phenomena under investigation. These methods have been in use for a number of years in the form of weather radar (for detecting precipitation or clouds) and other techniques. It has been only recently that concerted efforts to make full use of the electromagnetic spectrum and acoustic probing of the atmosphere have led to developments in Doppler radar, frequency-modulated/continuous wave (FM-CW) radar laser systems, and acoustic echo sounders. Each is helpful in obtaining data on all the important parameters of the lower atmosphere.

Remote sensing is a relatively new tool for investigating the structure and dynamics of the atmosphere. It has significant applications to weather and severe storm forecasting because it combines reasonably

accurate data with spatial and temporal resolution (in essentially real time) over much larger volumes of the atmosphere than is possible by other means.

With the arrival of the meteorological satellite, a capability for complete global weather observations was realized. Visible and infrared (IR) images from satellite systems are obtainable for the entire earth. Geostationary satellites hovering over the equator send data back to earth every half hour for a substantial portion of the Western Hemisphere. Moreover, the geostationary satellite has proved valuable as a means of indirectly providing data on winds in remote ocean areas through its ability to track cloud motions.

Remote sensing of the earth's atmosphere is, of course, often hampered by the presence of clouds of various density over the region being surveyed. However, by the end of this decade, it is anticipated that satellite sounding systems will be able to penetrate practically all cloud conditions, exclusive of precipitating clouds.

Radiometric methods have been developed for sounding the atmosphere from satellites. In addition to the IR sounders, which measure temperature and moisture profiles, experimental microwave sounders have been flown that are able to detect precipitation areas within large cloud masses.

The most useful ground-based remote techniques involve acoustics and radar. Although Doppler radar techniques are progressing rapidly, the acoustic radar field has advanced most in terms of routine application.

A very good ground-based remote sensing capability exists for characterizing wind velocity because of the availability of a wide range of Doppler techniques. An all-weather wind-profiling capability is attainable in the boundary layer, with good prospects for all-weather profiling to tropospheric heights using some combination of microwave and IR Doppler systems.

Significant improvements have occurred in some areas of meteorology during the past five years. One particular example is the application of vertical temperature profile radiometer data to large-scale

forecasting at the National Meteorological Center (NMC). However, routine applications of satellite data to mesoscale problems are still confined largely to visual and IR images of clouds, although quantitative radiometer data for the mesoscale remain on the verge of being used routinely.

The ability to remotely sense temperature and humidity in three dimensions is much poorer. It seems likely that it will be practical to measure temperature and humidity profiles, perhaps to tropospheric heights, within the next six years. However, it does not seem likely that remote measurement of the three-dimensional temperature and humidity fields will be available from ground-based remote sensors on this time scale.

In spite of some fine technical developments, weather radar has not made the impact on severe weather forecasting that was expected. The basic problem lies in determining how severe the thunderstorm is at any given time and how severe it will become in the following minutes or hours. Present-day operational radars of the U. S. Weather Services (e.g., CPS-9, WSR-57, FPS-77) do not actually measure wind speed, hail size, or rainfall rate; these parameters are, instead, related to radar return intensity, echo geometry, and echo development by empirical and theoretical means. Difficult problems still remain in developing relationships between radar measurements and intense wind, rain, and hail.

Recent developments in electronics and data processing have simplified the task of obtaining quantitative data for estimating these meteorological parameters through the use of digital radar. Digital video techniques offer advantages for the digital processing of rainfall data for flood and trafficability forecasting. Digital video techniques are also suited for producing digitally integrated echo intensity contours of severe storms; the data can be conveniently transmitted over land lines for remote display.

Forecasting Capabilities

Two differing viewpoints exist concerning the laws of atmospheric processes and how to forecast with them. One viewpoint is based on the

assumption that the laws of atmospheric motion are relatively fixed and that with enough observational data, a set of equations on atmospheric motion could be computerized and accurate weather forecasts produced. This is numerical forecasting. The other viewpoint entails the premise that atmospheric motions are random and that regardless of the size of the observational base, atmospheric processes cannot be completely described and probability methods must be used. This is probability forecasting.

Two technologies, Numerical Weather Prediction (NWP) and satellite meteorology, have revolutionized meteorology in the past 20 years. Intermediate-range forecasts of 1 to 3 days are now made by NMC, while the very short-range forecast of 1 to 6 hr is becoming more impacted by satellite data as near real-time GOES pictures (30-min intervals) become available. A merging of these technologies for making 6- to 18-hr forecasts through the use of mesoscale hydrodynamic numerical models is now envisioned. Other tools are seen as important supplemental forecast aids, e.g., mesoclimatology studies based upon satellite and radar data, special purpose simple models or forecast schemes, and empirical relations gained from forecaster experience and ingenuity.

Current numerical prediction capabilities prove that significant progress has been made in the past 10 to 15 years in the forecasting of synoptic-scale weather features and weather parameters that can be derived from them. However, the progress in forecasting precipitation and other small-scale weather elements has been much slower. Fine-mesh numerical models have resulted in improved forecasts of the location of precipitation areas, but important problems remain to be solved in the application of numerical techniques to the forecasting of smaller scale weather phenomena, such as thunderstorms and heavy precipitation.

Although the impact of operational prediction models, from the barotropic to the primitive equations, has been most noticeable in construction of sea-level and 500-mb prognostic charts, progress in precipitation and cloud forecasting based on numerical weather prediction at the NMC has been modest. At the same time the Air Force Global Weather Center is using a 15-level High Resolution Cloud Program that

extends up to 45,000 ft using surface, upper air, satellite, and radar data. A SESAME project of another kind is being formulated to address and study the distribution and intensity of mesoscale convective activity.

Temperature profile forecasts

The Technical Development Laboratory, NWS, has under development a larger scale three-dimensional planetary boundary layer model to predict temperature, humidity, and winds in the lowest 2 km of the atmosphere. The model, consisting of 12 levels within two layers (i.e., a 50-m-thick surface layer having constant fluxes of heat, momentum, and moisture and a transition layer extending to 2 km), has shown good agreement between the predicted and measured boundary layer temperatures and winds.

On the small scale, the Monin-Obukov log-linear model has been examined for adequacy in describing temperature and wind profiles in thermally stratified shear flows and diversified thermal stability.

The Galerkin method has also been used for the numerical solution of the nonlinear initial boundary value problem describing the vertical temperature profile for a thermally coupled soil-atmosphere boundary layer in a simple physical setting.

Humidity profile forecasts

Many mathematical descriptions have been presented for wind and temperature profiles over various types of terrain and vegetation. The humidity profile has been estimated using an empirical formula linking changes in humidity with changes in temperature and altitude. More accurate prognostic stratification curves of nighttime temperature and humidity have been constructed by taking into account the nonlinear temperature and humidity variations in the surface to 850-mb layer.

Wind profile forecast

The generalized Ekman equation has often been used for micrometeorological determinations of the wind profile. Both the eddy diffusivity and the thermal wind are important considerations when this power law equation is applicable. Comparisons have been made between tower-observed wind profiles and profiles predicted from models based on mixing-length theory and also in the case of a single roughness change

on the turbulent energy equation. Comparisons with the mixing-length model are moderately good, but some features of the observed profiles are missing in the theoretical predictions. The turbulent energy equation model has given slightly less accurate wind profile predictions.

Many mesoscale diagnostic and prognostic wind field models with complex terrain are available, but few are operational. For example, the Atmospheric Sciences Laboratory has some 18 models for various conditions, but only two or three are operational.

On the large scale, general circulation models have a role in studies of climatic processes, but it has been difficult to develop models whose climatologies compare favorably with observed climatologies in any great detail. Recognizing this problem, the World Weather Program has established a goal that would provide the data and knowledge needed to extend the range and accuracy of weather forecasts, particularly the prediction of climatic fluctuations and changes.

METEOROLOGICAL RESEARCH IN THE NATIONAL WEATHER SERVICE

by

Robert A. Clark*

Emphasis will be placed in this discussion on research related to those parameters of primary concern in hydrologic forecasting. Two research areas have been emphasized in recent years. One involves the development of dynamic models that employ techniques requiring a grid system for analysis. The second research area has been in the application of meteorological output statistics (MOS) for estimating meteorological variables.

Table 1 lists the National Meteorological Center (NMC) operational models being utilized in 1978. Of particular importance to hydrologic forecasting is the increased use of fine-meshed grids. The MFM (movable fine mesh) with a grid size of 60 to 100 km has yielded quantitative precipitation forecasts (QPF's). Currently this model is being run with a 100-km mesh length whenever a meteorological situation appears that might produce hydrologically significant problems. For hurricane forecasts a 60-km mesh length is used. Work continues at NMC on developing further fine-mesh models that may yield even better results than the MFM model. The primary limitation at the present time in the use of these fine-mesh models has been that of computer power. In order to go to models with even more levels in the atmosphere and finer grid mesh lengths over very large areas, it will probably be necessary to obtain machines several times faster than the current operational hardware composed of three 360/195 systems. Also, indications are that with the current data network and meteorological know how, grid lengths between 50 to 100 km may be the minimum that will show any improvement in numerical forecasts.

Further improvements may come about primarily through the use of MOS techniques that attempt to correct the output from dynamic models

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to localized conditions through statistical analyses. An indication of the improvement in QPF's through the use of finer mesh models is shown in Table 2 for four cases in 1976-77. It should be noted that the threat score for 24- to 48-hr forecasts showed considerable improvement when the MFM was run. A perfect forecast would yield a threat score of 1.0. A bias of 1.0 would also be desirable.

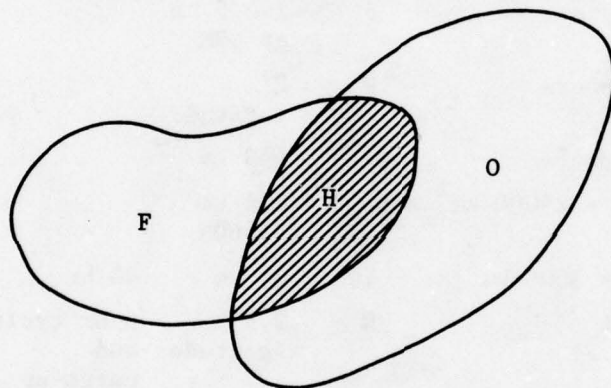
Table 1
NMC Operational Models, 1978

After 00 & 12 GMT	Model	Area	No. of Levels	Grid Size	Forecast Period
01:15	Barotropic-mesh	Hemisphere	2	381 km at 60N	48 hr
01:30	LFM-II	North America	6	127 km at 60N	48 hr
04:00	One of:				00 GMT: 84 hr 12 GMT: 48 hr
	6L PE-II	Hemisphere	6	190.5 km at 60M	
	9L HEM	Hemisphere	9	2° latitude	
	NGM: Grid A	Hemisphere	8-10	448 km	
	Grid B	25000 × 25000 km ²	8-10	224 km at 60N	
07:30	MFM	3000 × 3000 km ²	10	60 km	48 hr
10:00	9L GLOBAL	Global	9	2.5° latitude	6-hr cycle and catch-up

Table 2
Average Threat Scores and Bias* for 0.5-in. Isohyet,
Four Fall-Winter 1976-77 Precipitation Forecasts
12-Hour Accumulated Amounts

	Threat Score			Bias		
	24 hr	36 hr	48 hr**	24 hr	36 hr	48 hr**
Coarse Mesh PE (335 km)	0.34	0.14	0.02	0.97	1.14	2.81
LFM (168 km)	0.32	0.25	0.03	0.79	1.57	3.07
MFM (100 km)	0.52	0.36	0.30	1.25	1.77	2.00

* Computation of threat score and bias.



H = Area Correct

F = Area Forecast

O = Area Observed

$$\text{Threat Score} = \frac{H}{F+O-H}$$

$$\text{Bias} = \frac{F}{O}$$

** Three cases; precipitation offshore in fourth case.

RADAR RAINFALL OVER AN URBAN REGION

by
John L. Vogel*

Introduction

A major urban hydrometeorologic research project was initiated in 1976 around the southern tip of Lake Michigan, with special emphasis on the Chicago region. CHAP (Chicago Hydrometeorology Area Project) is aimed at developing short-term rainfall probability forecasts and providing real-time estimates of rainfall over Chicago, rainfall information for water-quality and runoff models, and extensive rainfall frequency data for the region. To provide this information, 320 recording rain gages were deployed over a 10,000-km² region and two sophisticated 10-cm radar systems were utilized to obtain real-time radar rainfall information (Figure 1). Data from the rain-gage network are used to calibrate and test the real-time operations of radar-measured rainfall and provide information for more conventional hydrometeorological analyses.

For this project the major radar is the HOT (Hydrometeorological Operational Tool). It is a 10-cm FPS-18 radar with associated signal processors and minicomputer (TI-980). This system was used successfully for the study of inadvertent weather effects at St. Louis (Changnon et al. 1977) and was the primary radar system during the 1977 operational season (May to October). During the first operational period, July to September 1976, use was made of the CHILL dual-wavelength (3- and 10-cm) radar, which was developed by the University of Chicago and the Illinois State Water Survey. The CHILL was operated in conjunction with another research project while the FPS-18 was being erected. To eliminate ground clutter echoes, the radars were situated 30 to 50 km south and southwest of Chicago, which is the major area being monitored (Figure 1).

* Illinois State Water Survey, Urbana, Illinois.

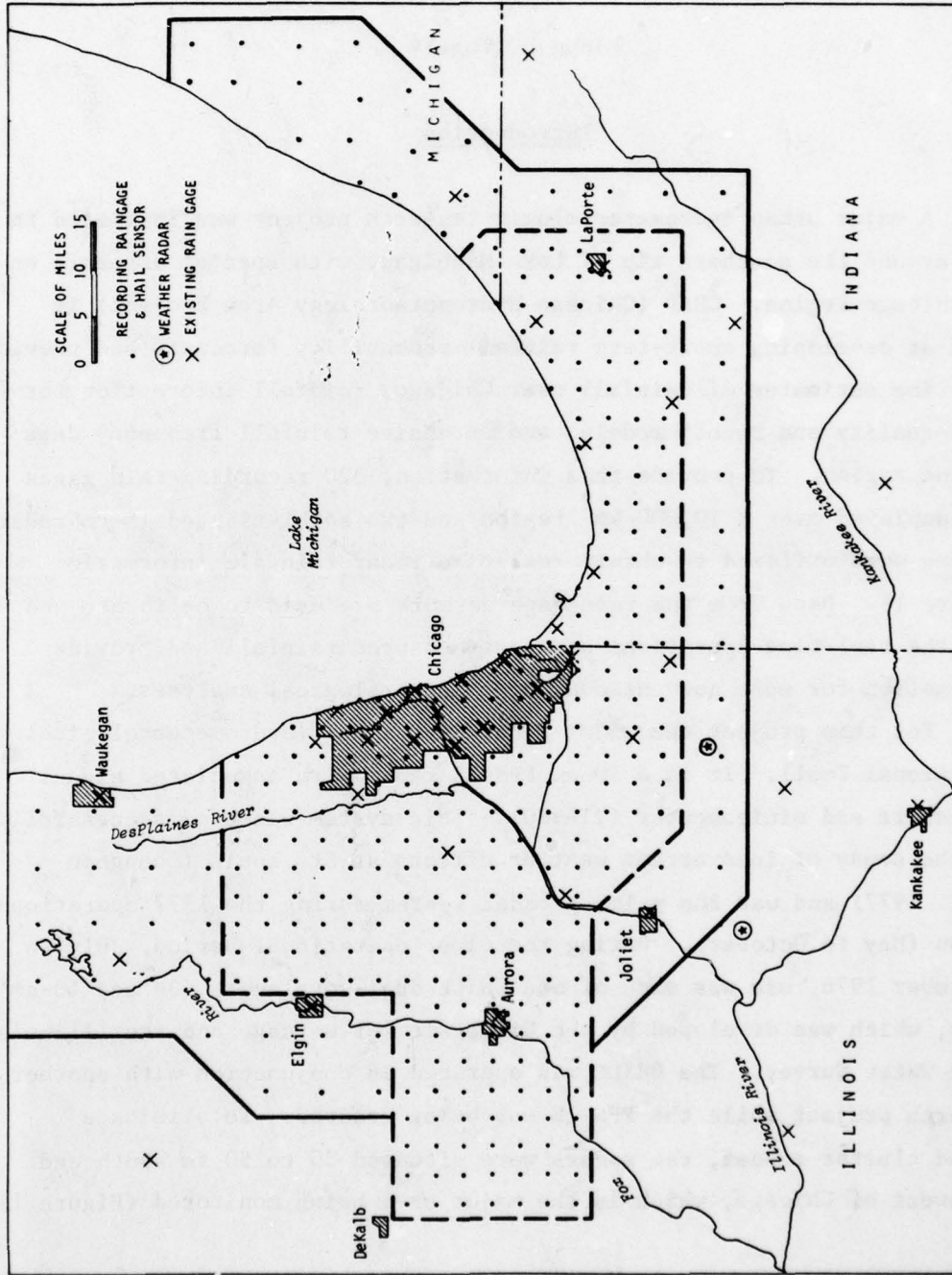


Figure 1. CHAP rain-gage network and radar sites

Details of the operational mode of the radars and of the analysis procedures used are available in Huff and Towery (1978). This paper will present some examples of the accuracy of radar-indicated rainfall in real time.

Data Analysis

Stout and Mueller (1968) have shown that radar reflectivity-rainfall rate relations (Z-R equations) show substantial differences even within a small region depending upon the precipitation type and that these Z-R relations differ within various regions of the world. Thus, radar cannot provide reliable rainfall rates from a single Z-R relation. Rather, the Z-R relation must be adjusted continually to provide reliable estimates of rainfall in real time. Brandes (1975) has developed a method of adjusting radar return, which has been modified at the Water Survey to provide for real-time adjustment of radar rainfall.

The accuracy of the gage-adjusted radar estimates of rainfall were calculated by several methods. In these computations, the accuracy was determined for gage adjustments based on full, 1/2, 1/4, 1/6, 1/9, and 1/12 density, where full density is 1 gage/25 km². This was done for 30- and 60-minute periods. Two comparison methods were employed. In method A, the areal mean rainfall for the total sampling area was determined. For method B, the areal mean rainfall was calculated only for those portions of the area which were receiving rainfall. Both of these methods are used by hydrologists, depending on the specific needs of a project. Accuracy comparisons were made in two ways. One method assumed the full-density rain-gage network as the standard, and the other used the full-density adjusted radar-indicated rainfall as the standard of comparison. Means and standard deviations were calculated for the rain-gage network and the adjusted radar rainfall.

Table 1 presents the comparison of gage-adjusted radar rainfall for 12 storms in 1976 and 1977, using the full-density gage network as a standard of comparison. The rainfall and radar values were averaged for

30 minutes in Table 1. For the table it was necessary that the adjusted radar and/or the gage-alone amounts were ≥ 2.54 mm (0.1 inch) for 30 minutes; thus only moderate to heavy rainfall rates were measured. The number of samples N , the average percent error $\bar{\chi}$, and the standard deviation σ are given in this table. For method A, areal mean rainfall for the whole sampling area, the mean errors for the adjusted radar rainfall ranged from 11% to 23%. The error increased as fewer gages were used to adjust the radar-derived rainfall. In general, the percent errors of the adjusted radar and gage-only data were similar for gage densities of 1/4 or less.

For method B, areal mean rainfall for only those areas receiving precipitation, the errors of the radar-indicated rainfall were somewhat larger, ranging from 18% to 32%. Once again the percent errors for the radar-indicated and the gage-alone rainfall were comparable when the raingage density was 1/4 or less. Unfortunately, the standard deviation about the average percent error is large for both methods. Thus, the reliability of an individual radar-derived estimate could be questionable.

Similar comparisons were made for a 60-minute averaging period. Some slight improvement was noted, but the percent error and standard deviation values were similar.

Table 2 presents calculations similar to Table 1, except the standard of comparison is the full-density adjusted radar rainfall. A comparison of the percent error values obtained from methods A and B shows that average percent errors are similar to Table 1. The average percent error for the radar-adjusted rainfall using a density of 1/12 is about 30%, regardless of whether the full-density radar-derived rainfall or the full-density rain-gage network is used as the standard of comparison. Overall, there was little difference between the gage and the radar rainfall percent errors. Thus, the radar did not improve on the accuracy of the rain-gage network. Generally, unadjusted radar rainfall values underestimated the precipitation amounts in the network.

Discussion and Results

Hildebrand and Wildhagen (1977) performed a similar analysis using data from Montana. Their errors for 60-minute average radar rainfall amounts

were somewhat greater than those found in the CHAP network. However, this could be due to a higher evaporation rate between the cloud base and the ground due to the drier climate of the High Plains. Wilson (1976) made comparisons between several different radar-adjustment techniques for estimating total and daily storm rainfall and found errors between 10% and 30%.

The accuracy of the adjusted radar rainfall can be expected to increase with increasing sample period and length of storm. Our results to date indicate that we can measure rainfall amounts for short sampling periods with almost the same accuracy of other groups. Thus, it is encouraging that we apparently are able to achieve the same level of accuracy with 30-minute amounts as others have for total storm or daily rainfall.

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Table 1

Percent Comparison of Gage and Adjusted
Radar Errors with Full-Density
Rain-Gage Network as Standard

<u>Gage Density</u>	<u>Adjusted Radar</u>			<u>Gage Alone</u>		
	<u>N</u>	<u>\bar{X}</u>	<u>σ</u>	<u>N</u>	<u>\bar{X}</u>	<u>σ</u>
<u>Method A</u>						
Full	78	11	13		0	0
1/2	78	14	16	78	5	5
1/4	78	17	15	78	11	12
1/6	78	21	22	78	16	13
1/9	78	21	21	78	21	20
1/12	78	23	23	78	30	26
<u>Method B</u>						
Full	199	18	20		0	0
1/2	200	22	26	202	12	16
1/4	201	25	22	190	23	24
1/6	200	30	34	189	29	30
1/9	199	33	43	173	30	31
1/12	200	32	44	160	34	28

Table 2

Percent Comparison of Gage and Adjusted
Radar Errors with Full-Density Adjusted
Radar Rainfall as Standard

<u>Gage Density</u>	<u>Adjusted Radar</u>			<u>Gage Alone</u>		
	<u>N</u>	<u>\bar{X}</u>	<u>σ</u>	<u>N</u>	<u>\bar{X}</u>	<u>σ</u>
<u>Method A</u>						
Full	78	11	13		0	0
1/2	77	12	12	77	7	8
1/4	77	15	13	77	11	9
1/6	77	18	15	77	15	14
1/9	77	25	21	77	20	28
1/12	77	33	27	77	20	17
<u>Method B</u>						
Full	199	18	20		0	0
1/2	197	19	17	204	12	16
1/4	190	27	30	205	18	20
1/6	187	34	45	203	26	38
1/9	174	32	34	204	29	37
1/12	161	39	33	204	30	34

WATER SUPPLY AND DISTRIBUTION

by

MAJ John Allen*

I'm going to talk about water supply and, specifically, water supply in a desert environment.

I'm sure most of you are familiar with the southwestern United States. Suppose you are part of a 25-man rescue team that must cross 50 miles of this 100°F+ desert. To provide a margin of safety, the planners of this operation have doubled the normal ration of water to 16 gal/day/man. Do you think you will make it? How effective will you be? Historical examples indicate that 30 to 50 percent of the team will not make it, and those that do will be nonfunctional and will die shortly without water resupply.

Let me cite some historical examples.

- a. During a July 1916 attack against a Turkish battalion at Ramadi, Iraq, near Baghdad, the British lost one third of a brigade-size force to the heat.
- b. On 8 September 1942, 700 men of the 46th Armored Infantry Regiment received only 2 qt of water while on maneuvers in the California desert. The day was spent quietly under camouflage. The regiment received orders that afternoon to conduct a night march to envelop their opponent by dawn. The force departed at 1900 hr. By midnight, all crew-served weapons had been abandoned in the sand. By 0700 hr, half the regiment had dropped out along the route of march. The exercise was cancelled as efforts turned to rescue.
- c. Although the 1967 Arab-Israeli War lasted only 6 days, the Egyptian force deployed in the Sinai lost an estimated 20,000 men to the heat, and these were acclimated men.
- d. During the recent Brave Shield XVI exercises at 29 Palms, California, American troops suffered 200 heat injuries equally distributed between combat and support troops. Average water consumption had been over 13 gal/man/day (8 gal for drinking and 5 gal nonpotable), but that had not been enough.

Everyone knows that when a human is thirsty, he'll drink by

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instinct--so why are we concerned? The problem is when your body needs water the most, you will not drink. Let me explain.

An indoor worker in a temperate climate, such as Western Europe or the United States, will drink roughly 1 qt of water each day. Troops working outdoors in such an environment have been observed to drink 3 qt in a half hour. The key to such great consumption is body heat, regardless of whether that heat is from rigorous activity or from the desert sun, or both.

An average size man walking in Iran, Iraq, the Jordan Valley, or the Sinai can lose more than a quart of water each hour. The threat from this loss is such that if water is not replenished, a soldier walking along the Persian Gulf, for example, would probably drop before the end of a single day. Without deliberate rehydration (bulk drinking), combat squads in some desert environments will disintegrate as fighting units within the short span of a single day.

The reason for this impairment is water loss due to the body's natural cooling process. To be more specific, 2 percent of body weight is a common water loss for sports activity. The participant begins to feel thirst at 1 percent loss and some fatigue as the percentage increases. Most players of recreational sports stop their activity before exceeding the 2 percent level.

Four percent of body weight (150 lb loses 6 lb) represents a significant loss. The individual is often no longer obsessed with thirst, because other things are on his mind. His muscles are beginning to feel uncomfortable; he is conscious of every step; he is beginning to feel sleepy; and, most important, he is becoming unresponsive to conversation, orders, or directives. Troops walking in the desert sun at 105°F will probably reach this state of dehydration within 3 hr.

Six percent of body weight loss represents incapacitation for most men. At this level of loss, the simple act of breathing becomes difficult; a severe headache compounds the man's plight; speech is indistinct and difficult; thirst is present, but he is so apathetic that he will not bother to drink. There will be no response to commands or guidance. Troops walking in the desert sun at 105°F probably reach

this state of dehydration within 5 hr.

There are other factors which affect an individual's desire to drink, for example, palatability. In the desert the water may have to be cooled. The objective is to drop water temperatures at the point of consumption. A correlation between water temperature and willingness of troops to drink has not yet been established. It is known, however, that the British were sufficiently worried after early troop losses in Iraq to provide 4.4 lb of ice per man per day. It is also known that 8 lb of ice per man per day was a production objective during Brave Shield XVI.

Taste also affects consumption. If water doesn't taste good, regardless of other factors that encourage consumption, most men will not drink adequately. There is also a correlation between taste and temperature, i.e., if we can't cool it adequately, possibly we can make it taste better by adding powdered additives to make it more palatable and to increase consumption.

This lead-in to my subject was done to indicate the broad scope of water supply and that the problems of water supply do not stop when the water source is located, purified, and distributed.

In June 1977, TRADOC tasked the U. S. Army Logistics Center to chair a Joint Working Group (JWG) on water distribution and supply in a desert environment. The primary objective or driving force behind this effort was to identify and/or develop an immediate water supply and distribution capability for the 18th Airborne Corps Mid-East contingency plan. The JWG participants are listed in Table 1.

We have had two JWG meetings, and some of the areas we have investigated are listed in Table 2. The activities involved in the "Quick Fix" are given in Table 3.

To determine the amount of water that needed to be transported, the JWG first had to establish water-usage planning factors. We used JCS Pub 3 and FM 101-10-1 as a basis and validated the planning factors for a desert environment with experience. Table 4 lists the consumption factors the JWG approved. To arrive at the total potable and nonpotable water requirements (Table 5), we then looked at the specific scenario

ME II (operational environment) in which the 18th Airborne Corps would operate.

Using this total volume requirement, we then looked at the area of operations to locate sources of water and, using the scenario ME II, attempted to identify the necessary purification, transport, and distribution methods and equipment.

We were limited in our source in that the only surface water available in the immediate area was under enemy control. Therefore, we developed water pipelines with storage bladders and well-drilling equipment. We have also investigated new methods and improved on the existing purification methods shown in Table 6. We are now investigating bulk line-haul equipment and a total distribution method from source to soldier (Figure 1).

In our investigations to determine optimum hardware requirements for the water supply and distribution requirements of the 18th Airborne Corps, MERADCOM proposed the possible solutions (KIT) as shown in Figure 2. Assuming we have an operational water supply and distribution system, what can be done to ensure that each soldier does, in fact, drink enough? We have to consider those psychological and palatability factors discussed earlier. To increase palatability, we are investigating both using powdered additives to increase taste appeal and cooling of the water at point of consumption.

A study titled "Base Development Studies" was recently completed and approved by DA Deputy Chief of Staff for Logistics in October 1977. The recommendations from Volume V, "Centralized Water Production, Distribution and Disposal Study," are as follows:

- a. The Army should establish a Central Management Office for all water-related research and development and planning activities.
- b. The Army should review all ongoing military R&D work related to water supply and wastewater reuse and recycle, with particular emphasis on (1) overall expenditure of resources; (2) increasing water-production capacity of the water purification unit under development at MERADCOM; (3) improving efficiency in the usage of water (more service per gallon); (4) analyzing the feasibility and general application of current reuse/recycle research and development efforts; and (5) exploring the possibility of tri-service involvement in requirements such as well-drilling teams.

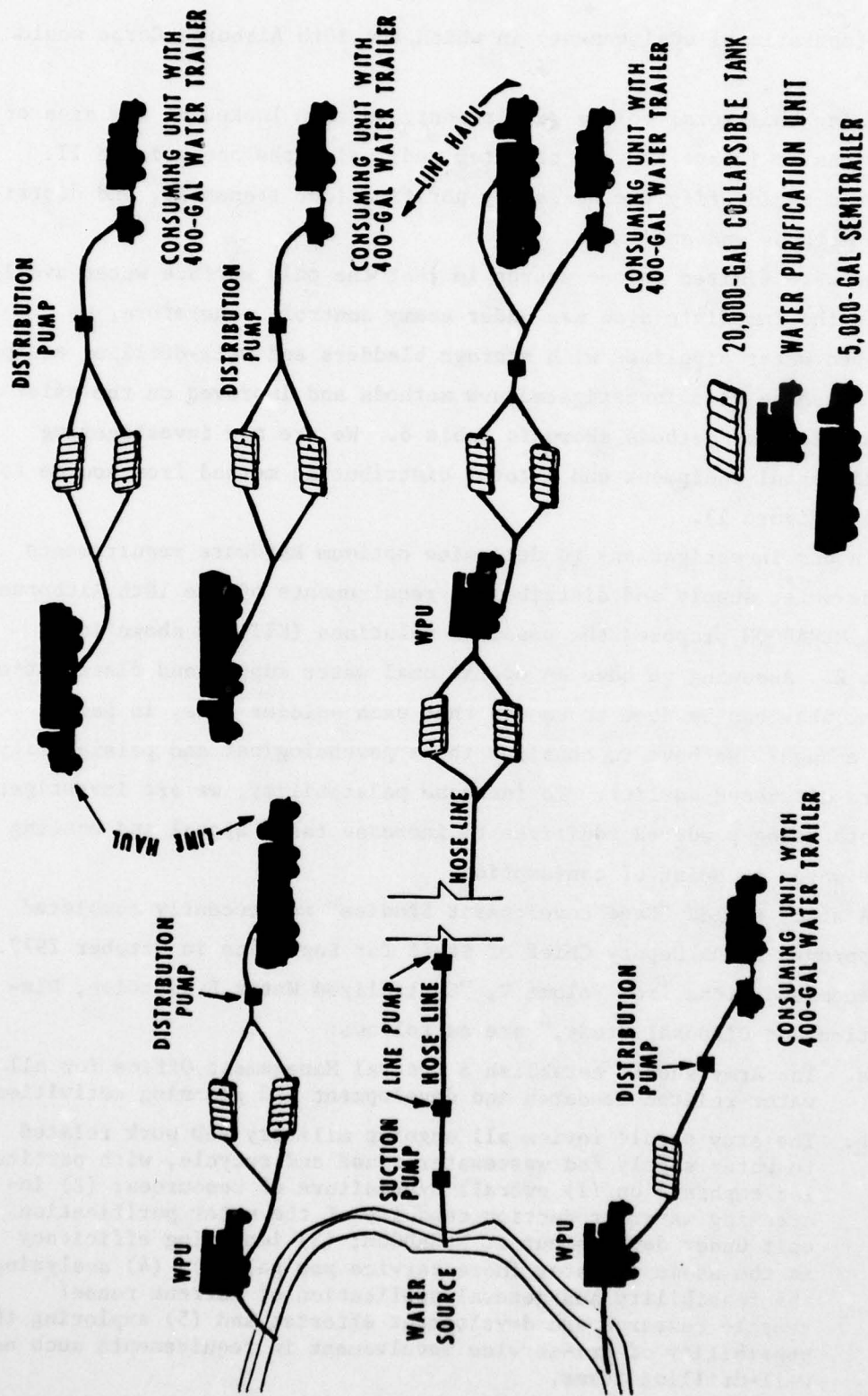


Figure 1. Simplified schematic of water purification and distribution method in ME II scenario from the water source to consuming unit

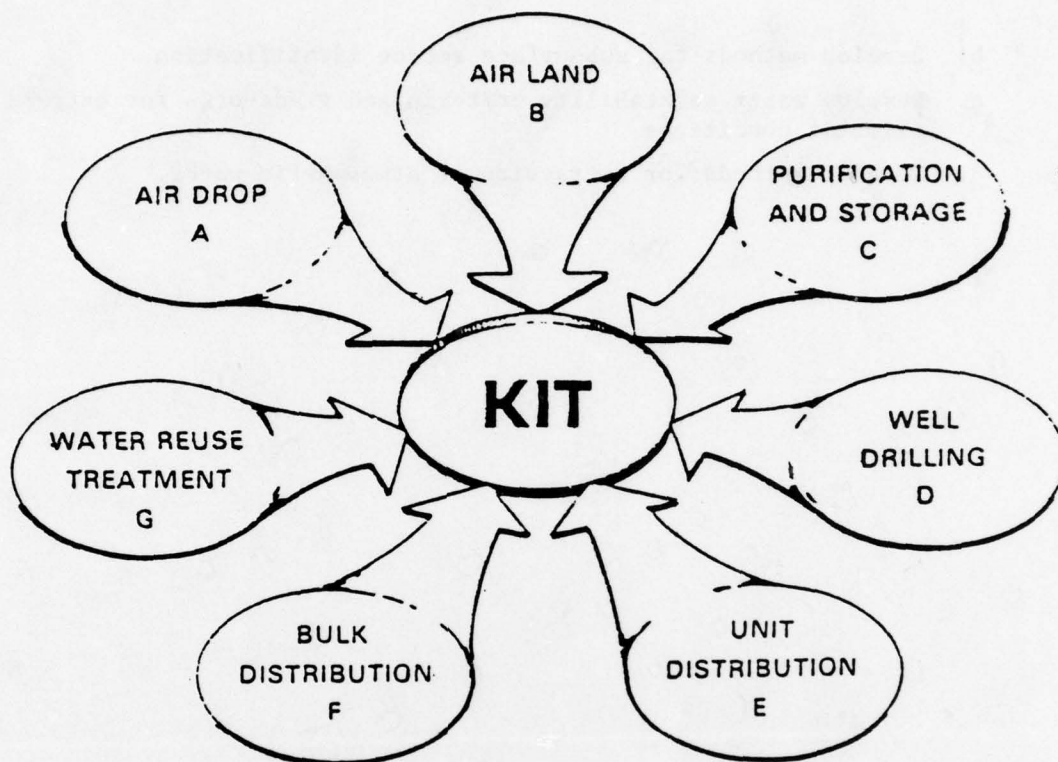


Figure 2. Integrated water supply and handling system

- c. The Army should develop greater tactical and nontactical capability to exploit ground and seawater sources for the production of potable water.
- d. The Army should develop an automated water resources data and information storage and retrieval system for selected geographic locations throughout the world.
- e. The Army should develop greater capability to distribute potable and nonpotable water by pipeline in the theater of operation (TO) and develop improved capability to collect wastes and wastewaters in the TO.
- f. Training programs and personnel policies related to water supply and wastewater disposal should be developed to provide the needed capability and to encourage career military personnel to remain in critical occupations.

In addition to these recommendations, further research is needed in the following areas, some of which are expansions of previous recommendations:

- a. Develop TO construction methods which are less water consumptive.

- b. Develop methods for subsurface source identification.
- c. Develop water palatability criteria and trade-offs for extreme climatic conditions.
- d. Develop methods for extraction of atmospheric water.

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ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS F/G 8/8
PROCEEDINGS OF THE MILITARY HYDROLOGY WORKSHOP, 17-19 MAY 1978,--ETC(U)
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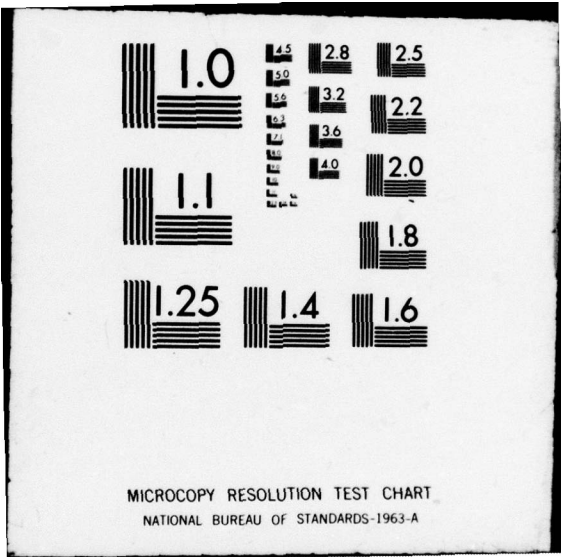


Table 1

Joint Working Group (JWG) Participants

US Army Logistics Center
HQ Department of the Army
Surgeon General
Academy of Health Sciences
HQ Materiel Development and Readiness Command (DARCOM)
US Army Natic R&D Command: (USANARADCOM)
US Army Mobility Equipment R&D Command (MERADCOM)
US Army Tank Automotive R&D Command (USATARADCOM)
HQ Training and Doctrine Command (TRADOC)
US Army Engineer School (USAES)
US Army Quartermaster School (USAQMS)
US Army Transportation School (USATS)
HQ Forces Command (FORSCOM)
18th Airborne Corps
Office Chief of Engineers (OCE)
HQ US Army Europe (USAREUR)
US Army Research and Standardization Group (Eurpoe)
US Army Medical Bioengineering R&D Lab
Industry (UNIROYAL)

Table 2
JWG Areas of Investigation

XVII Airborne Corps "Quick Fix"
Water-Use Planning Factors
Total Volume Required
Location and Development of Subsurface Water
Purification Equipment and Methods
Transportation and Distribution Equipment and Methods
Palatability
Detection of Chemical Agents
Recycling/Reuse

Table 3
Quick Fix Activities

Convert 5000-Gal Fuel Tankers (M857) to Water Tankers
Modify 600-gph ROWPU* to Add With Booster Pump for
Seawater Operations
Overhaul 150-gph Distillation Units in Depot (7)
Procure Commercial Well Pumps
Procure Commercial Well-Drilling Machines (500 ft)
Procure Small Fabric Containers

* ROWPU = Reverse Osmotic Water Purification Unit.

Table 4
Consumption Factors

Potable

Individual Consumption and Personal Hygiene	6 gal/man/day
Food Preparation (2 B Ration and 1 C Ration)	2 gal/man/day
Hospitals	60 gal/bed/day
Bakeries	1400 gal/unit/day
Graves Registration	50 gal/KIA*
Vehicle Consumption	0.5 gal/veh/day

Nonpotable

Laundry	250 gal/unit/hr
Shower	950 gal/unit/hr

Aircraft

Turbine Flushing	5 gal/turbine/ 5 hr flying time
Aircraft Washing	100 gal/aircraft/ 25 hr flying time

* KIA = Killed in action.

Table 5

Daily Water Requirements

	Water Requirements, gal				
	<u>D-Day to D+10</u>	<u>D+10 to D+20</u>	<u>D+20 to D+30</u>	<u>D+30 to D+40</u>	<u>D+40 to D+60</u>
<u>Potable</u>					
Individual Consumption	199,578	213,504	421,482	635,488	536,112
Food Preparation	66,526	71,168	140,494	211,816	178,704
Hospitals	24,000	24,000	88,800	91,200	91,200
Bakeries	4,200	4,200	7,000	8,400	8,400
Vehicles*	2,123	2,494	4,580	7,762	8,118
Graves Registration	27,050**			56,750+	
	<u>323,477</u>	<u>315,366</u>	<u>662,356</u>	<u>1,011,376</u>	<u>822,534</u>
<u>Nonpotable</u>					
Shower Units (20 hr/day)	57,600	57,600	57,600	172,800	172,800
Laundry Units (20 hr/day)	75,000	75,000	140,000	165,000	165,000
Aircraft	9,120	11,960	18,160	44,280	50,520
Engineer Construction		2,001,664	2,485,394	3,614,112	5,066,357
	<u>141,720</u>	<u>2,146,224</u>	<u>2,701,154</u>	<u>3,996,192</u>	<u>5,453,677</u>
Peak Total Potable	1,001,376				
Peak Total Nonpotable	5,453,677				
Peak Total Requirement	6,276,211				

* Because of the low daily demand and dispersed locations, nonpotable water requirements for vehicles should be included in the potable water category.

** (D-Day to D+30)

+ (D+30 to D+60)

Table 6

Existing Purification Methods and Characteristics

Erdlator

Can remove sediment and add chlorine.

Cannot remove dissolved salts

3000, 1500, and 420 GPH

Chemical Warfare Agent Pretreatment Set

Destroys the agents before processing in the Erdlator

Post Ion Exchange Unit

Removes soluble radioactivity after Erdlator

Vapro Ompression Distillation

Removes dissolved salts and sediment, adds chlorine 150 GPH

Carbon-Polymer (Lentross) Unit

Purifies water from laundries, showers, and kitchen waste water

Reverse Osmosis

Can provide potable water from any source
(fresh, salt, brackish)

Removes chemical, biological, and radioactive contaminants

600, 1500, and 2-5000 GPH

Ultrafiltration

Filters undissolved, suspended, or emulsified matter from a liquid solution

GROUNDWATER RECONNAISSANCE EXPLORATION

by

R. Theodore Hurr*

The needs and requirements of groundwater reconnaissance exploration for military purposes are different in scope and time from groundwater reconnaissance exploration as currently conducted by the U. S. Geological Survey (USGS). The current methods of groundwater investigations by the USGS generally follow this order: First, there is a geologic reconnaissance. This will include reviewing available literature, examining the study area to become familiar with the geology described in the literature, and ascertaining what amount of geologic mapping may be necessary to understand the groundwater hydrology.

Next, data will be collected from wells in the area. The visits to the well sites consist of locating the wells geographically and determining the geologic source of the water withdrawn by the wells, the depth of the wells, the water level in the wells, the water quality, the rate of withdrawal, and the use of the water. Frequently, the water levels in many different wells are measured in a short time by a large number of personnel so that the data can be used to construct a potentiometric or water table map for the aquifer or aquifers. These data provide information on the direction of groundwater movement and thus indicate the areas of recharge and discharge.

Specific-capacity tests are often made by pumping wells and measuring drawdown in the pumped well. Specific capacity is the rate of pumping divided by the drawdown after a specified elapsed period of pumping. These data can be used to extrapolate the potential yield of the well and to provide estimates of the aquifer properties. If additional quantitative data on aquifer transmissivity and storage are needed, then an aquifer test may be made. Using a pumped well and at least one observation well, measurements of drawdown are made in all wells during

* U. S. Geological Survey, Lakewood, Colorado.

and after the pumping period, and a detailed analysis is made of the aquifer response. These data are used to make estimates of probable well yields and duration of supply.

Samples of water may be taken from the pump discharge and prepared at the site for laboratory analysis of the water quality. Parameters such as specific conductance, temperature, pH, and dissolved oxygen may be measured at the site. The quality of the water determines its suitability as a water supply.

Springs may be measured to determine natural discharge and stream-flow may be measured to determine the relation between groundwater and surface water. These relations have an effect on both the quantity and quality of the potential supply. During and subsequent to the collection of these data, all of the data are interpreted and analyzed, and then a report is written presenting the data and the interpretation of the data.

The time required to complete such an investigation as described probably will range from 6 to 12 months depending upon the size of the area being studied. This is far too much time, however, if you are in immediate need of a water supply for military personnel who have no more water than they can carry in their canteens. A means is needed to quickly locate and evaluate potential groundwater supplies.

A hydrologist, using his experience, knowledge, and scientific intuition, frequently will be able to indicate where to drill and approximately how deep to drill just by a quick examination of the area. In the event that a hydrologist is not available, however, some method should be developed to transfer some of his capabilities to someone who is present.

I believe that the research efforts of military hydrology, therefore, should be to catalog, in advance, for different parts of the world, the various biologic and geologic parameters and indicators as to their hydrologic significance. The biologic indicators are primarily vegetation--location, type, and assemblages. The geologic parameters and indicators are structure, landform, lithology, soil, and so forth. The next step, then, would be to train personnel to recognize and

interpret onsite data and to assess the groundwater potential of an area in a brief time. Lastly, perhaps efforts should be made to develop remote sensing or geophysical equipment, or both, for site-specific evaluation of potential groundwater supplies.

LOCATION OF SUBSURFACE WATER SOURCES

by
Sherman Grazier*

By way of introduction, I am from the Concepts and Studies Division of the U. S. Army Engineer School at Fort Belvoir, Virginia. In the combat developments arena, our business is identifying problems and defining conceptual requirements for their solution. This is an oversimplification, of course, for brevity.

In the area of military hydrology, specifically the subject of water supply, our analyses have revealed a critical military problem: location of subsurface water sources. In areas where surface sources are adequate, the use of subsurface water sources can probably be envisioned only in a nuclear or chemical warfare environment. However, their use becomes critical in arid regions where surface sources are inadequate, not within reasonable distance to the users, or nonexistent.

The Army has in the acquisition process various equipment items to support military requirements for water in arid regions: (1) water will be purified using reverse osmosis equipment from fresh, brackish, and saline sources, (2) water will be transported using tactical pipelines and 5000-gal semitrailers, and (3) subsurface water sources will be developed using truck-mounted well-drilling rigs and associated equipment.

The first two systems noted above provide solutions when surface sources are available. The drill rig can provide a solution providing we can find subsurface water.

This leads directly to the problem of locating subsurface water sources. Applying current operational doctrine to the problem results in a requirement for a "capability to rapidly determine where to drill a well to achieve a high assurance of developing an adequate subsurface water source."

* USA Engineer School, Fort Belvoir, Virginia.

Our analyses indicate that two tools are necessary to provide the needed capability: (1) water resources data bases, which should provide readily accessible information on locations and characteristics of surface and subsurface water sources in specific geographical areas, and for field use, map products with supporting tabular data, and (2) equipment/techniques for identifying productive well site locations. Because of the expected rapidity of military operations, we cannot afford prospecting time for potential sites. We must have a high assurance of developing an adequate source when we drill.

Conceptually, the map products would be used to locate general areas; the equipment/techniques would be used to locate an optimum or best site within a general area. We would like to drive a stake and say, "Drill here!"

To close, the need for acquiring the capabilities discussed has been recognized and approved for development by the Department of the Army. It can be included in projected R&D actions.

WORKSHOP RESEARCH RECOMMENDATIONS

Streamflow Monitoring and Forecasting

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Present capability

Present capability of streamflow monitoring and forecasting is summarized below:

a. Streamflow monitoring

Methods for monitoring streamflow are well documented in numerous hydrologic texts and U. S. Geological Survey (USGS) reports. Most of these methods, however, require access to the stream itself, which may or may not be the case in the event of conflict. Some of the more modern techniques for measuring stage, such as the use of nitrogen bubble gages, require relatively simple installations in contrast to the older float-type gages that use stilling wells. There appears to be little requirement for additional military research in measurement techniques where access is available.

b. Streamflow forecasting

Extensive technology is currently available for forecasting streamflow through such organizations as the National Weather Service, USGS, Soil Conservation Service, Corps of Engineers, Bureau of Reclamation, Tennessee Valley Authority, and international organizations such as the World Meteorological Organization. Numerous reports have been issued by these agencies on techniques employed.

Over the past 30 years, the technology for forecasting

streamflow has gone from basically an index technique that utilized antecedent precipitation as an indication of soil moisture to a conceptual model that does extensive soil moisture accounting. As such, streamflow forecasting has essentially gone from event forecasting (e.g., major floods or major streams) to continuous streamflow forecasting that accounts for all the components (surface, interflow, and groundwater). Current models also account for runoff from snow-covered areas.

Unfortunately, most of the models now in use require a substantial file of historic data for calibration of basic hydrologic parameters utilized in these models. Also, real-time data on rainfall, snow water equivalent, and temperature are required.

On the major rivers where streamflow forecasting is basically a routing problem, forecasting techniques have gone from simple stage-time relationships to rather complicated dynamic routing techniques that accurately predict the movement of flood waves. Again, the latter technique requires detailed hydraulic information.

For smaller streams, real-time forecasting has not utilized the rather high level of technology available because of the very short time interval between the rainfall event and flood peak. In most cases for small streams, precomputed tables have been developed that utilize antecedent soil moisture as an index and require only the input of rainfall quantity and duration. These streamflow forecasting techniques are generally referred to as self-help techniques in that the real-time computations are done on or near the site, rather than in some remote center having electronic computer capability. They frequently can be accomplished by an engineer or technician having little hydrologic training. For small streams many procedures are currently available for developing estimates of runoff using normally available hydrologic and hydraulic data.

Research needs

Prior to defining research needs, some ground rules were set forth concerning available resources and assumptions made concerning military requirements for hydrologic forecasts. These were:

- a. Adequately trained personnel are readily available for hydrologic analysis.
- b. Both historic and current data bases exist for the following data types:
 - (1) Hydrologic.
 - (2) Topographic.
 - (3) Hydraulic.
 - (4) Geomorphological.
 - (5) Land cover.
 - (6) Soils.
 - (7) Meteorological.

- c. Trained personnel for providing the above data exist with necessary equipment.
- d. Capabilities exist for hydrologic computation, e.g., electronic computers, manual computing techniques, etc.
- e. Military requirements can be defined and specified.

Specific areas of suggested research have been listed below by several categories. These include high (H), medium (M), or low (L) priority, with respect to needed research, and short term (ST) or long term (LT), with respect to our assessment as to whether the research could be accomplished within a short or long time span. In most cases those needs listed as ST are research areas in which great amounts of information and technology are currently available. The LT areas are not nearly as amenable to solution.

Suggested research areas are shown in the following list. We have also listed a category, short term -- long term. This category is one in which there is a considerable amount of knowledge and results could probably be obtained within a short time frame. However, any real major progress probably can be accomplished only in a relatively long (several years) time frame.

a. Short Term - High Priority

- (1) Dam break. Much is already known about methods for handling this problem. Basically, information on the hydraulic characteristics of the valley below dams is needed more than further research on techniques. However, standard procedures need to be developed for use by field personnel who might be confronted by a problem such as a potential dam break.
- (2) Alternative procedures. This is an area for which a great deal of information is available. There are numerous models for forecasting streamflow, ranging from very simple to very complicated techniques. This is an area in which manuals need to be developed to provide the hydrologists working under field conditions with alternatives for various levels of computational capability, data availability, and manpower resources.
- (3) Adaptive models for sparse data areas. This is a more difficult problem and is related to (2) above. It is important that the hydrologist recognize models that can be used best in areas having variable topographic and

vegetative features and also variable amounts of data. For example, data availability may define the type of model employed.

- (4) Adaptation and testing of various models for specific areas and military problems. This is a very important research need in that more should be done in establishing the quality of various models and adapting them to specific problems. Of particular importance are the requirements related to specific outputs generated by military needs and how these relate to hardware and software availability.

b. Short Term - Medium Priority

Relation of hydrologic soil moisture index to trafficability. This offers a fruitful area for determining trafficability in a region since most hydrologic models used in forecasting rainfall/runoff utilize some form of soil moisture index that may range from a simple index that uses antecedent precipitation to an accounting of moisture in the soil mantle through some type of conceptual model.

c. Short Term - Low Priority

Rain on snow. A lot of research has been done in this area, but most models still do not handle the phenomenon adequately. Hydrologists with prior experience should be contacted and efforts continued.

d. Short Term -- Long Term - High Priority

Remote sensing of state of the stream. There seems to be adequate knowledge on measuring streamflow and other hydraulic characteristics of a stream when access is readily available. However, there appears to be a real need for determining information on stream characteristics by remote means.

e. Short Term -- Long Term - Medium Priority

Ice problems. This is another area in which there is a rather considerable volume of information. The state of the art for forecasting ice conditions is, however, still primitive when attempts are made to forecast ice jamming and breakup on streams and rivers. However, there are many short-term contributions that could be made in a relatively short time frame.

f. Long Term - High Priority

- (1) Parameterization of stage frequency as a function of basin characteristics and antecedent conditions. This is a very important area since conditional probabilities related to hydrologic conditions should be very important from both a planning and operational point of view. Certainly much is known about statistical techniques that can be applied in

hydrology. The preparation of manuals and software for utilization by the military hydrologist should have very high priority. Probably one of the weakest areas in hydrology is our evaluation of the goodness of hydrologic output. The identification of pertinent parameters to stage frequency determination and their functional relationship to basin characteristics and antecedent conditions is of major importance.

- (2) Remote sensing of soil moisture. This offers real potential since techniques such as the Soil Conservation Service curve number procedure might be utilized, particularly for small watersheds. Of course, it also has trafficability implications.
- (3) Relation of model parameters to basin characteristics. This is another study area that offers considerable potential for helping the military hydrologist in areas in which he may have only topographic maps and/or aerial photography. In this case model parameters relate to any of the several parameters that are utilized in the numerous rainfall/run-off relationships that he might apply.

g. Long Term - Low Priority

- (1) Identify basin characteristics from maps or remote sensing data. This relates to the identification of certain basin characteristics that can, in turn, be related to model parameters. This can also be used to identify certain hydrologic characteristics that are related to landform. Such knowledge might prove very useful to the military hydrologist working in an area for which little hydrologic data exist. It would enable him to say something about the hydrologic characteristics of such an area.
- (2) Identify channel characteristics from basin characteristics. This is directly related to the discussion of (1) above. Much can be inferred about the hydrology of a basin from certain basin characteristics. In particular, it should be possible to infer something about the channel characteristics that would be of considerable use to a military hydrologist working in a sparse data area.

Soil Moisture Monitoring and Forecasting

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Present capability

The discussion started with a brief summary of measurement and forecasting techniques utilized by the Air Force during the Vietnamese conflict. Within the civilian community there exists a wealth of knowledge as far as measuring and forecasting of soil moisture is concerned. There are a number of sophisticated instruments and procedures for measuring soil moisture, and there are several comprehensive models in use for forecasting soil moisture. However, there is a definite need to collate and evaluate the various soil moisture measuring and forecasting activities and research.

In comparison, the state of the art in the military appears primitive. The techniques and procedures are old and could well benefit from the knowledge existent in the civilian community.

Research needs

The discussion was then turned to the short- and long-term research required to adapt or develop soil moisture measurement and forecasting technology. Any technology considered would have to be constrained by military operations, take into account new developments in remote sensing and computer technology, allow for calibration, assume that terrain and hydrological data will be available, and be simple, rugged, and easily employed.

It was decided to utilize the draft report "Military Hydrology Status and Research Requirements" as a guide to discussion by either

modifying, adding to, or deleting portions of the statements of requirements contained therein. In general it was felt that the priorities should be in the following order: to define the military requirements for soil moisture; to adapt or develop ground measurement techniques; to adapt or develop soil moisture models; and to adapt or develop remote sensing techniques. It was felt that ground measurement techniques would be needed to develop and validate modeling. Modeling in turn would set the design parameters required for any remote sensing system. Keeping these priorities in mind, the research requirements are stated in two broad areas, short- and long-term research. Each of these areas is in turn divided into two subareas, measurement and forecasting. The requirements are listed in order of priority within each subarea.

a. Short-term research

(1) Monitoring/measuring

- (a) Examine psychrometric, surface-lying microwave, gravimetric, water potential, and thermal and nuclear (to include gamma radiation) techniques to define those most suitable for rapid ground determination of soil moisture.
- (b) Evaluate existing airborne microwave or optical/thermal systems for gaining a synoptic record of soil moisture over large areas. The system should be aircraft or satellite compatible with emphasis on existing passive microwave and synthetic aperture radar systems to provide a day-night all-weather capability. Included should be an evaluation of current systems designed for other purposes to determine if they can be modified or adapted to measure soil moisture.
- (c) Evaluate the effects of surface geometry, as well as soil and vegetation parameters, on the above remote sensing systems. Particular effort must be given to vegetated areas and the ability of passive or active remote systems to monitor soil moisture through the probable spectrum of biomass. The ability to use vegetation parameters as an indication of soil moisture should also be examined.
- (d) Based on the evaluations, look critically at future systems that might be constructed.

(2) Forecasting

- (a) Screen existing soil moisture models (physically based) to establish those most applicable to military

operations, bearing in mind the simplification needed at various levels (Corps, Army, DA) as far as data acquisition and analysis are concerned.

- (b) Identify and evaluate input information required for the various models and the degree of accuracy required. Included would be an evaluation as to the availability of the information.

b. Long-term research

(1) Measuring/monitoring

- (a) Cooperate in developing an air-droppable sensor-transponder for measurement of soil moisture with depth. This system should be incorporated in the long-term technology with any air-droppable meteorological systems developed. The advanced version of this system should be commandable (able to be turned on periodically to obtain an in situ soil moisture value).
- (b) Cooperate in developing advanced satellite/aircraft-based and ground determination techniques for monitoring soil moisture and acquiring terrain data inputs for soil moisture forecasting procedures.
- (c) Cooperate in the development of low-cost transmitters for in situ soil moisture measurements.
- (d) Evaluate potential advanced military sensor systems to assess their applicability to military hydrology problems.

(2) Forecasting

- (a) Develop a physically based soil moisture forecasting model utilizing grid arrays and remotely obtainable soil and terrain parameters. The model will incorporate the best of the concepts investigated and will utilize real-time and forecast weather data.
- (b) Evaluate the model and develop guidance for most effective use and for data base generation.
- (c) Identify data that are indispensable for soil moisture measurements at the desired levels of accuracy and establish data acquisition systems where systems are not available.
- (d) Evaluate and/or develop monitoring and modeling techniques for freezing and thawing conditions in soil.

Meteorological Monitoring and Forecasting

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Research needs

The initial discussions concerned the types of meteorological information most essential for planning military operations and for forecasting other items such as streamflow and soil moisture. It was the unanimous opinion that precipitation was the single most important information type and that short-term capability update research should stress methods to monitor and forecast precipitation. Ground-based digital radar systems were discussed as a potential means to measure precipitation over large areas. The question arose as to the applicability of existing field Army radar systems for rainfall measurement or monitoring. It was felt that the existing Army systems would certainly not provide all the information needed, but they should be investigated as a backup system or for providing very general information to supplement weather radar systems as needed.

Formulation of specific research needs was accomplished by addressing the strawman plan of research for meteorological monitoring and forecasting presented in the draft report "Military Hydrology Status and Research Requirements." Two new items were identified to supplement the items already included in the plan: development of a synoptic climatic data base and development of initialization procedures for mesoscale models. The climatic data base is needed as basic background information for forecasting meteorological phenomena, and the

initialization procedures are essential for the successful use of any mesoscale meteorological models for forecasting. Minor modifications were made to other items; however, none were changed dramatically.

Mr. Cionco presented excerpts from two documents that present additional requirements for meteorological data: "Tactical Environmental Support System," which presents a matrix of surface environmental parameters and specific Army elements that are users of those parameters, and "Tactical Requirements for Weather Support, XVIII Airborne Corps," which presents a summary of weather data needs for a variety of operations. The second document is a fairly detailed summary of needs and points out a requirement for long-range (30-day) forecasts of precipitation and temperature. This need was incorporated in the research plan under long-term technology advancement research requirements.

A major point of discussion concerned the responsibility for acquiring meteorological data and for conducting the research and development required to meet Armed Forces needs for meteorological data in the area of military hydrology. The Air Force, of course, does supply a considerable amount of weather data to the Army; however, these data are not necessarily available for battlefield areas if the battlefield areas are far from an Air Force weather station, normally located at an air base. Certainly, the Army must be able to acquire the needed meteorological data (on a mesoscale) for such instances. It was agreed that a closer look was needed at the relative responsibilities of the Army and Air Force operational elements to determine the items that the Army should expect to supply itself.

It was also evident that considerable research is ongoing that can impact on the research requirements resulting from this workshop. For example, the U. S. Army Cold Regions Research and Engineering Laboratory is conducting research in the area of snow depth/water equivalent estimation and modeling; the Atmospheric Sciences Laboratory is involved in upgrading existing air-droppable weather stations and development of some mesoscale forecasting models; numerous universities such as Texas A&M and University of Illinois (through the Illinois State Water Survey) are actively evaluating digital radar systems for precipitation

measurements; and, of course, the Air Force and the National Oceanic and Atmospheric Association have considerable ongoing research efforts in meteorology forecasting and monitoring. This serves to illustrate that the Corps of Engineers should not have to bear the burden of funding all of the research requirements outlined in the plan of research. It does, however, emphasize the need to initiate or expand communications between the various agencies and organizations conducting research relevant to military hydrology needs to ensure that maximum use is made of ongoing research and development efforts.

a. Short-term capability
update research requirements

(1) Measuring/monitoring

- (a) Define an off-the-shelf digital radar system for monitoring precipitation. The system should be capable of accurately detecting precipitation over a 20- to 200-km range and have range and azimuth resolutions of approximately 1 km and 1 deg, respectively. Complementary work required includes evaluation and testing of the system.
- (b) Develop improved precipitation-radar return relations.
- (c) Develop capabilities of existing airborne and satellite sensor systems for providing data on such things as precipitation, state of the ground, snow depth (water equivalent), and clouds.
- (d) Develop an integrated methodology for use of presently available satellite-aircraft-remote ground station-digital radar systems for a comprehensive meteorological data-acquisition capability.
- (e) Refine existing portable ground-based and air-droppable meteorological stations.

(2) Forecasting

- (a) Examine, test, and modify existing mesoscale forecast procedures to update current capability for both short-term (6- to 8-hr) and longer (1- to 3-day) forecasts. Initial emphasis should be on precipitation only.
- (b) Define and develop initialization procedures for mesoscale forecasting models.
- (c) Adapt existing physically based relations for modeling mesoscale wind fields, temperature, and humidity.
- (d) Develop climatic data bases for selected world regions.

Data bases should include temperature, wind, humidity, and precipitation data to provide essential background information needed for forecasting.

(3) Long-term technology
advancement research requirements

(1) Measuring/monitoring

- (a) Upgrade digital radar capability obtained under short-term research to include both hardware and software.
- (b) Develop refined radar return-precipitation relations for global scale.
- (c) Implement integrated concept for satellite-airborne-remote ground station-digital radar systems developed under short-term research. Incorporate advanced data-acquisition methods for meteorological parameters.
- (d) Develop techniques to quantify precipitation, temperature, and relative humidity by airborne and satellite remote sensing.

(2) Forecasting

- (a) Develop advanced numerical prediction capability for 1- to 5-day forecasts of precipitation, temperature, humidity, and wind for battlefield scenarios.
- (b) Formulate extended forecast capability for periods of 5 to 30 days for temperature and precipitation.
- (c) Formulate snowmelt forecasting procedures integrating capability to estimate snow volume, extent, and impact of melting.
- (d) Update and expand climatic data bases to include both new data and new regions.

Water Supply

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Research needs

Short- and long-term research requirements are outlined below. Each research item should include instructional packages, including possible use of videotape, film, or programmed instruction, for effective technology transfer of the methodologies and techniques. The plan should include the use of civil expertise and input of field-level users to ensure compatibility.

a. Short-term research requirements using current technology

- (1) Establish format for Military Hydrology Data Bank and initiate storage and entry into format for the Standard Catalog of Recurring Scenarios (SCORES) and selected Continental United States (CONUS) training areas.
- (2) Develop methodology for rapid location and evaluation of groundwater sources with special emphasis on arid regions. Techniques to determine presence, quantity, and quality of groundwater should be developed using geologic and topographic criteria, remote sensing techniques, and current mathematical models.
- (3) Review and evaluate for military application the geophysical, rapid well-drilling, and well-logging methods of groundwater investigations. Explore the feasibility of multifrequency electromagnetic systems to measure depth to water table.
- (4) Review methods, site location, and design of water harvesting technology and evaluate the applicability to military operations in arid regions.
- (5) Evaluate the feasibility of using a remote and air-droppable sensor technology for determining water quality of potential surface water sources.

b. Long-term research requirements for advancing technology

- (1) Develop generalized procedure for determining quantity, quality, and location of surface and groundwater sources through remote sensing technology.

- (2) Develop methods such as air-droppable (gravity or rocket propelled) penetrometer and electromagnetic systems to evaluate shallow water aquifers.
- (3) Develop new technology and systematic procedures for augmenting flow and yield of surface and groundwater sources.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

United States. Waterways Experiment Station, Vicksburg, Miss.

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