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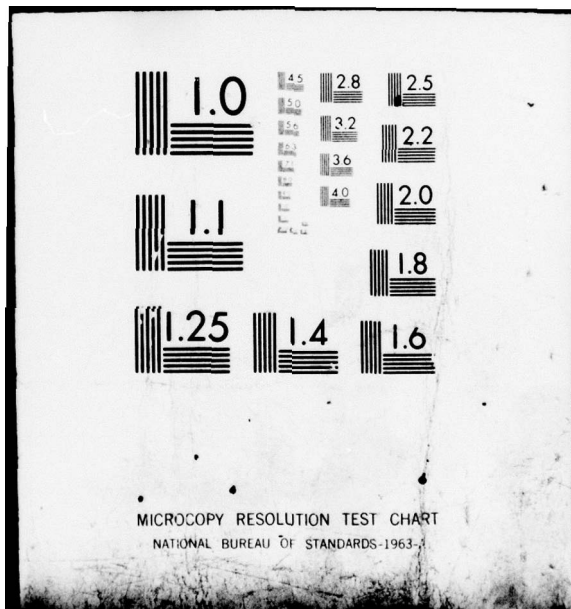
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MILITARY HYDROLOGY

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# MILITARY HYDROLOGY

Report I

## STATUS AND RESEARCH REQUIREMENTS

by

Wesley James and L. E. Link, Jr.

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U. S. Army Engineer Waterways Experiment Station  
P. O. Box 631, Vicksburg, Miss. 39180

December 1979

Report I of a Series

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20. ABSTRACT (Continued).

requirements for hydrologic data are extensive in terms of scope, accuracy, and response time. Evaluations of Army and civilian capabilities in the field of hydrology were made; with reference to the Army, the evaluations revealed an absence of modern methodologies, inadequate resources, and a lack of trained personnel. A research plan was developed to provide a short-term update of military hydrology based on adaptations of existing civilian technologies and a long-term advancement in capabilities through improved technologies. Proposed work is presented under five "thrust" areas: (a) meteorology, (b) soil moisture, (c) streamflow, (d) water supply, and (e) training and technology transfer.

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## PREFACE

The work reported herein was conducted from Oct 1976 to Jun 1978 under the Department of the Army Project No. 4A762719AT40, "Mobility, Soils, and Weapons Effects Technology," Task Area A3, "Geoscience Techniques and Methodologies," Work Unit 009, "Hydrology Support for Military Operations," sponsored by the Office, Chief of Engineers, U. S. Army. Richard Barnard and Walter Swain were the Technical Monitors for OCE.

The study was conducted by the U. S. Army Engineer Waterways Experiment Station (WES) under the general supervision of Messrs. W. G. Shockley, Chief of the Mobility and Environmental Systems Laboratory, and B. O. Benn, Chief of the Environmental Systems Division (ESD), and under the direct supervision of Dr. L. E. Link, Jr., Chief of the Environmental Research Branch (ERB). This report was prepared by Dr. Wesley James, Senior Research Civil Engineer, ERB, and Associate Professor of Civil Engineering, Texas A&M University, and Dr. Link. The ESD and the ERB are now part of the Environmental Laboratory of which Dr. John Harrison is Chief.

A Military Hydrology Workshop cosponsored by the U. S. Army Research Office and WES was held at Vicksburg, Mississippi, 17-19 May 1978. Recommendations of this workshop are incorporated into this report.

Acknowledgment is made to the personnel of the U. S. Army Hydrologic Engineering Center, Davis, California; the U. S. Army Electronics Command Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico; the Department of Hydrology and Water Resources, University of Arizona, Tucson, Arizona; the 319th Engineer Detachment, New Kensington, Pennsylvania; and the Military Hydrology Workshop attendees for their valuable inputs to the study effort.

Commanders and Directors of the WES during the conduct of this study and preparation of this report were COL J. L. Cannon, CE, and COL N. P. Conover, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

	<u>Page</u>
PREFACE . . . . .	2
PART I: INTRODUCTION . . . . .	5
Background . . . . .	5
Objectives and Scope . . . . .	6
PART II: REQUIREMENTS FOR HYDROLOGIC DATA . . . . .	8
Sources of Information . . . . .	8
Navy and Air Force Requirements . . . . .	8
Army Requirements . . . . .	8
Summary of Requirements . . . . .	22
PART III: ARMY CAPABILITY . . . . .	25
Army Organization for Hydrologic Data Support . . . . .	25
Current Procedures . . . . .	33
Summary . . . . .	34
PART IV: MEASUREMENT AND FORECASTING, A STATE-OF-THE-ART ASSESSMENT . . . . .	35
Introduction . . . . .	35
Meteorology . . . . .	36
Soil Moisture . . . . .	40
Streamflow . . . . .	45
Water Supply . . . . .	55
PART V: ASSESSMENT OF RESEARCH NEEDS . . . . .	62
Introduction . . . . .	62
Meteorological Monitoring and Forecasting . . . . .	62
Soil-Moisture Monitoring and Forecasting . . . . .	64
Streamflow Monitoring and Forecasting . . . . .	64
Water Supply Evaluation . . . . .	68
Technology Transfer . . . . .	70
PART VI: PLAN OF RESEARCH . . . . .	71
Introduction . . . . .	71
Meteorological Monitoring and Forecasting . . . . .	72
Soil-Moisture Monitoring and Forecasting . . . . .	74
Streamflow Monitoring and Forecasting . . . . .	77
Water Supply Location and Evaluation . . . . .	80
Technology Transfer . . . . .	82
PART VII: CONCLUSIONS AND RECOMMENDATIONS . . . . .	84
Conclusions . . . . .	84
Recommendations . . . . .	84

CONTENTS

	<u>Page</u>
LITERATURE CITED . . . . .	85
TABLES 1-7	
APPENDIX A: MILITARY HYDROLOGY, AR 115-21, AFR 105-10 . . . . .	A1
APPENDIX B: RESPONSES TO WES REQUEST FOR ASSISTANCE, MILITARY HYDROLOGIC DATA SUPPORT . . . . .	B1

MILITARY HYDROLOGY  
STATUS AND RESEARCH REQUIREMENTS

PART I: INTRODUCTION

Background

Definition

1. Military hydrology is a specialized field of hydrology that deals with the characteristics of surface and subsurface water features that may affect the planning and conduct of military operations.

Importance

2. Hydrologic information is important in planning and executing offensive and defensive operations. It is required before and during military operations for planning, flood forecasting, designing of bridging and stream-crossing equipment, locating and designing facilities, training and equipping troops for special assignments, determining communication routes, and locating river-crossing sites. Such information is of considerable importance in determining the utilization of inland waterways and in evaluating the effects of artificial flooding on military operations, the available water supply, and cross-country mobility.

General procedures

3. Collection, analysis, and dissemination of hydrologic information is normally accomplished by a military team or detachment. They conduct field surveys and assemble data from various sources, including terrain analyses, aerial and ground imagery, agencies or units engaged in the collection of hydrologic data, existing hydrologic stations, and technical publications. In relation to a specific problem, the assembled data must be analyzed, published in appropriate form, and given timely dissemination to appropriate military units.

Authority

4. Under AR 115-21, AFR 105-10 Military Hydrology, 15 May 1977 (copy included as Appendix A), the Joint Chiefs of Staff assigned the

responsibility for military hydrology for the U. S. Armed Forces to the Chief of Staff, U. S. Army. The Office, Chief of Engineers, has been assigned responsibility by the Chief of Staff for performing functions and activities dealing both with research and development and support of operational elements.

#### Initiation of research program

5. Very little effort has been expended within the last few decades to keep the Army's hydrologic capability on a par with available technology. Therefore, no major advances in hydrologic procedures have been adopted since the 1950's and many methodologies for collecting hydrologic data, data analysis and forecasting, and information dissemination are based on antiquated technology. Recent developments in such areas as computers, mathematical modeling, and remote sensing have provided a new dimension to hydrology and provide the basis for significant advancements in the Army's capability to rapidly acquire needed hydrologic information.

6. In response to this situation, a work unit, "Hydrology Support for Military Operations," was initiated at the U. S. Army Engineer Waterways Experiment Station (WES) in FY 77 under the sponsorship of the Assistant Chief of Engineers. The overall objective of the work unit is to develop an improved hydrological capability for the Armed Forces, including support to the Navy and the Air Force. The work concerns the collection, analysis, and presentation of information regarding all aspects of water that may affect military planning and operations and places special emphasis on problems relating to battlefield situations.

#### Objectives and Scope

7. The objectives of the work reported herein were to define the problem and to develop a viable study plan that would provide for both short-term updates and long-term technological advancements in the Army's hydrological capability. Initial efforts were devoted to evaluating the current state of the art in hydrology, defining present capabilities of field units to provide military hydrologic information, and establishing

the requirements of the Armed Forces for hydrologic information. Comparisons were made between current state of the art, present capabilities of field units, and military requirements for the purpose of defining specific steps necessary to develop an improved hydrological capability for the Armed Forces.

8. This report presents a synopsis of the military requirements for hydrologic data (Part II), the Army capability for acquiring hydrologic information (Part III), a state-of-the-art assessment of hydrologic measurement and forecasting techniques (Part IV), a general evaluation of research needs (Part V), and a plan of research to meet the needs identified (Part VI). Part VII presents the conclusions and recommendations regarding military hydrology. Appendix A presents AR 115-21, AFR 105-10, entitled "Military Hydrology." The responses to WES's Request for Assistance, concerning the hydrologic data requirements of engineer and combat units, are included as Appendix B.

## PART II: REQUIREMENTS FOR HYDROLOGIC DATA

### Sources of Information

9. Several sources of information were utilized to define military requirements for hydrologic data. Letters requesting military hydrologic requirements were sent to the Army, Navy, and Air Force; Federal agencies were contacted with regard to previous or ongoing relevant studies; and existing Army technical manuals, field manuals, technical bulletins, and related military documents were reviewed to evaluate Army data requirements. The following paragraphs summarize the results of those efforts.

### Navy and Air Force Requirements

10. The Naval and Air Force response to the requests for hydrologic data needs indicated that their requirements were primarily for water supply and facilities design (see Appendix B for copy of responses). Rainfall and runoff data for the design of drainage structures and estimation of flood potential were required for the location and construction of new facilities. General guidelines for locating suitable water supplies were also needed.

### Army Requirements

#### Recent studies

11. The U. S. Army Combined Arms Combat Development Activity at Fort Leavenworth, Kansas, conducted a study entitled "Topographic Data Base Requirements of Army Materiel Systems," 30 June 1977. The study identified several hydrologic characteristics or parameters as being top priority items for military operations, including water depth, channel characteristics, bottom characteristics, bank characteristics, seasonal variations, and type and location of crossing. In addition, topographic and landform characteristics listed included relief, slopes,

surfaces, interruptions, profile, elevations, and vegetation types. From a hydrographic point of view, these would be considered watershed characteristics essential for predicting streamflows. Surface material characteristics listed included type, depth, extent, seasonal state, and bearing capacity. Again, these factors are closely associated with infiltration, runoff, and soil moisture.

12. Gap-crossing hydrologic requirements were obtained from a draft report by the U. S. Army Engineer School, Combat Developments Directorate, Fort Belvoir, Virginia, and are tabulated in Table 1.

13. The tactical requirements for weather support for engineer operations of the XVIII Airborne Corps are summarized in Table 2. This table shows the frequency, spacial resolution, accuracy, and use of temperature, precipitation, and evaporation information. The Tactical Environmental Support System (TESS), Army Training and Doctrine Command, report of March 1976 summarized the users of environmental data (Table 3) and environmental capabilities and sources (Table 4).

#### Existing documents

14. TOE 05-540H, November 1976. The current Table of Organization and Equipment for Engineer Topographic and Intelligence teams (TOE 05-540H) provides for a Terrain Team II for "the collection, evaluation, and dissemination of military terrain data, the production of military terrain studies, and for consultant services in military geology and hydrology."

15. Draft ARTEP 5-335, January 1977. The coordinating draft for ARTEP 5-335 for Engineer Topographic Units defines several hydrology-related tasks to be performed by specialized teams or platoons. Briefly, terrain analysis teams of topographic units should be capable of the following:

- a. Task 19-50: Obtain and evaluate source data including information from hydrologic stations.
- b. Task 19-51: Conduct a terrain study on coastal and beach features, including coastal hydrology.
- c. Task 19-55: Perform a study of hydrology.

Table 1  
Gap-Crossing Hydrologic Requirements\*

Gap

Definition. Any depressed topographical discontinuity which is of military significance and is wider than 6 metres.

Cross section

Gap Width. The minimum clear span that would be required for an equipment bridge, measured to the next 0.5 metre. (NB, this distance should include the safe angle of repose requirements on both banks and also the practicability of vehicle access.)

Bank height. The vertical height of both banks measured from the existing water level to the nearest 0.1 metre.

Bank slope. The average slopes of both banks should be designated by one of the following values:

Steep	(31-90 degrees)
Medium	(17-31 degrees)
Flat	(0-17 degrees)

Streamflow

Water width. The distance of the existing width of flow excluding fords or backwaters, measured to the next 0.5 metre.

Water depth. The maximum and critical minimum depths of water occurring across the water width, measured to the nearest 0.1 metre (critical minimum depths are related to the bridging equipment likely to be used and should be located in respect to the water width).

Current velocity. The maximum speed of the water on the surface to the nearest 0.5 metre per second.

Estimated worst stream conditions. The worst case conditions of streamflow are assessed from height of debris on the banks, water depth indicators, or any other means. The information required is:

- (1) The estimated greatest depth and width of the flow and if these conditions are affected by the tide.
- (2) Whether existing bridge is flooded during conditions of highest water.
- (3) The ice and ice flow conditions.

Range of streamflow. The effect of average low and average high water conditions on streamflow characteristics.

(Continued)

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\* Source of data: U. S. Army Engineer School, Combat Developments Directorate, Fort Belvoir, Virginia.

Table 1 (Concluded)

---

Obstacles and Structures

Obstacles. Natural and artificial obstacles on the banks and floodplain such as snags, levees, buildings, trees, marshes, and swamps.

Structures. Water-control structures such as rapids, falls, narrows, dams, drops, and checks.

Terrain

Local relief. The difference in elevation between the highest and lowest points in an area of four square kilometres around the gap.

Terrain type. The terrain type is recorded by describing characteristics such as soil type and vegetation coverage and also by the following classification:

- (1) Flat. Little or no local relief.
- (2) Plains. Local relief less than 150 metres.
- (3) Low hills. Local relief between 151 and 300 metres.
- (4) High hills. Local relief between 301 and 600 metres.
- (5) Mountains. Local relief greater than 600 meters.

Table 2  
Tactical Weather Requirements for XVIII Airborne Corps Engineering Operations\*

Type Operation	Valid Period (days)	Frequency (days)**	Point or Area†	Spatial Resolution††	Critical Value	Accuracy Required	Echelon and Who Needs	Impact (Why Information Needed)
<b>A. Forecast</b>								
(1) Trafficability precipitation‡								
a. 5-day	0.5	2	MS	2/MS	1" (25.4 mm) in 2-hr period	+0.5" (+12.7 mm)	Corps/BdeG,S2 G,S3	Correlate to moisture content of soil
b. 30-day	0.5	OR	MS	2/MS	2" (50.8 mm) in 24-hr period	+0.5" (+12.7 mm)	Corps/BdeG,S2 G,S3	Correlate to moisture content of soil
(2) River condition (water depth, current, river stage, ice thickness)								
Precipitation								
a. 5-day	0.5	OR	WS	2/MS	3" (76.2 mm) in 24-hr period	+0.5" (+12.7 mm)	Corps/BdeG,S2 G,S3	High intensity precipitation affects water depth and current
b. 30-day	0.5	OR	WS	2/MS	3" (76.2 mm) in 24-hr period	+0.5" (+12.7 mm)	Corps/BdeG,S2 G,S3	High intensity precipitation affects water depth and current
Temperature								
a. 5-day	0.5	OR	WS	2/MS	32°F (0°C) for 3-day period	+5°F (+3°C)	Corps/BdeG,S2 G,S3	Long periods of low temperatures affect load bearing capacity of frozen water bodies
b. 30-day	0.5	OR	WS	2/MS	32°F (0°C) for 3-day period	+5°F (+3°C)	Corps/BdeG,S2 G,S3	Long periods of low temperatures affect load bearing capacity of frozen water bodies
<b>B. Observation</b>								
(1) Trafficability precipitation (30-day)	--	OR	MS	2/MS	Max 24-hr precipitation, max monthly precipitation, mean monthly precipitation	+0.5" (+12.7 mm)	Corps/BdeG,S2 G,S3	Determine abnormal or extreme wet or dry conditions
(2) River condition								
a. Precipitation (30-day)	--	OR	MS	2/MS	Max 24-hr precipitation, max monthly precipitation, mean monthly precipitation	+0.5" (+12.7 mm)	Corps/BdeG,S2 G,S3	Determine abnormal river stages (high or low water) and probability of crossing obstacle in given period
b. Temperature (30 day)	--	OR	MS	2/MS	32°F (0°C)	+5°F (+3°C)	Corps/BdeG,S2 G,S3	Determine abnormal river stages (high or low water) and probability of crossing obstacles in given period
<b>C. Planning data</b>								
(1) Trafficability								
a. Precipitation‡	30	OR	A	1/A	Mean monthly value for entire year over previous 20 years		G,S2/G,S3	Probability of becoming significant in a short period of time (24 hr)
b. SFC Temp	30	OR	A	1/A	Mean monthly value for entire year		G,S2/G,S3	Probability of becoming significant in a short period of time (24 hr)
c. Evaporative Rate	30	OR	A	1/A	Mean monthly value for entire year		G,S2/G,S3	Probability of becoming significant in a short period of time (24 hr)
(2) SFC visibility								
	30	OR	A	1/A	1/8 to 1/4 mile (3.2 to 6.3 km)		G,S2/G,S3	Probability of becoming significant in a short period of time (24 hr)
(3) River conditions								
a. Precipitation	30	OR	A	1/A	Mean monthly value for entire year over previous 20 years		G,S2/G,S3	Probability of crossing obstacle in given period and duration of freeze
b. Temperature	30	OR	A	1/A	Mean monthly value for entire year over previous 20 years		G,S2/G,S3	Probability of crossing obstacle in given period and duration of freeze
Climatic Impaction								
(4) Vegetation								
a. Precipitation	365	OR	A	1/A	Mean monthly value for year		G,S2/G,S3	Determine the type of climate (tropical, desert, subtropical, continental or polar) and pattern of principal vegetation formations
b. Temperature	365	OR	A	1/A	Mean monthly value for year		G,S2/G,S3	Determine the type of climate (tropical, desert, subtropical, continental or polar) and pattern of principal vegetation formations
c. Climatic summary	365	OR	A	1/A	Mean monthly value for year over previous 20 years		G,S2/G,S3	

\* Include current and future systems requirements, e.g. (helicopters, electrooptical systems, etc.) for mid-1980's. Height of SFC, preferred format is printed copy, unit response time is 48 hr.

\*\* OR--on request.

† MS--1:50,000 map sheet, WS--watershed, A--area.

†† 2/MS--two per map sheet, 1/A--one per area.

‡ Include only Minimum Essential Parameters (MEP) for weather support to each operation and material system.

Table 3  
Army Environmental Requirements by User

Surface Environmental Parameters	Users																		
	Airborne	Air Defense	Amphibious	Armor	Artillery	Aviation	CBR	Civil Affairs	CBT Intel Coll	Infantry	Medical	Military Police	Missile and Munitions	Ordnance	PSY Warfare	Quartermaster	Signal	Special Forces/Rangers	Transportation
Altimeter Setting						X												X	
Ceiling	X	X	X			X													
Crosswind (Trajectory)				X														X	
Current (River, etc.)				X								X						X	X
Density Altitude						X												X	
Depth (Water)			X								X							X	X
Dew Point	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Electrical Storms						X			X							X	X		
Freeze-Thaw Depth													X	X		X			X
Ground Albedo							X												
Humidity	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Ice Thickness	X			X		X			X	X		X				X		X	X
Illumination	X	X	X	X	X	X	SUN X	X	X	X	X	X	X	X	X	X	X	X	X
Natural Disaster	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Obstruction to Vision	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Precipitation	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Riverbank Conditions			X	X								X						X	X
River Stage	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Seashore Condition			X															X	X
Severe Weather	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Sky Cover	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Snow Depth				X		X			X	X		X						X	X
Soil Bearing Strength			X	X		X							X	X		X			X
Soil Moisture			X										X	X		X		X	X
State of the Ground	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
State of the Sea			X						X			X			X			X	X

(Continued)

(Sheet 1 of 3)

Table 3 (Continued)

Users

Surface Environmental Parameters	Airborne	Air Defense	Amphibious	Armor	Artillery	Aviation	CBR	Civil Affairs	CBT Intel Coll	Infantry	Medical	Military Police	Missile and Munitions	Ordnance	PSY Warfare	Quartermaster	Signal	Special Forces/Rangers	Transportation
Surface Pressure		X			X														
Surface Temperature	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Surface Winds/Gusts	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tides	x	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Trafficability	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Visibility	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Wet-Bulb-Globe Temperature	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Wind Chill	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Water Quality								X	X		X	X			X	X		X	
<b>Aloft Environmental Parameters</b>																			
Acoustical Propagation												X			X				
Atmospheric Electricity						X							X	X					
Cloud Albedo							X												
Density Profile					X														
Depth of Surface Mixing Layer							X												
Effective Temperature					X														
Effective Winds					X														
Electromagnetic Propagation		X													X		X	X	
Fallout Winds							X						X					X	
Geomagnetic Storm																	X		
Height of Inversion Bases							X					X							
Icing						X													X
Ionospheric Conditions															X				
Ionospheric Disturbance																	X		
Moisture Profile					X										X				

(Continued)

(Sheet 2 of 3)

Table 3 (Concluded)

Users

Aloft Environmental Parameters	Airborne	Air Defense	Amphibious	Armor	Artillery	Aviation	CBR	Civil Affairs	CBT Intel Coll	Infantry	Medical	Military Police	Missile and Munitions	Ordnance	PSY Warfare	Quartermaster	Signal	Special Forces/Rangers	Transportation
Pressure Profile					X														
Refractive Index		X		X	X												X		
Turbulence	X					X	X								X			X	
Temperature Profile					X	X	X							X	X				
Winds Aloft	X					X					X				X			X	
Wind Profile	X				X		X								X				
Other Environmental Parameters																			
Seeability		X		X	X	X				X									X
Slant Range Visibility		X				X													

(Sheet 3 of 3)

Table 4  
Environmental Capabilities/Sources

Surface Elements	USAF		Air				Engineer		Medical			
	AWS		Defense		Artillery		Aviation		AIR	AMB	CBR	
	K	F	K	F	K	F	K	F	K	F	K	F
Altimeter Setting	AB	AB					A	A	A	A	A	
Ceiling	ABC	ABC			A	A	A	A				
Crosswind (Trajectory)												
Current (River, stream, etc.)									ABC	ABC		
Density Altitude	ABC	ABC										
Depth (Water)									ABC	ABC		
Dew Point	ABC	ABC			A	A	A			A	A	
Electrical Storms	ABC	ABC										
Freeze-Thaw Depth	C	C							C	C		
Ground Albedo	AB	AB										
Humidity	ABC	ABC			A	A	A			A	A	
Ice Thickness	C	C										
Illumination	C	C										
Natural Disaster	A	A										
Obstruction to Vision	ABC	ABC			A	A						
Precipitation (Type, amount, etc.)	ABC	ABC			A		A		A	A	A	
Riverbank Conditions									A	A		
River Stage									ABC	ABC		
Seashore Condition									A	A		
Severe Weather	ABC	ABC										
Sky Cover	ABC	ABC			A	A	A	A				
Snow Depth	ABC	ABC			A	A	A		AC	AC	A	A
Soil Bearing Strength									A	A		
Soil Moisture									A	A		
State of the Ground	AB	AB							A	A		
State of the Sea	AB	AB										
Surface Pressure	ABC	ABC			A	A	A	A	A	A	A	
Surface Temperature	ABC	ABC			A	A	A	A	A	A	A	
Surface Winds/Gusts	ABC	ABC	A	A	A	A	A	A	A	A	A	A
Tide	C	C								A		
Trafficability									A	A		
Visibility	ABC	ABC			A	A	A	A				
Wet-Bulb-Globe-Temperature	AB	AB			A	A						
Wind Chill	ABC	ABC			A	A	A	A				
Water Quality									A	A		

Note: A-Observed, B-Forecast, C-Climatology, K-Current, F-Future Capability.

- d. Task 19-62: Select sites for assault river crossing including trafficability, stream width, depth, and velocity plus seasonal variations.
- e. Task 19-63: Perform an urban analysis including the location and quality of water available.

16. FM 30-10 Military Geographic Intelligence, March 1972. A review of some important hydrologic characteristics and their effect on military operations is summarized below from FM 30-10. A collection checklist for hydrology intelligence is presented as Table 5.

17. Water bodies become obstacles whenever the water becomes deep enough or turbulent enough to threaten the safety or operation of vehicles. Streams, ditches, and canals are linear features and can have an important effect on the cross-country movement. Ponds, lakes, marshes, swamps, and bogs are areal obstacles to movement. Water bodies vary temporally in their characteristics depending on weather and season. Although streams tend to be relatively low and slow during periods of low precipitation and high and rapid during periods of high precipitation, the relationship is not simple.

18. The ease of crossing streams depends on the characteristics of both the vehicles and the drainage features. The significant characteristics of drainage features are width of channel, depth and velocity of water, nature of bottom, and height, slope, and strength of banks. The width of a stream, although important to bridging, is of relatively little significance to ferrying and fording. For fording, the maximum depth of water permissible is between 0.9 and 1.3 metres for most tanks and 0.6 and 0.9 metres for most trucks. Stream velocities should generally be less than 1.5 metres per second for reasonable safe fording. The bottom of stream channels must be firm enough to support the vehicles. Hard, vertical banks will be obstacles to tanks if their height exceeds 1.3 metres and to trucks if their height exceeds 0.3 metre. Reasonably adequate information is commonly available on large streams, but often is not available for small streams.

19. Groundwater is very significant militarily because it is a prime source of water supply. The water table has a profound effect on soil conditions for cross-country movement purposes and

Table 5  
Collection Checklist for Hydrology\*

**WATERSHEDS:**

1. *Identification.* Local name and military designation.
2. *Location.*
  - a. Map reference—Include series and sheet number(s) of both tactical and air-ground series.
  - b. Political unit, area, UTM coordinates, and geographic coordinates.
3. *Area dimensions.*
4. *Surface materials.* Soil and rock type distribution.
5. *Vegetation.* Cross reference to the vegetation collection file.
6. *Precipitation.* Cross reference to climatic summary collection file.
7. *Flooding.* Cross reference to climatic summary collection file.
  - a. Maximum flood history (dates, duration, extent, and effects).
  - b. Periods of high and low water (dates, extent, and effects).
8. *Ice conditions.*
  - a. Freezing and breakup dates (earliest, latest, and mean).
  - b. Extent and depth of frozen surface.
  - c. Bearing capacity of ice.
9. *Hydraulic developments.*
  - a. Location and purpose (flood control, water storage, irrigation).
  - b. Water control structures (dams, locks, canals, dikes, etc).
10. *Main stream.*
  - a. Name and location.
  - b. Length and pattern.
11. *Major tributaries.*
  - a. Names and location.
  - b. Length and pattern (type, texture, and alignment).
  - c. Drainage basins (area, slope, and shape).
12. *Standing bodies of water.* Lakes, reservoirs, snowfields, ponds, etc.
  - a. Name, location, and size (surface area).
  - b. Inlets and outlets.

13. *Glaciers.* Area and boundaries.
14. *Marshes and swamps.* Type and surface area.

**WATERCOURSES AND WATER BODIES:**

1. *Identification* (same as 1 above).
2. *Location* (same as 2 above).
3. *Type.* River, canal, lake, inland sea, glacier, etc.
4. *Pattern.*
5. *Direction of flow.*
6. *Crossings.* Cross reference to appropriate collection file.
7. *Navigability.* Cross reference to inland waterways collection file.
8. *Flooding.* Cross reference to climatic summary collection file.
  - a. Type and causes (normal, flash, or artificial).
  - b. Normal periods and duration.
  - c. Area extent and damage expected.
  - d. Key dams or structures.
  - e. Effects on movement and structures.
9. *Tidal effects.*
  - a. Tides (tidewater extent, variation, and datum).
  - b. Tidal currents (location, direction, velocity, and period).
10. *Banks.*
  - a. Composition and stability.
  - b. Height and slope.
  - c. Condition (eroded, turfed, improved, etc).
11. *Bottom.*
  - a. Composition and stability.
  - b. Occurrence of boulders and unusual conditions (type and location).
12. *Width, representative points.*
  - a. Mean high and low water.
  - b. Periods of occurrence.
13. *Depth, by sectors.* Mean high and low water.
14. *Velocity, at various locations.* Mean high and low water.
15. *Discharge.* Minimum and maximum; by season or month.

(Continued)

\* Source of Data: FM 30-10 Military Geographic Intelligence, March 1962.  
 (Sheet 1 of 3)

Tabel 5 (Continued)

- 16. *Ice conditions.*
  - a. Freezing and breakup dates.
  - b. Extent of frozen surface and load capacity of ice.
  - c. Periods of drift ice and ice jam frequency and location.
- 17. *Nature of adjacent terrain.* Cross reference to appropriate collection file.
- 18. *Special considerations.* Cross currents, undertows, eddies, etc.
- 19. *Formations.* Islands, bars, shoals, rapids, falls, or atolls.
  - a. Location and pattern.
  - b. Area extent and elevation.
  - c. Surface material and vegetation cover.
- 20. *Utilization of water body or watercourse.*
  - a. Water supply.
  - b. Navigation.
  - c. Electric power production.
  - d. Drainage.
  - e. Irrigation.
  - f. Flood control.
  - g. Waste disposal.
- 21. *Channel data.*
  - a. Length and slope.
  - b. Cross section at selected points.
  - c. Profile of bed.
  - d. Depth of bottom material.
  - e. Depth of bank material.
- 22. *Water surface profiles.* High, normal, and low water.
- 23. *Storage dams.*
  - a. Identification and location.
  - b. Purpose (power, water supply, irrigation, flood control, etc).
  - c. Type (fixed, movable, gravity, etc).
  - d. Construction material (earthfill, rockfill, concrete, etc).
  - e. Security and safety features.
  - f. Dam dimensions (height, length, width, and thickness).
  - g. Operating characteristics.
  - h. Outlets (number, type, location, size, shape, length, etc).
  - i. Reservoir characteristics (dimensions, capacity, depth, etc).
  - j. Intake structures (location and type).
- 24. *Conduits.*
  - a. Location, purpose, and type (canal, tunnel, pipe, within dam).
  - b. Alinement and length.
  - c. Related intake structures.
- 25. *Spillways.*
  - a. Location and type (overflow, chute, side-channel, siphon, etc).
  - b. Length, width, and spacing of piers.
  - c. Gates (type, number, width, and height).
- 26. *Hydroelectric plants.* Location and layout.
- 27. *Drainage and irrigation structures.*
  - a. Location and purpose.
  - b. Appurtenant works (canal, ditches, etc).
  - c. Related hydraulic structures (type, dimensions, characteristics).
- 28. *Navigation locks.*
  - a. Location and number of chambers.
  - b. Length and width of chambers.
  - c. Height difference between upstream/downstream levels.
- 29. *Water treatment plants.*
  - a. Location and type of treatment.
  - b. Capacity and source of water.
- 30. *Bank protection works.*
  - a. Location and length of river reach concerned.
  - b. Material and type of construction (retaining walls, groins, etc).
- 31. *Flood protection structures, other than dams.*
  - a. Location and terminal points.
  - b. Age (known or estimated) and condition.
  - c. Flood plain protected.
  - d. Alinement and type (levee, dike, flood wall).
  - e. Construction material (rockfill, masonry, wooden piles, etc).
  - f. Security and safety features.
  - g. Dimensions and elevation of structure.
  - h. Overtopping data (stream depth, discharge, and frequency).
  - i. Outlets (number, size, and characteristics).

(Continued)

(Sheet 2 of 3)

Table 5 (Concluded)

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**WET AREAS:**

1. *Identification.* (Same as 1 above.)
2. *Location.* (Same as 2 above.)
3. *Associated watercourses.*
4. *Seasonal variations in wetness.*
5. *Conditions causing inundation.*
  - a. Stream overflow.
  - b. Flooding by tides.
  - c. Rainfall/run-off imbalance.
  - d. Irrigation.
6. *Type of area.* Swamp, marsh, bog, paddy field.
7. *Transportation crossings.* Cross reference to appropriate collection file.
8. *Flood data.* Frequency, duration, and periods of occurrence.
9. *Water resources.*
  - a. Quantities (by season).
  - b. Quality (contamination, turbidity, taste, odor, color, chemical content, organic matter, dissolved mineral matter, etc).
  - c. Developments aspects (accessibility for intake points, water depth, availability of natural filtration materials, etc).
10. *Ice conditions.*
  - a. Freezing and breakup dates.
  - b. Extent of frozen surface and load capacity of
11. *Animal and vegetable life.* Kind and prevalence.

- i. Rates of drawdown at specified yields.
  - j. Sustained yield (after prolonged pumping).
  - k. Rate of recovery after pumping.
  - l. Effects on yield of nearby wells.
  - m. Quality of water (color, odor, taste, temperature, dissolved solids, bacterial contamination, turbidity, and variation in quality).
5. *Springs.*
- a. Locations and spacing.
  - b. Relation to topography.
  - c. Natural yield and seasonal variations.
  - d. Possible yield after development.
  - e. Method of development.
  - f. Quality of water (color, odor, taste, temperature, dissolved solids, bacterial contamination, turbidity, and variation in quality).

**GROUND WATER:**

1. *Identification.* (Same as 1 above.)
2. *Location.* (Same as 2 above.)
3. *Areal extent.*
4. *Wells.*
  - a. Distribution.
  - b. Relation to topography.
  - c. Characteristics.
  - d. Diameter and depth.
  - e. Casing or lining used (depth).
  - f. Materials and aquifers penetrated.
  - g. Yield of aquifers.
  - h. Static level of water (seasonal variations).

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(Sheet 3 of 3)

construction of underground installations.

20. TB 5-550, January 1968. TB 5-550, Compilation of Intelligence on Military Hydrology, gives guidance on the types of hydrologic information needed for military planning and operations with respect to natural and artificial flooding, river crossing, and water supply. Subjects covered include watersheds, rivers, stream and precipitation gages, bridges, fords, dams, reservoirs, hydroelectric plants, flood protection structures, locks, and irrigation and drainage projects.

21. TM 5-700, July 1967. TM 5-700, Field Water Supply, provides guidance on water quality characteristics, water treatment processes, the establishment and development of water points, use of existing facilities, and contamination of water. Also covered are the basic steps in water purification, field tests, equipment, and establishing and developing water sources under arctic and desert conditions. The importance of an adequate water supply for the health and welfare of the soldier and the conduct of virtually all military operations is stressed. Since water must be palatable and potable as well as available, the Army's supply capability must be highly efficient and mobile.

22. TM 5-235, July 1964. TM 5-235, Special Surveys, gives guidance on conducting hydrographic surveys of the following nature:

- a. Tidal observations.
- b. Streamflow, stream gaging, and equipment.
- c. Measurement of streamflow.
- d. Special hydrographic projects, such as dredging, reservoir capacity, and water resources.
- e. Subaqueous surveys.
- f. Methods of locating and taking soundings, and equipment.
- g. Beach surveys.

23. Military Hydrology Bulletin 1, June 1957. MHB-1, Application of Hydrology in Military Planning and Operations, stresses that hydrologic problems encountered in advance military planning must generally be solved by making hydrologic investigations leading to the determination of streamflow characteristics. A large proportion of hydrologic problems encountered in military operations must be solved by field

investigations to obtain details not available in the planning stage. Since the advent of the atomic bomb, dams formerly believed impregnable to bombing attack may now become formidable weapons of war. A great deal of cognizance, therefore, should be given to the artificial-flooding capabilities of all large dams.

24. In view of the short time usually allowed military personnel to make hydrologic evaluations in the field, it is essential that manuals or handbooks of hydraulic warfare be prepared for their use. Rapid solution of hydrologic and hydraulic problems can be made only if basic data are systematically collected and indexed for quick reference. Military hydrology manuals, featuring short-cut methods and containing aids such as nomographs for determining runoff and streamflow relations, should be available in all field staff headquarters. Manuals containing instructions for operating and servicing hydrographic equipment should also be available to military hydrology units operating in the field. Military personnel assigned to important positions connected with hydraulic warfare operations and flood prediction services should be given advance training to acquaint them with basic procedures used in making hydrologic investigations and with the uses and scope of military hydrology manuals.

25. TB 5-550-1, December 1956. TB 5-550-1, Flood Prediction Services, presents a description of typical conditions under which flood prediction and flood warning services should be established for military purposes; it outlines the organizational arrangements and facilities needed to establish and operate such services under alternate circumstances; and it presents information and instructions of a general nature that would be useful in establishing a military flood prediction service. It also includes a description of equipment for military flood prediction services.

#### Summary of Requirements

26. The data requirements discussed in paragraphs 10-25 cover a broad spectrum that ranges from design of drainage structures for new

facilities to assessment of river-crossing and terrain conditions for planning assault operations. Anticipated future battlefield scenarios stress the need for near-real time acquisition and processing of data to supply information needed to plan offensive and defensive operations. It is this overall requirement that should have priority in the work to develop improved hydrologic capabilities. As such, hydrologic capabilities that are needed for planning and conducting operations in battlefield conditions will be given highest priority.

27. With a limited number of exceptions, the specific "requirements" listed in paragraphs 10-25 can be lumped into the following general categories:

- a. Terrain geometry (channel and terrain surface).
- b. Terrain surface conditions (state of the ground).
- c. Streamflow-water body character.
- d. Water supply.

A significant research effort in developing new methods and tools for acquiring terrain geometry information has been and is currently ongoing at the U. S. Army Engineer Topographic Laboratory (ETL). Thus, this research program need not address these requirements further, except for continued coordination with ETL on developments in their research work. An additional category, "Meteorologic Conditions," is essential because the weather is clearly the initial driving force for most all hydrologic phenomena.

28. The major requirements relevant to this program are, thus, meteorologic conditions, terrain surface conditions, streamflow-water body character (hereafter termed "streamflow"), and water supply. Terrain surface conditions, or state of the ground, are necessary as input for runoff and streamflow forecasts. One item of this category, soil moisture, will be given individual attention in this study. Antecedent soil moisture impacts streamflow through its influence on the amount of precipitation that infiltrates and the rate of infiltration. Soil moisture has a major impact on the movement of forces and suitability of sites for a variety of activities. In addition, it is a very dynamic parameter, which increases the uncertainty of its impact on military

operations unless closely monitored and accurately forecast. On the basis of these criteria, the military hydrologic data requirements of major significance to this study fall into the following categories:

- a. Meteorology.
- b. Soil moisture.
- c. Streamflow.
- d. Water supply.

## PART III: ARMY CAPABILITY

### Army Organization for Hydrologic Data Support

#### Old structure

29. Team II, Military Hydrology. The following description of Military Hydrology Team organization was obtained from FM 1, Engineer Administrative and Headquarters Teams, TOE 05-500G-Series. Team II (Military Hydrology) is capable of predicting river stages and discharges and natural and artificial flood velocities, depths, and widths in a drainage basin with an area up to 100 square miles (259 km<sup>2</sup>); preparing hydrologic analyses of river-crossing sites; and preparing studies of the hydrologic and hydraulic factors involved in military installations. When necessary, the theater commander will provide for the allocation of additional communication facilities and for joint operation of Air Weather Service units, Naval Hydrographic units, and Corps of Engineers units.

30. Normally one team is assigned per field army or independent corps, although a team may be assigned to a geographic area, determined by stream and drainage characteristics.

31. The team is organized into a headquarters and four branches: precipitation, hydraulic surveys, analysis and prediction, and administration and supply.

32. Team II, Terrain. Engineer Topographic and Intelligence Team II (Terrain) described in TOE 05-540H provides for the collection, evaluation, and dissemination of military terrain data; the production of military terrain studies; and for consultant services in military geology and hydrology. The team is 100 percent mobile, and one team is allocated per field army, separate corps, or a force less than a corps for special activities.

#### 319th Engineer Detachment (Terrain-Hydro) USAR

33. The basis for organization of this unit comes from TOE 05-540H Terrain Team II, which is comprised of the following personnel:

<u>Description</u>	<u>Grade</u>	<u>Strength Level</u>
Terrain Intelligence Officer	MAJ	1
Geologist	CPT	1
Hydraulics Engineer	CPT	1
Utilities Engineer	CPT	1
Highway Engineer	CPT	1
Soils Engineer	CPT	1
Intelligence Sergeant	E-8	1
Terrain Intelligence Analyst	E-6	2
Soils Analyst	E-4	1
Cartographic Draftsman	E-4	1
Clerk Typist	E-4	<u>2</u>
	Total	13

34. This TOE has been modified by MTOE 05-540H AR 04 EDATE 770930 specifically for the 319th Engineer Detachment USAR (Engr Det) to give them the designation of (Terrain-Hydro) and extended hydrological capabilities. This has been accomplished with the addition of the following personnel:

<u>Description</u>	<u>Grade</u>	<u>Strength Level</u>
Geologist	CPT	1
Hydraulics Engineer	CPT	1
Civil Engineer	MAJ	1
Topographic Engineer	CPT	1
Meteorologist	1LT	1
Topographic Surveyor	E-6	1
Topographic Surveyor	E-5	1
Topographic Surveyor	E-4	1
Supply Specialist	E-4	<u>1</u>
	Total additional	9
	Total authorized strength	22 (11 officers, 11 enlisted)

35. The 319th Engr Det, as of Aug 77, is staffed with nine officers and eight enlisted persons.<sup>1</sup> All of the officers have college degrees; four have masters' degrees; and one has a doctors' degree. Two enlisted men have college degrees. A total of five of these degrees are in civil engineering. Two officers possess MSCE degrees. In addition, one officer has attended a 1-week course on Hydrology and one officer has attended a 1-week course on HEC-2 Flood Plain Hydraulics, both of

which were conducted at Pennsylvania State University.

36. The 319th Engr Det is authorized a minimum of special equipment for the performance of its mission consisting of the following:

- a. Construction group book set.
- b. Photographic equipment.
- c. Drafting equipment.
- d. Stereoscope.
- e. Soil test set.
- f. Carpenter's tool kit.
- g. Pocket transits.

37. In accordance with FM 5-1, this equipment has been restricted to the transportation, tools, and supplies related to this specialty. In addition, the unit on extended active duty would not be "self-sufficient in such matters as administration, shelter, messing, supply, storage facilities, signal communications, and medical service." Support would be provided by the organization to which it was attached.

Self-appraisal by  
319th Engineer Detachment USAR

38. Experience has shown that the present staff is qualified to accept a variety of hydrologic assignments, as demonstrated by an outstanding performance record for past projects. It must be noted that most past hydrologic experience has been similar to that required for site selection for assault river crossing (Task 19-62, ARTEP 5-335) with little or no experience on the four other hydrologic tasks from that ARTEP identified in paragraph 15. With respect to the general hydrologic problems defined in Military Hydrology Bulletin 1 (para 23-24), this unit currently has little or no on-the-job and/or formal training for dealing with such problems as the production of hydroelectric power, flow through a breached dam, or the establishment of a flood prediction service. In addition, there is minimum knowledge for the location, set up, and operation of precipitation gages or continuously recording water-stage gages. Unit personnel in general have a strong background in science and engineering but are lacking in formal military training and applications of hydrology.

39. A review of the authorized equipment for the 319th reveals numerous deficiencies. Numerous verbal requests have been made through many channels in an attempt to obtain the proper hydrologic equipment for training, home station projects, and Army Training (AT) projects. The unit, consequently, has obtained by hand receipt from various organizations the following items:

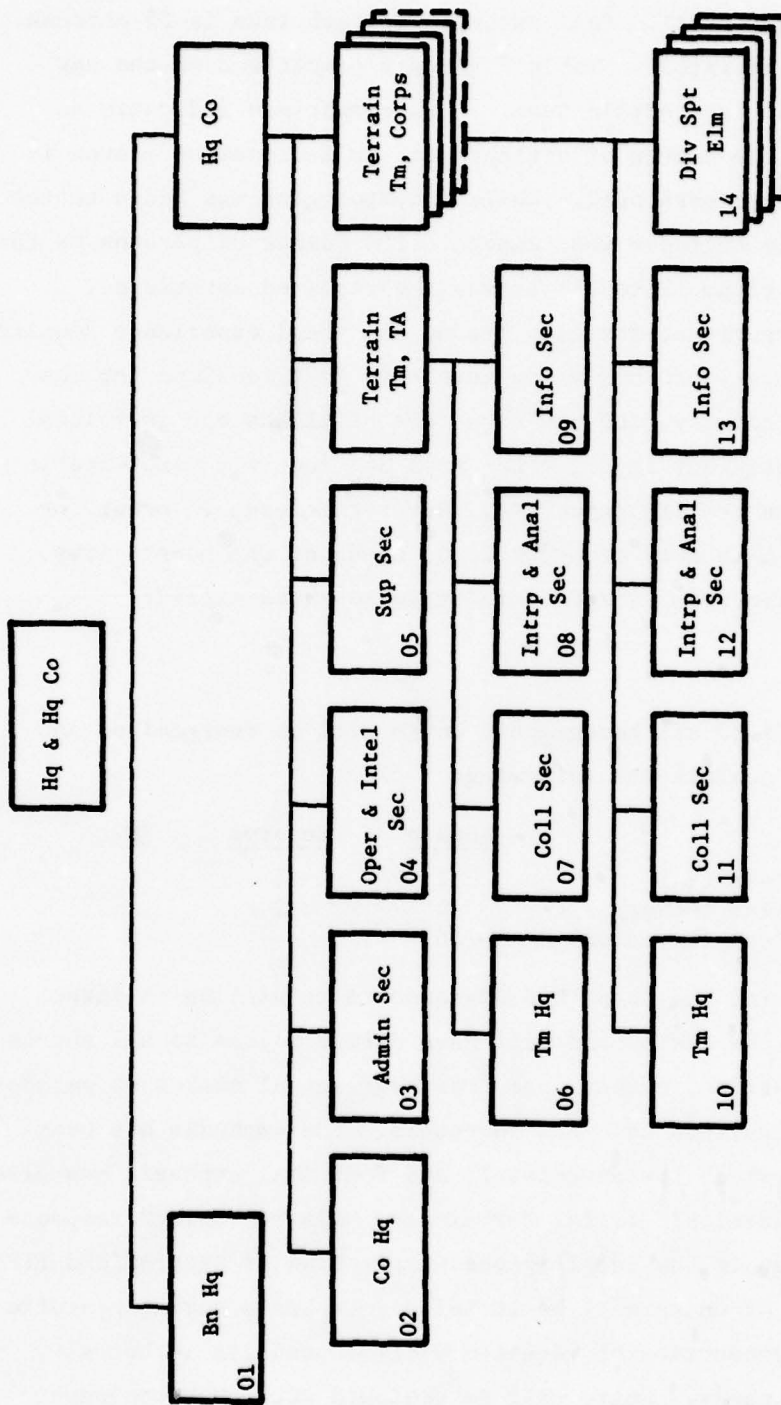
- a. 1 transit.
- b. 1 level rod.
- c. 1 survey set, precision level.
- d. 1 precipitation gage.
- e. 1 pygmy current meter.
- f. 1 Price type A current meter.
- g. 1 staff gage.
- h. 1 automatic water-stage recorder.
- i. 1 reel equipment.

Additional equipment items such as tag lines, explosive ordnance munition devices, sounding equipment, boats, etc., which are necessary for completion of AT projects, are normally obtained from other agencies during active duty training or AT. With the exception of the precipitation gage and stage recording equipment, all of the above items have been used either for home station projects or for AT projects. Experience gained through such use and the continuing assignment of hydrological projects for AT indicate the need for inclusion of this equipment in the MTOE.

40. The review of the 319th identified several important deficiencies of a general nature which could hinder the unit in accomplishing its mission in a theater of operations. These deficiencies are: (a) lack of a hydrologist in the organizational structure of the unit; (b) lack of specialized training in military hydrology; and (c) lack of proper hydrologic equipment.

#### New structure

41. The organizational chart for Headquarters and Headquarters Company, Engineer Topographic Battalion, from TOE 05-336H is given as Figure 1. Headquarters Company includes one terrain team (TA) and



NOTE: [ ] Augmentation. Not included in totals.

Figure 1. Organizational chart for Headquarters and Headquarters Company, Engineer Topographic Battalion, Theater Army

three terrain teams (Corps). Full strength of each team is 25 persons (7 officers and 18 enlisted). Table 6 gives a comparison of the new and old structure of the terrain team. This comparison indicates an increase of one in the number of officers and an increase of eleven in the number of enlisted personnel. While a hydrologist was added to the staff, the hydraulic engineer was removed. The number of persons on the team was increased (from 13 to 25) as was the required experience. Based on average experience for each grade, the total experience required for the new structure is 20 man-years more than that required for the old structure. In summary, the new structure still has one individual designated as a specialist in the water area and requires more experienced personnel than the old structure. Never-the-less, in order for the new terrain team to meet the hydrologic needs of the modern Army, the team will require specialized training in advanced military hydrology.

Future structure

42. During FY 80 all topographic units will be reorganized and the structure will contain the following:

	<u>Active</u>	<u>Reserve</u>	<u>NG</u>
Terrain Team (TA)	1	1	1
Terrain Team (Corps)	4	2	
Terrain Team (Division)	16		8

Under the new doctrine the Corps and division teams will be in direct support working in the CEWIOC and will have direct access to all source intelligence. Expertise, numbers per team, and actual number of personnel in the force structure have all increased. The emphasis has been put on direct support at the user level, and doctrinal emphasis has also changed from the classical, formal terrain analysis to "quick" response products in response to the Intelligence Preparation of Battlefield (IPB) concept. Missions of units will be to build data bases during peacetime to facilitate the production of required wartime products in hours instead of days or weeks. Units will be equipped with the Topographic Support System (TSS) Modules beginning second quarter FY 82.

Table 6

Comparison of New and Old Structures of Army Terrain Team

	A. Comparison by Job Description		
	Number of People		
	<u>New*</u>	<u>Old**</u>	<u>Change</u>
1. Officers (subtotal)	7	6	+1
<u>a.</u> Terrain, topo and soils			+3
(1) Terrain intel analyst	3	0	
(2) Topo engr	2	0	
(3) Geologist	1	1	
(4) Soils engr	0	1	
(5) Terrain intel officer	0	1	
<u>b.</u> Water			0
(1) Hydraulic engineer	0	1	
(2) Meteorologist	0	0	
(3) Hydrologist	1	0	
<u>c.</u> Other			-2
(1) Utilities engineer	0	1	
(2) Highway engineer	0	1	
(3) Civil engineer	0	0	
2. Enlisted (subtotal)	18	7	+11
<u>a.</u> Terrain			+5
(1) Terrain intel analyst	3	0	
(2) Surveyors	2	0	
(3) Soils analyst	1	0	
(4) Cartographic specialist	2	0	
(5) Terrain analyst	0	2	
(6) Cartographic drafter	0	1	
<u>b.</u> Other			+6
(1) Civil engr assistant	4	0	
(2) Physical science assistant	2	0	
(3) Supply specialist	0	0	
(4) Intelligence sgt	0	1	
(5) Operations sgt	1	0	
(6) Clerk typist	3	2	
(7) Material qual specialist	0	1	

Total change in manpower = +12 people

(Continued)

\* From TOE 05-540H 3IJ.

\*\* From TOE 05-540H 3II.

Table 6 (Concluded)

<u>B. Comparison of Experience</u>					
	<u>No. of Positions</u>			<u>Average</u>	<u>Change</u>
	<u>New</u>	<u>Old</u>	<u>Change</u>	<u>Experience</u>	<u>Man-Years</u>
				<u>Years</u>	<u>Experience</u>
1. Officers					-1
MAJOR	1	1	0	13	0
CPT	4	5	-1	7	-7
1st LT	0	0	0	1	0
2nd LT	2	0	+2	3	+6
2. Enlisted					+21
E-8	0	1	-1	15	-15
E-7	1	0	+1	10	+10
E-6	2	2	0	5	0
E-5	5	0	+5	3	+15
E-4	5	2	+3	2	+6
E-3	5	2	+3	1	+5

Total change in experience requirement = +20 man-years

### Current Procedures

43. Current procedures used by the Army to provide hydrology support for military operations are discussed in this section. Available military manuals were reviewed to provide the basis for this evaluation. The following manuals were examined:

<u>Title</u>	<u>Manual No.</u>	<u>Date</u>
Flood Prediction Service	TB 5-550-1	December 1956
Applications of Hydrology in Military Planning and Operations	MHB-1	June 1957
Flood Prediction Techniques	TB 5-550-3	February 1957
Compilation of Intelligence on Military Hydrology	TB 5-550-2	January 1958
Water Supply Water Sources	TM 5-813-2	July 1965
Field Water Supply	TM 5-700	July 1967
Engineer Intelligence	FM 5-30	September 1967
Weather Support for Field Army Tactical Operations	FM 31-3	December 1969
Military Geographic Intelligence (Terrain)	FM 30-10	March 1972

44. Basic hydrologic procedures described in these manuals were developed in the late 1930's as a result of the national flood control effort. These procedures have been in general use by the engineering community in the United States and have remained basically unchanged until the late 1950's when computer models were first introduced. The manuals do not reflect advances in runoff estimating procedures developed in the 1960's, hydrologic simulation models developed in the 1960's and 1970's, nor remote sensing procedures for hydrologic data acquisition developed in the 1970's. Primarily as a result of the watershed management requirements of recent Federal legislation, digital hydrologic simulation models are now in general use by the engineering consulting firms and governmental agencies. Modern hydrologic methodologies in common usage by the engineering community have not been adopted by the military. Because of military constraints, short-term capability update research is required to apply modern civilian hydrological methodologies to military problems.

45. The hydrological prediction capability currently resides in

the terrain analysis teams. Due to the nature of the data products required, this capability should be developed to provide responsive information on hydrology and soil trafficability. It is anticipated that access to computer facilities will be an essential part of the prediction process. The Army is developing a Worldwide Military Command and Communication System which will have a large computational capability available at Corps level. This capacity will be necessary for a combined remote sensing data collection and processing program interfaced with a streamflow prediction model. The use of remote sensing as a means for obtaining hydrologic data must be supplemented by ground-truth information by the terrain analysis teams.

#### Summary

46. The evaluation of the Army's hydrologic capability revealed the following:

- a. Absence of modern methodologies.
- b. Inadequate resources.
- c. Lack of training.

Basic hydrologic procedures presently utilized by the Army were developed in the 1930's and adapted to military application during World War II. A review of available military manuals indicated that modern hydrologic procedures in common usage by the engineering community have not been adopted by the military.

47. The self-appraisal by the 319th Engr Det revealed deficiencies in training and equipment. Even with the recent changes in the TOE, resources are not adequate to meet the needs of a modern Army. The application of remote sensing technology, computer processing procedures, and advanced modeling methods is essential to provide hydrologic information in a tactical time frame.

48. The development of methods to transfer hydrologic technology to the user is an essential part of this project.

PART IV: MEASUREMENT AND FORECASTING,  
A STATE-OF-THE-ART ASSESSMENT

Introduction

49. The amount of runoff from a storm depends on both watershed characteristics--such as size and shape of drainage area, soils, slope, vegetation, and soil moisture--and storm characteristics--such as direction of storm and rainfall amount, intensity, and duration. Hydrologic parameters will vary throughout the watershed and most will vary with time. Topography and soils remain basically unchanged with time, while land cover will vary at least seasonally. Variations in meteorological parameters occur both spacially and temporally, making direct measurement difficult and accurate forecasting at a local level nearly impossible. Because of the time delay in response of the watershed, direct measurement of precipitation permits limited forecasting of streamflow.

50. Unattended data-collection stations can be established in the basin and the data transmitted to a central receiving site for processing. Parameters suitable for measuring are air and soil temperatures, evaporation, humidity, wind speed and direction, precipitation, snow depth, soil moisture, water depth, and water velocity.

51. The following paragraphs discuss the current technology available to address the above phenomena. The discussion is divided into meteorology, soil moisture, streamflow, and water supply. Most of the information for this section was obtained from three contract studies conducted for the project. These are:

- a. "An Evaluation of Existing Capabilities for the Measurement and Forecasting of Selected Weather Variables (Emphasizing Remote Means)," by H. H. Monahan and R. M. Cionco of the Atmospheric Science Laboratory, White Sands Missile Range.<sup>2</sup>
- b. "Existing Capabilities for Measurement and Forecasting of Soil Moisture by Remote Means," by D. D. Evans, S. S. Hostetler, and L. P. Onyskow, Department of Hydrology and Water Resources, University of Arizona.<sup>3</sup>

- c. "Measurement and Forecasting of Streamflow by Remote Means," by A. F. Pabst and R. J. Cermak of the U. S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, California.<sup>4</sup>

## Meteorology

### Measurement

52. Remote and direct measurements of meteorological parameters are discussed in this section. Remote sensing is applicable to meteorological measurement because it combines reasonably accurate data with spacial and temporal resolution over a large volume of the atmosphere. Limitations to remote sensing include: (a) most optical and infrared (IR) measurement systems have greatly reduced measurement capabilities in fog, cloud, or precipitation; (b) some radar systems require the presence of precipitation or chaff to provide echoing targets; and (c) acoustic systems are usually adversely affected by the impact noise produced by rain or hail.

53. Direct wind-speed measurements can be made by several types of anemometers such as the cup, propeller, or pressure-tube. In addition, a ground-based remote sensing capability exists for wind velocity field, primarily because of the availability of a wide range of Doppler techniques. All-weather wind profiling capability is attainable in the boundary layer, with prospects good for all-weather profiling to tropospheric heights, using some combination of microwave and IR-Doppler systems.<sup>2</sup> The geostationary satellite can provide information on winds in remote ocean areas by monitoring cloud motion.

54. In 1974 a dropwindsonde was used in field operations for the first time. Deployed from an aircraft flying at about 10 km, the dropwindsonde transmitted vertical profiles of horizontal winds, pressure, temperature, and humidity. The sonde has four sensors, including a windfinder, an improved aneroid cell, a bead thermistor, and a carbon hygrometer. Windfinding is accomplished by Omega navigation signals received and retransmitted by sonde to the aircraft.<sup>2</sup>

55. Direct measurement of air temperature can be made by mercury

thermometers, electrical-resistance thermometers, thermocouples, gas-bulb thermometers, or other types of instruments. Horizontal temperature gradients are generally small, while vertical temperature gradients can be significant. A relatively new technique for remote measurement of temperature in the lower atmosphere employs the Radio Acoustic Sounding System. A burst of sound propagating upward in the air is tracked by Doppler radar. Air temperature at each height is determined from the instantaneous speed of the sound pulse and a complete profile can be obtained in a few seconds.<sup>2</sup> Acoustic systems are usually adversely affected by the impact noise produced by rain or hail.

56. Measurement of humidity is one of the least accurate instrumental procedures in meteorology.<sup>5</sup> Humidity measuring instruments include psychrometer, hair hygrometer, dew-cell hygrometer, spectral hygrometer, and carbon hygrometer. The measurement of atmospheric water vapor using Raman backscatter from a pulsed laser is feasible, and deriving humidity profiles from backscatter of acoustic radar signals may be possible. Humidity profiles have been determined by lidar measurements within and adjacent to a water vapor absorption line.

57. Three types of direct recording precipitation gages in common use are the tipping bucket, weighing gage, and float gage. In addition, the Workman intensity gage, which senses the flow of water down a movable trough, and the Raymond-Wilson gage, which measures the electrical resistance of flowing water, have the capacity to measure high intensity showers.

58. Lidar has been explored as a means of determining rainfall rate over an extended atmospheric path. A laser rain gage measures precipitation by scattering of light by raindrops.

59. A radar precipitation measuring system was developed in the mid-1960's. Special equipment automatically measures the returned power for incremental areas and converts it to equivalent rainfall rates. The rates are then integrated with respect to time. Radar measurements of rainfall are generally within one half to twice the gage measurements within a 110-km range with larger deviations for longer distances. Since measurements by ordinary gage networks may be appreciably in error

as a result of inadequate sampling, and since radar can detect and estimate precipitation between gages in a network, conjunctive use of radar and gage network should yield more accurate measurements than can be obtained from either one alone.<sup>5</sup>

60. Recent developments in electronics and data processing have simplified the task of obtaining quantitative data for estimating meteorological parameters. Digital radar offers advantages for processing rainfall data.

61. A scheme for estimating convective rainfall from Geostationary Operational Environmental Satellite imagery is described by Scofield and Oliver.<sup>6</sup> The scheme is based on the rate of expansion of the coldest contour displayed on the enhanced IR pictures. The greater the expansion rate, the greater the rainfall to be expected. Forecasters were able to estimate rainfall amounts using this procedure for several thunderstorms over portions of southwest Texas in June 1977. Estimates were within 10 to 20 percent of the maximum rainfall.<sup>7</sup>

62. Measurement of depth of snow can be accomplished with a measuring stick, snow stakes, and aerial snow depth markers. The water equivalent of the snow can be determined with a snow tube, a pressure pillow, or a nuclear-radiation snow gage. Since gamma emissions from the soil are attenuated by the snow, areal measurements of the snow cover water equivalent can be made from an aircraft. Gamma spectral data corrected for soil moisture, background radiation, altitude, and air density yield areal values of water equivalent, accurate within 1.2 cm.<sup>5</sup> Visible and near-visible satellite sensors can be utilized to determine the areal extent of snow; however, they cannot be used to detect snow under clouds or forest canopies. Side-looking radar with wavelengths of 1 cm or less can provide comprehensive information on snow cover.

63. The National Oceanographic and Atmospheric Administration (NOAA) National Environmental Satellite Service produced weekly snow and ice cover charts of the Northern Hemisphere based on satellite data from 1966 to 1976. NOAA in 1976 reported that satellite-derived areal snow cover maps of 20 river basins are being produced on an operational basis

and disseminated to user agencies within 24 hr of a satellite pass over the watershed.<sup>8</sup>

64. In a study by McGinnis et al.,<sup>9</sup> snow depth measurements were closely related to scene brightness as measured from the NOAA Z satellite. The brightness was a function of depth up to a depth of 30 cm and constant above 30 cm. The relationship between snow depth and brightness would depend on land cover and other factors.

#### Forecasting

65. Meteorological satellites provide the capability for complete global weather observations. Visible and IR images from polar-orbiting satellites provide day and night surveillance of weather systems over the entire earth. Spatial and temporal variations in cloud cover can be monitored from satellite platforms.

66. Numerical weather prediction and satellite meteorology have resulted in significant progress in forecasting synoptic-scale weather features. The accuracy of the forecast up to 72 hr depends largely on the type of weather regime existing at the time the forecast is prepared. In general, it is very difficult to issue detailed forecasts beyond 48 hr. Recent improvements in forecasting for periods from 12 to 48 hr should continue.<sup>2</sup>

67. In general, synoptic-scale data lack the detail required to be applied to Army division and lower unit operations. Mesometeorology includes the study of local effects having characteristic horizontal dimensions of 1 to 100 km. Mesoscale dimensions coincide roughly to the scale of the battle area.<sup>10</sup> Progress in accurately forecasting precipitation and other small-scale weather elements has been very limited in the last 10 to 15 years.<sup>2</sup> Data and time constraints plus mathematical and theoretical limitations make accurate small-scale predictive modeling of weather nearly impossible under most conditions.

68. Statistical procedures are being developed to forecast precipitation. A stochastic model has been developed to determine the cumulative distribution function of the total rainfall per event for the various seasons. One- and four-minute precipitation rate records have also been used to develop stochastic model relations between clock

hours and precipitation rate distributions.<sup>2</sup>

#### Weather modification

69. Weather modification activities include attempts to alter precipitation, hail, lightning, fog, frost, and radiation. Cloud seeding with either dry ice or silver iodide is usually done to either dissipate clouds or stimulate precipitation. Methodologies for dissipating fog have been proven effective. However, evaluating modification techniques for other weather parameters has proven difficult and uncertain.

70. Potentially, weather modification activities could have great impact on either a meso- or synoptic-scale, either defensively or offensively. As examples, soil trafficability could be improved or degraded drastically by, respectively, preventing precipitation or causing it to increase markedly over what would normally occur; or air to ground or ground to ground visibility could be altered by inducing or dissipating fog. Considerable research needs to be conducted on weather modification; efforts will almost certainly be of a long-term nature.

#### Soil Moisture

71. Soil moisture was identified by the hydrologists in the NOAA River Forecast Center at Kansas City as the parameter that consistently causes the greatest trouble in river level forecasting.<sup>11</sup> Saturated soils will absorb little rainfall while dry soils will generally absorb a great deal of rainfall. Point sampling methods of soil moisture generally cannot provide synoptic coverage. Passive and active microwave and thermal IR have the potential for soil moisture assessment over large areas.

72. In the following paragraphs, several important factors affecting soil moisture (soil type, soil cover and land use, evapotranspiration, and infiltration) are discussed in addition to soil moisture.

#### Measurement

73. Soil type. Hydrologic properties of a soil or a group of soils are an essential factor in the hydrologic analysis of watershed data. Soils can be classified according to their hydrologic properties

if considered independently of watershed slope and cover. Four major soil groups are recognized by the Soil Conservation Service (SCS) curve number procedure for estimating runoff.

74. Aerial photographic interpretation of soils was developed to a relatively high state of the art after World War II. Drainage patterns, topography, photo tones, erosional characteristics, gully features, vegetation, and land-use elements are used to identify and interpret landforms.<sup>12</sup> Generally, boundaries of areas having similar air photo pattern elements are drawn on the photos and the pattern elements for each area interpreted. Hypotheses are formulated concerning basic geomorphic structures and inferences made concerning the soils. Many of the data handling procedures can be automated; however, it is doubtful that the interpretation procedure can be computerized.

75. Soil cover. While soil cover is relatively unimportant for major floods, it has considerable influence on the amount of runoff from smaller storms. Interception-storage capacity of the vegetal cover is usually satisfied early in the storm. In addition, vegetation increases infiltration compared to barren soil because it retards surface flow; the root systems make soil more pervious and the foliage shields the soil from raindrop impact.

76. Evapotranspiration. Although the amount of evapotranspiration is small during a rain, it must be considered in the soil moisture model. The amount of water that leaves the watershed through evapotranspiration is very significant over time. The rate of evaporation is influenced by solar radiation, air temperature, vapor pressure, wind, and perhaps atmospheric pressure. Transpiration is basically a process by which water is evaporated from the air spaces in plant leaves and is controlled essentially by the same factors that influence evaporation. In addition, transpiration is affected to some degree by the characteristics of the vegetation. The hydrologist is primarily interested in the combined evaporation and transpiration. The three basic methods of estimating evapotranspiration are theoretical (based on physics of the process), analytical (based on energy or water budgets), and empirical. A number of evapotranspiration models are available. The

adequacy of the various models depends on how accurately several terms can be measured or estimated, and those models generally accepted for civilian application may not be the most applicable for military hydrology.

77. Infiltration. Infiltration is the flow of water into the ground through the soil surface. It can affect not only the magnitude but also the distribution of the surface runoff. The infiltration rate is influenced by such factors as vegetation, temperature, rainfall intensity, and properties of the soil and soil surface. Numerous investigators have studied the process, and numerous empirical equations for infiltration have been proposed. The equation selected for military hydrology should be compatible with the available data.

78. Holtan's infiltration equation relates infiltration rate to vegetative cover, soil moisture capacity, final infiltration rate, and cumulative infiltration. It includes parameters which are physically related to the infiltration process and are potentially remotely measurable characteristics of the basin.

79. Measurement constraints. For both trafficability and structure placement, soil moisture constraints are most likely at either high or low moisture contents and probably not for the intermediate range.<sup>3</sup> Penetrability, slipperiness, and stickiness constraints may occur when the soil is wet, while dust and soil looseness constraints may exist when the soil is dry.

80. The relation between precipitation and runoff is influenced by several factors including soil moisture. The quantity of runoff from a storm depends on the moisture conditions of the watershed at the onset of the storm and the storm characteristics. Water accounting techniques applied on a daily basis are often used to estimate soil moisture deficiency.

81. Measurement methods. Several in situ soil moisture measurement methods are briefly discussed in the following paragraphs:

- a. Gravimetric methods. The change in weight of a sample before and after treatment to remove the water is the standard and most direct method for measuring water

content, but its application to field conditions is limited.

- b. Lysimeter methods. Water content is determined by weighing a mass of soil in the field, using a suitable permanently installed apparatus.
- c. Nuclear methods. A radioactive source is placed in the soil, and the emission is absorbed or modified by any water held in the soil. Calibration of the detector unit permits an interpretation of radiation in terms of moisture (for example, fast neutrons from a radium-beryllium source are changed by the hydrogen in soil water to slow neutrons, which are then counted).
- d. Penetrometer methods. The resistance of a soil to penetration of a calibrated probe is correlated with water content.
- e. Tension methods. The tension with which water is held in a soil increases with decreasing moisture content. Water is drawn into the soil through a porous medium, creating a partial vacuum in the water reservoir.
- f. Thermal methods. The heat conductivity and specific heat of a soil increase with moisture content.
- g. Chemical methods. Moisture determinations are made either by the results of a reaction between a substance and the water in the soil sample (for example,  $\text{CaC}_2$  reacts with  $\text{H}_2\text{O}$  to form  $\text{C}_2\text{H}_2$ , and the pressure of gas produced or the loss of weight of the escaped gas is a measure of water content) or by the dilution of a substance by water (for example, changes in the specific gravity of alcohol as the result of dilution by the water in the soil sample).
- h. Electrical methods. The resistance and/or capacitance between electrodes in the soil or in a porous medium placed in the soil changes with water content. The amount of water is determined by means of previously prepared calibrations.

82. Soil moisture differences at or very near the soil surface can be detected remotely; however, in addition to water content, other soil characteristics influence reflection and emission for all spectral ranges. Several approaches to remote sensing of soil moisture are discussed in the following paragraphs:

- a. Albedo. Since wet soils are usually darker than dry soils, percent reflection from soil can be used as an indication of surface moisture. The method is limited to bare soils or areas with sparse vegetation. The color of

the bare soil for dry and saturated conditions at selected points throughout the basin would be required before this method could be applied to quantitatively estimate soil moisture.

- b. Plant stress. When vegetation becomes very dry it turns brown. The reflectance changes in plant cover can be used to indicate soil moisture. The main advantages in using plants as an indicator of soil moisture are that the results are integrated throughout the root zone and soil may not be visible through the plant cover. The method is most sensitive as the soil moisture approaches the wilting point.<sup>3</sup>
- c. Soil temperature. As water becomes limited for soil evaporation and plant transpiration, the temperature of the vegetation and soil increases. The diurnal soil temperature range and the maximum soil surface temperature minus the maximum air temperature have been used in studies as indicators of soil moisture. The soil surface temperature regime is influenced by soil moisture conditions to some effective depth. A good correlation has been found for an average water content in the top 5 to 9 cm.<sup>3</sup> The daily solar heating depth can extend to about 75 cm and a moisture-energy soil model would be required to evaluate the relation between temperature and soil moisture.
- d. Microwave. Owing to the difference in the dielectric constant of water, which may be as much as 80 at microwave frequencies, and dry soil, which is typically less than 5, the amount of moisture contained in a given soil can greatly affect its dielectric properties. Resulting emissivities for a bare smooth field may range from 0.5 for a wet soil to greater than 0.9 for a dry soil. It is these variations which are basically responsible for the differences in tone between wet and dry fields which appear on passive microwave images.<sup>12</sup> Microwave methods of estimating soil moisture have several advantages over methods using shorter wavelength radiation. Microwaves are not influenced as much by cloud cover, vegetation, or surface roughness and they reflect soil-moisture conditions to a greater depth. It has been shown that uniform vegetation up to 1.25 m tall has a minimal effect on the response of 1.4 GHz emission to soil moisture and that soil-moisture measurements are accurate to about  $\pm 5$  percent moisture at an 80 percent confidence level.<sup>13</sup> While remote sensing methodology for soil moisture is just being developed, it appears that a reasonably accurate microwave system should be available in the near future.

### Forecasting

83. Reasonably accurate estimation or forecasting of soil moisture requires data input from several sources. The major types of input are hydrometeorologic, process, and physical data. Precipitation on the watershed, together with physical characteristics and equations representing physical processes, controls the response of the system. Soil-moisture accounting models attempt to complete the land phase of the hydrologic cycle: surface detention and runoff, evapotranspiration, interception, infiltration, interflow, percolation, and groundwater. When a model is used to simulate the processes, it produces output which can be compared with soil-moisture measurement obtained by remote sensing. Magnitude of the process parameters can be adjusted so that the model output agrees with the measured soil moisture.

84. The soil-moisture model forms an integral part of most continuous watershed simulation models used to forecast streamflow.<sup>14</sup> There are several dozen soil-moisture models in use. A number of models will provide an estimate of the soil moisture for several layers. The major limitation of existing models to military application is the large number of parameters that must be evaluated. These models were developed without consideration for military limitations and were not designed to take advantage of new remote sensing technology.

### Streamflow

#### Measurement

85. Water stage. Direct measurement of water surface elevation can be accomplished with several devices including a staff gage, wire-weight gage, and continuous recording float gage. Pressure sensing gages are often used in oceanography with a radio transmitter in a surface buoy and could probably be adapted for military hydrology purposes. Repetitive oblique photography of a bridge pier or a vertical pile could be used to monitor river stage provided adequate control points are in the photography.

86. If the stage is to be used for estimating river discharge,

then the gage should be located at a point in the stream where there is a relatively consistent relation between stage and discharge. When controlling features are situated in a short length of channel, a section control exists. If the stage-discharge relation is governed by slope, size, and roughness of channel over a long distance, a channel control exists.

87. Discharge. The gate settings on a dam can be calibrated and used to estimate discharge from the spillway, sluiceway, and turbine gates. On small streams, flow measurement can be made with weirs or flumes. Bridges and culverts can also be utilized to estimate the flow. Where such controls are unavailable, stream gaging procedures can be employed. A method often used in water quality studies is to meter a tracer into the stream and measure the resulting concentration downstream after the tracer is completely mixed in the stream.

88. Several ultrasonic systems for river gaging are now in operation but all of them use the same basic theory. The basic principle is to measure the velocity of flow in the channel by simultaneously transmitting sound pulses through the water from transducers located in the banks on either side of the river. The transducers are not located directly opposite each other but are staggered so that the angle between the pulse path and the direction of flow is between 30 and 60 degrees. The difference between the time of travel of the pulses crossing the river in an upstream direction and those traveling downstream is directly related to the average velocity at the depth of the transducers. This velocity can be related to the average velocity of flow in the whole cross section. By incorporating an area factor in the electronic processor, the system will give river discharge.<sup>15</sup>

89. For large streams the moving boat method could be used. The boat is equipped with a specially designed component current meter which indicates an instantaneous velocity. The measurement is made by traversing the stream along a preselected path normal to the flow. During the traverse a fathometer records the geometry of the cross section and the current meter measures the combined stream and boat velocities. In addition the angle between the vane on the current meter and the course

of the boat is observed and recorded.<sup>15</sup>

90. Electromagnetic gaging stations have been used in Great Britain. The basic principle of this method is the Faraday generator effect where an electrical conductor in motion in a magnetic field induces electrical potential. In the case of the river, the conductor is the flowing water and the electrical potential induced in probes embedded in the banks and bottom is proportional to the average velocity of flow. The accuracy of the electromagnetic station is generally expected to be as good as a current meter station.<sup>15</sup>

91. Velocity. Since velocity in a stream varies both vertically and transversely, accurate discharge measurements usually require several velocity measurements. The variation of the vertical velocity profile is generally such that the mean velocity for a section can be represented as the average of the velocities at two tenths and eight tenths depth below the surface, approximately as the velocity at six tenths depth below the surface, or roughly as 85 percent of the surface velocity. While there are a large number of different types of current meters used to measure water velocity, the Price meter is probably the most commonly used meter in the United States for hydrologic purposes. Electromagnetic current meters are commonly used in the ocean environment. Surface currents can be measured photogrammetrically by time-lapse aerial photography of a floating object.

92. The U. S. Army ETL is developing an optical current meter. Test models of both vertical and slant range optical sensors are being built and tested.

93. Stream gaging will be required to evaluate watershed parameters and to validate models. Since it will continue to be an important aspect of military hydrology, research is required to improve stream gaging methodology and instrumentation. Air droppable sensors capable of taking and relaying stream depth and velocity measurements might have potential application. However, measurements are very sensitive to location along the stream and position in the cross section, and the system would have to be calibrated in place for accurate gaging.

94. Conveyance. Information on the channel cross section is

necessary for forecasting stream stage and velocity. Several procedures are commonly used to measure channel cross sections. Hydrologic stations are often located at bridges, and soundings can be made with a lead line from the bridge. Where a fixed platform across the stream is unavailable, soundings can be obtained from a boat to determine the wetted cross section of the channel. Because floodwaters are generally very turbid, aerial remote sensing has limited application for water-depth measurement in streams. The cross section above the water level can be determined by ground survey procedures, or, if the ground cover is not too dense, by photogrammetry.

95. The U. S. Geological Survey (USGS) is developing a laser altimeter system for aerial profiling of terrain to define the stream cross sections.<sup>16</sup> The system incorporates both an inertial subsystem for navigation and a laser subsystem for altitude. The first prototype system is scheduled for testing in 1980 and is to have a precision of measurement of  $\pm 15$  cm in altitude and  $\pm 3$  m in geographical location. The system will not penetrate water and profiles should be measured during low water stage. Since the surface of the vegetation will be profiled, the output from the system will probably require interpretation in order to delineate the ground profile. This system has a high potential for application to military hydrology. Not only can the stream cross section above the water be defined, but by comparing cross sections several miles apart, the longitudinal slope of the stream can be estimated.

96. One of the more common equations for computing uniform flow in an open channel is:

$$Q = \frac{AR^{2/3}S^{1/2}}{n} = KS^{1/2} \quad (1)$$

where

- Q = flow in cubic metres per second
- A = cross-sectional area in square metres
- R = hydraulic radius in metres
- S = longitudinal slope of channel

n = Manning's roughness coefficient

K = conveyance of the channel

Manning's roughness coefficient  $n$  is not constant for a stream and varies with surface roughness, channel vegetation, silting and scouring, channel irregularity and alignment, and water stage and discharge. Because of the seasonal growth of vegetation in the channel or on the banks, the value of  $n$  may increase in the growing season and diminish in the dormant season. Tables of typical  $n$  values for channels of various types are available as well as photos of typical channels whose roughness coefficients are known.<sup>17</sup> In order to exercise sound judgment, the hydrologist should have a basic understanding of factors affecting the value of  $n$  and experience in computing  $n$  values from stage, discharge, and channel data.

#### Forecasting

97. Hydrologic modeling. Depending on the size of the basin, rain on the watershed may require several hours or several days before it affects the stage at a particular point in the stream. Thus, real-time monitoring of precipitation will allow limited forecasting of streamflow. Several hydrologic models are available which were developed to estimate streamflow for various watershed and meteorological conditions.<sup>14</sup> Two general types of models are the continuous streamflow simulation models and the precipitation-runoff event simulation models. Given enough parameters, almost any program can be fitted to watershed data to reproduce the historic flow record, but extrapolation beyond the range of historic record or transfer to another watershed may be seriously in error unless the program realistically describes the hydrologic process.

98. The precipitation-runoff event simulation models are generally used to estimate the design discharges such as the 25-, 50-, or 100-year return period flow. The output from event simulation models generally includes streamflow hydrographs (streamflow vs time) for various points throughout the watershed. Lumped parameter approaches, such as the unit hydrograph methods, are generally incorporated in this type of model even though a good opportunity exists to use distributed parameter approaches (spatial variations in parameters throughout the watershed

are considered).<sup>18</sup> Since event simulation models are generally used for major storms when vegetation, land use, and soil moisture are of relatively minor importance, existing models may not adequately describe minor runoff events.

99. Continuous simulation models are normally applied to systems that are operated for a period representing many years of streamflow, usually for planning purposes. Because of the large number of parameters to be evaluated, several years of streamflow and rainfall records are generally required for model calibration.

100. Simulation models for forecasting are used to produce flows for from a few hours to several days in advance, and the forecast is periodically updated. While the basic logic of the simulation programs can be identical, the model used for forecasting should have somewhat different operating characteristics from the ones used for planning or design purposes.

101. Several methods of determining runoff volume, time distribution of runoff, and channel routing are summarized in Table 7 along with the data required for calibration of each method. Those methods which require more data based on the physical characteristics of the basin and less data on historic information are probably most applicable to military hydrology. Data requirements for the hydrology study should parallel the requirements for the terrain analysis where possible.

102. The SCS curve number procedure for estimating direct runoff from rainfall appears to give fairly reasonable results for a wide range of conditions. The method was developed for use with ungaged watersheds and model parameters are related to physical characteristics of the terrain.

103. Land use and land cover. Land-use and land-cover information probably plays a more important roll in military hydrology application than it does in civilian applications. Hydrologic engineering design studies are usually conducted for extreme events where the land cover and land use have only a minor effect on the volume of runoff. Most military applications are concerned with the size of floods that can be expected during a short-duration operation. Short-return period

Table 7  
Streamflow Forecasting Methods and Data Requirements\*

Computation	Method	Data Required for Calibration
Runoff volume	Rainfall-runoff relation (Antecedent Precipitation Index)	Precipitation amount and duration, streamflow hydrograph, antecedent rainfall, and day of the week (all historical events)
	(Soil Conservation Service)	Antecedent precipitation, soil type, vegetative cover, land use
	Loss rate function (HEC-1)	Precipitation and streamflow for at least one historical event
	(Holtan's equation)	Vegetative cover, soil moisture capacity, steady-state infiltration rate (determined from historical rainfall-runoff data)
	Soil moisture accounting (Hydrocomp Simulation Program)	Normal annual rainfall, impervious area, vegetative cover (type and density), concurrent precipitation and streamflow hydrographs
Time distribution of runoff	Unitgraph	Precipitation and streamflow hydrograph for one or more historical events
	Isochrone	Time of travel data
	Overland flow routing	Length, slope, roughness of land
Channel routing	Hydrologic	Channel and floodplain cross sections, slope, historical discharge hydrographs, rating curves
	Hydraulic	Channel and floodplain cross sections, slope, roughness, rating curves

\* Source: Reference 4.

floods will be most common, and land use and land cover have major influences on the volume of runoff. Extreme events are possible but the probability of their occurrence during a military operation is small.

104. Remote sensing techniques, including aerial photography and satellite imagery, can effectively be utilized in land-cover surveys.<sup>19</sup> Remote sensing techniques do not record land-use activities directly. The interpreter uses patterns, tones, textures, shape, and site associations to derive information about land use from what is basically information about land cover.

105. The USGS has established a four-level classification system for use with remote sensor data.<sup>20</sup> In general, level 1 classification can be accomplished with LANDSAT imagery, level 2 classification can be accomplished with high-altitude imagery, level 3 can be accomplished with medium-altitude imagery, and level 4 can be accomplished with low-altitude imagery. Classification level 1 includes nine categories while level 2 includes 38 categories. A level 2 USGS land-use and land-cover classification for the greater Atlanta region was found to be about 90 percent correct.<sup>21</sup> For a detailed hydrologic study of a watershed where existing land use is utilized to estimate runoff, classification level 1 may not be adequate to describe the land-use categories. Present-day LANDSAT imagery will probably have to be supplemented with high-altitude photography. Future satellite imagery (LANDSAT D) with its improved satellite resolution may be adequate for land-use and land-cover classification of the watershed.

106. Dam-break flooding. The recent Teton dam failure is an example of the magnitude and dynamic characteristics of a flood wave created by a dam break. Since this type of flood could have a tremendous impact on military operations, an important aspect of military hydrology is accurate estimation of the flood characteristics created by man-made breaching of major dams.

107. A recent study entitled "Guidelines for Calculating and Routing a Dam-Break Flood" was completed by the Hydrologic Engineering Center (HEC).<sup>22</sup> Both a one-dimensional analytical model and modified Puls flood-routing techniques were used to describe the flood wave

attenuation. The report indicated that a one-dimensional model was not applicable to all stream channels and additional studies are required to define the range of applicability of the modified Puls routing procedure.

108. In another HEC study, an alternate procedure was presented using dimensionless curves.<sup>23</sup> The curves were developed for an instantaneous, complete breached dam and a prismatic downstream channel. Flood wave time of arrival, maximum depth profile in the downstream channel, and time of maximum depth for downstream points can be estimated by a procedure utilizing the dimensionless curves.

109. Unit hydrograph computation. The conventional method of computing a unit hydrograph requires that the storms selected for analysis have a duration of 10 to 30 percent of the drainage area lag time and have a uniform rainfall intensity throughout the period of rainfall excess.<sup>18</sup> These two constraints will generally limit the utility of this method to streams with several years of streamflow records. It is anticipated that rainfall and streamflow data will be extremely limited for military hydrology applications.

110. New analytical procedures are available for developing unit hydrographs from complex storms. The least squares procedure for determining a unit hydrograph from a complex storm is essentially the same as that used in least squares linear regression analysis.<sup>24</sup> Computer programs for this method are readily available. However, the unit hydrograph derived by this procedure may not exactly equal 1 in. (25.4 mm) of runoff, may have some negative ordinates, and may contain oscillations in the recession limb.

111. Linear programming procedures allow constraints that ensure that the unit hydrograph volume will equal 1 in. (25.4 mm) of runoff, that there will be no negative ordinates, and that the falling limb will monotonically decrease.<sup>25</sup> This procedure minimizes the sum of absolute deviations rather than the sum of the squares of deviations and will probably consistently give more reliable results than the least squares procedure.

112. Routing. Numerous one-dimensional flow routing models are currently available. Routing models range from simple hydrologic

routing to complex hydraulic routing models. Hydrologic routing utilizes the continuity equation and an assumed relationship between storage and discharge. Hydraulic routing uses partial differential equations for unsteady flow in open channels. In general, the more complex the model, the more data and computer time required.

113. Finite difference models may require a large amount of cross-sectional and roughness information. However, they have the ability to produce stage and velocity information along the length of the stream.

114. Linear flow-routing models are simpler and less expensive to operate than finite difference models when stream stage and velocity information is required at only a few points along the stream. Multiple-input linear models have been shown to give reasonably accurate results for a wide range of flows. However, backwater conditions should be avoided and model parameters cannot be established accurately without calibration.<sup>26</sup> Finite difference routing models are preferred if stage and velocity information is required.<sup>26</sup>

115. Military applications will probably require velocity and stage information at several potential crossing sites. If hydrologic routing procedures are utilized to determine streamflows at various sites, hydraulic backwater computations will be required to determine the velocity and stage of the stream at these sites. Detailed channel information will be required for the reach of the stream downstream of each site for subcritical flow and upstream of the reach for supercritical flow.

116. Snowmelt. Most mathematical models of watersheds are developed for rainfall; however, several include special subroutines for snowmelt. Hydrologic models that include snow are usually divided into three basic components: (a) snow cover and melt; (b) precipitation-runoff; and (c) runoff distribution and routing. A model using a deterministic representation of the physical processes is dependent on the availability of input data. The more sophisticated snowmelt models use maximal and minimal daily temperatures, short-wave radiation, snow evaporation, and precipitation. Most models have been developed for

heavily forested mountain watersheds with deep snow covers, and additional testing of models is needed in nonmountainous regions and areas of shallow snow cover.<sup>27</sup> For large watersheds, especially in elevation, cover, and aspect, runoff simulation results can be improved by subdividing the watershed into homogeneous areas. New snow measurement techniques such as pressure devices, lysimeters, isotopic snow gages, and natural gamma radiation detectors provide the potential for updating the results of the simulation model. Anderson<sup>27</sup> indicated that additional studies are required to: (a) determine the best procedure for calculating heat exchange between the air-snow interface; (b) examine the problem of liquid-water retention and transmission, especially in new snow; (c) determine the effect of capillary slush layers on the retention of liquid water; and (d) determine the effect of frozen ground on runoff.

### Water Supply

#### Water quantity

117. Hydrologic investigations are required to provide estimates of quantity and quality of surface water and groundwater. Surface-water supplies may be generally categorized as perennial or continuous unregulated rivers, rivers or streams containing impoundments, or natural lakes. Groundwater and surface water are both part of the hydrologic cycle and are mutually interdependent. Almost every country is endowed with valuable groundwater resources. Evaluation of water resources of an area requires the collection and analysis of all available data on the climate, hydrology, geology, topography, and existing water supply.

118. Utilization of published geologic data, supplemented by geologic field reconnaissance, will often furnish a preliminary appraisal of groundwater conditions. Remotely sensed data can be used to map features such as vegetation, surface temperature, surface-water distribution, landforms, faults, fractures, and lineations, thereby making possible some inferences on soils, geology, and water supply conditions.

119. The geologic formations and landforms in which groundwater can be found have been described in literature.<sup>28</sup> There are certain clues that are helpful in locating groundwater. Sedimentary formations comprise only about 5 percent of the earth's crust yet supply about 95 percent of the groundwater. Groundwater is likely to occur in larger quantities under valleys than hills. In arid regions, certain types of plants give the clue that there is groundwater at a shallow depth. Any area where water shows up at the surface as springs, seeps, swamps, or lakes will have some groundwater, though not necessarily in large quantity or of usable quality.<sup>28</sup>

120. Maps, satellite imagery, and aerial photography can be utilized to inventory surface water reservoirs, lakes, and streams. Remote sensing can be used to study the geology of the area and identify formations which have the highest potential for groundwater production.<sup>29</sup> Large-scale aerial photography can often be used to identify springs and seeps directly from the photography or indirectly by identification of specific vegetation types normally associated with abundant water. When the temperature of the groundwater discharge differs significantly from that of the surrounding area, thermal imagery can be used to locate springs or seeps. Often the environment is warmer around the groundwater discharge point, and the plant growth over the surrounding area may be well advanced in the early spring. Under these conditions, color IR taken in early spring might be useful in detecting springs and seeps.

121. In areas where the rock permeability is low, fractures and faults may act as collectors, and wells located on fracture traces often have yields several times higher than other wells. Aerial photography and side-looking radar can be utilized to identify faults and other geologic structures.

122. Geophysical methods detect differences, or anomalies, of physical properties within the earth's crust such as gravity, density, magnetism, elasticity, and electrical resistivity. Differences in these properties can be interpreted to yield information on geologic structure, rock type and porosity, water content, and water quality.

Of the several geophysical methods, electrical resistivity and seismic refraction are the most applicable to surface investigation of groundwater.<sup>30</sup>

123. A quantitative study of groundwater will require subsurface investigations. Test wells with logging techniques can provide information on the formation, water quality, and groundwater movement. Driller's log, drilling-time log, resistivity logging, potential logging, temperature logging, sonic logging, and radioactive logging are the primary logging techniques utilized for subsurface investigations of groundwater. Information on aquifer yield, permeability, and groundwater movement can be obtained from pump tests and tracer studies.

124. Model studies and numerical analysis methods may have application when direct analysis and adequate field investigations are not possible. However, in order to develop a model, detailed knowledge of hydraulic and hydrologic characteristics of the groundwater basin is required. A hydrologic study is required for validation of the model. Once the model has been verified, it can be used to predict the behavior of the basin under alternate plans for withdrawal and recharge of water.

#### Water quality

125. The quality of water is affected by both natural factors and activities of man. Pure water is never found in nature but will contain some impurities. Parameters used to evaluate in situ water quality include dissolved oxygen, biochemical oxygen demand, bacterial contamination, temperature, trace elements and gases, nutrients, pH, turbidity, dissolved solids, grease and floating solids, and color. Preferable limits for these parameters depend on the beneficial uses of the water such as esthetics, contact and noncontact recreation, fish and wildlife propagation, and water supply.

126. Water for military use must be treated to the degree required. For drinking, cooking, and washing, it should be safe, clear, and free of objectionable tastes and odors. Generally, a water supply can be selected which will require limited treatment rather than one involving complex renovation processes. There are a significant number of refractory substances not commonly found in natural water which are

not removed by the most common treatment processes. The engineer needs criteria for selecting raw water sources that can be treated to drinking water standards with minimum treatment.

127. The intensity and composition of light that is scattered from within the water column can be utilized to estimate certain water quality characteristics. The return light that reaches the airborne sensor can include energy reflected from the bottom of the water body reflected from within the water, reflected light from the water surface, and light scattered in the atmosphere. Light reflected from the water surface yields information on the water surface geometry, surface, floating debris, and water roughness, but yields little information on the water column characteristics.

128. The reflected light from the water surface will be partially polarized parallel, and, depending on the viewing angle, a polarizing filter might be used to minimize the light return from the surface of the water. Generally, direct sunlight reflection from the water surface should be avoided in water quality studies.

129. Since the light scattered in the atmosphere is generally predominantly blue, the effect of light path radiance can also be reduced by using a minus blue filter on the sensor. The subsurface light may include both return from the volume scattering within the water and reflection from the bottom. The intensity and composition of the light scattered within the water column are related to the characteristics of the suspended and colloidal material in the water. The variation in return is a function of the viewing and incident light orientation and can be reduced and processed by the procedures developed by various investigators.

130. Airborne sensors, unlike the spectrophotometer used in the laboratory analysis of water samples, measure the scattered light rather than the transmitted light through the water column. Bands of strong absorption in the transmitted light will usually appear as absorption bands in the scattered light. Variation in return can be caused by a variation in water depth or a change in water characteristics. As the water attenuation rate is a function of the wavelength of light, the

bottom return can generally be eliminated by using the longer wavelength of bands, restricting the sensors to a limited region of the spectrum.

131. Turbidity is an optical property of water which causes light to be scattered and absorbed rather than transmitted in a straight line. The intensity of scattered light at right angles to the incident light is often used to measure turbidity. Turbidity is caused by fine inorganic and/or organic particles in suspension. Since the particles may contain disease-causing organisms, removal of turbidity is often a required treatment process for surface-water supplies.

132. True color in natural waters generally results from contact with organic debris. Water taken from swamps, weedy lakes, and streams containing vegetation is most likely to be colored. Color as such is harmless, but objections due to its appearance and to the taste and odor are sometimes associated with it.

133. Toxicological effects of waterborne organics have been observed principally in connection with chlorinated hydrocarbons and organic phosphorous compounds used as pesticides. These substances may enter the water from runoff, air drift, and direct application for the control of algae. Inorganic substances that may exert harmful effects include nitrate, mercury, selenium, cadmium, and lead. With the increased reuse of water, the possibility of waterborne viral diseases also increases. Treatment processes commonly employed for civilian water supplies may not remove all undesirable impurities from raw water.<sup>31</sup>

134. Plant growth, in the form of microscopic algae and rooted aquatic weeds, is generally limited in nature by lack of nutrients, primarily nitrogen and phosphorus. Municipal, industrial, and agricultural return flows are rich in nutrients. Excessive algal growth imparts tastes and odors to the water. Visible and near IR sensors can be utilized to monitor algal blooms.

135. Temperature influences other parameters including density, viscosity, vapor pressure, solubility of dissolved gases, and the rate of chemical reactions. The measurement of surface-water temperature over large areas is practical using sensors operating in the 8- to

14-micron range. Imaging scanners showing surface thermal patterns have proven valuable in the study of currents and mixing conditions as well as detection of oil slicks.

136. The ability of passive microwave remote sensors to measure variations in salinity or total dissolved solids has been reported by several researchers. Since a microwave radiometer measures apparent temperature, it is necessary to have an independent measure of surface temperature such as from a thermal infrared radiometer. Even though the accuracy is still very coarse, with an accuracy of no more than 1000 ppm, it might be useful in classifying surface lakes into three general classes: salt, brackish, and fresh. This type of a system, combined with an optical system, might give an indication of the type of treatment required for water supply.

#### Treatment

137. Advanced water treatment technology has increased the availability of raw water supplies, and sources previously considered unsuitable can now be utilized. The degree of treatment required to provide potable water varies with the quality of the supply. Generally, as the complexity of the water treatment increases, both the cost of the plant and skill to operate the plant increase. Groundwaters generally require less treatment than do surface waters and often only require disinfection. Surface and groundwater supplies under anaerobic conditions may contain iron and manganese compounds. Aeration followed by filtration is commonly used for removal. Suspended solids in surface water supplies will generally require chemical coagulation and clarification, filtration, and disinfection. Conventional plants or commercially available, preengineered plants such as Rotoflow, Accelapale, Met-pro (Erdlator), Water Boy, and Aquarius can be utilized for treatment of surface waters with limited dissolved solids.<sup>32</sup>

138. In areas having brackish water supply, the use of desalting processes may be feasible. Although these processes are relatively expensive, they are capable of producing a high-quality potable water from saline raw water. The distillation processes have been most widely used throughout the world for seawater while membranes have been used

generally for brackish waters with less than 5000 ppm dissolved solids. A significant aspect of desalting is its capability to provide a completely controllable new source of fresh water; however, it requires an acceptable method of disposing of the waste brine.

## PART V: ASSESSMENT OF RESEARCH NEEDS

### Introduction

139. Research needs for the military hydrology project can be divided into two general categories. The first category is research requirements to improve the immediate capability of the military by adapting existing hydrologic technology to military applications. The second category is research requirements directed at developing advanced hydrologic technology for military application. Major differences between military and civilian hydrology include: (a) military operations require hydrologic forecasts for a full range of conditions and flows while civilian hydrology is primarily concerned with major events; (b) forecasts for the military must be continuously updated with the latest available information on an extremely short time frame while time constraints are generally not as critical for civilian applications; and (c) data sources and/or facilities may not be available and information may be extremely limited for developing military hydrologic forecasts while these resources are generally available for civil projects. Several procedures for measurement and forecasting should be developed to meet the range of conditions expected during military operations.

140. A schematic diagram of the aspects of military hydrology is given in Figure 2. The major research areas--meteorological monitoring and forecasting, soil-moisture monitoring and forecasting, streamflow monitoring and forecasting, water supply evaluation, and technology transfer--will be discussed in the following paragraphs.

### Meteorological Monitoring and Forecasting

141. While accurate precipitation forecasting on the local level would be very desirable for military hydrologic applications, it is doubtful that any research effort in this area would produce significant results within the financial and time constraints of this project.

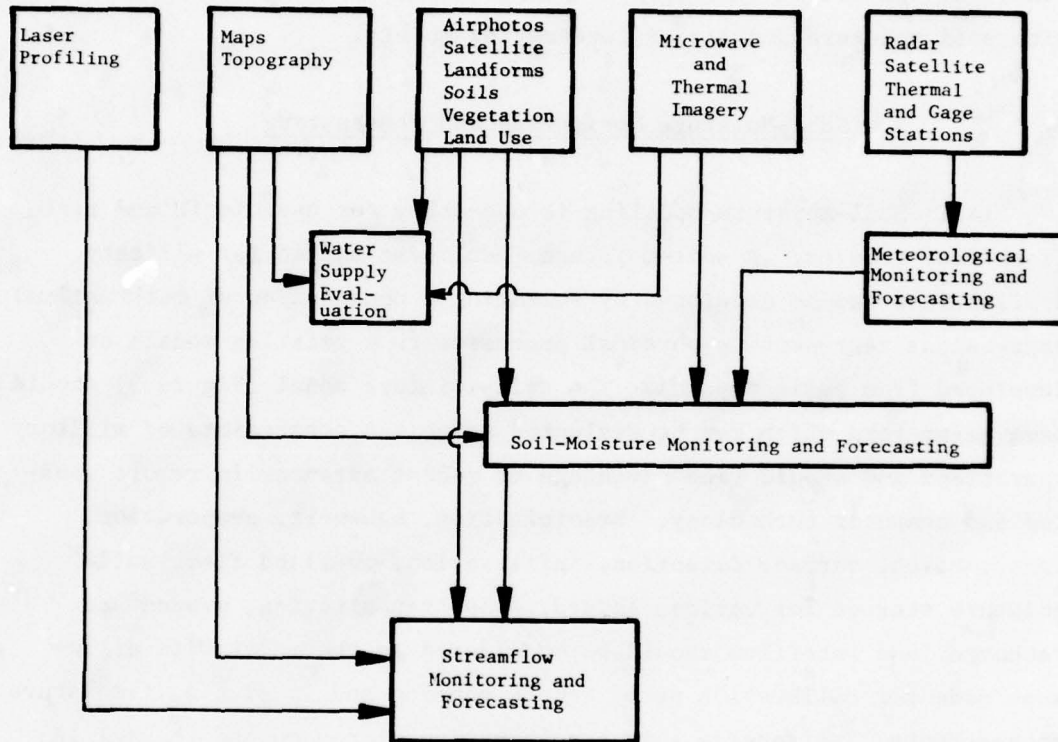


Figure 2. Schematic diagram of the aspects of military hydrology

One of the major limitations of hydrologic studies is inadequate precipitation measurements. It is recommended that a major meteorological research effort be devoted to developing a military capability for real-time monitoring of the intensity and distribution of precipitation over the watershed using state-of-the-art technology. The system developed for monitoring would probably include ground radar, ground precipitation stations, and satellite imagery. Output would have to be compatible with soil moisture and stream forecasting models.

#### Soil-Moisture Monitoring and Forecasting

142. Soil-moisture modeling is necessary for hydrologic and trafficability studies. A soil-moisture model best suited for military applications can be developed by selecting a combination of mathematical expressions representing physical processes from existing models or developed from basic physics. The soil-moisture model (Figure 3) should have parameters which can be evaluated under the constraints of military operations and should take advantage of recent advances in remote sensing and computer technology. Precipitation, snowmelt, evaporation, interception, surface detention, infiltration, overland flow, soil-moisture storage for various layers, evapotranspiration, groundwater recharge, and interflow should be considered in the model with allowance made for calibration using remote sensing and in situ soil-moisture measurements. It appears that a combination microwave and thermal IR scanner system could be developed for remote monitoring of soil moisture. The soil-moisture model must be compatible with the precipitation monitoring system, terrain study requirements, and the stream forecasting effort. Since the terrain and hydrologic studies will require soils, soil cover, land use, and topographic information, these data should be considered available for the soil-moisture model.

#### Streamflow Monitoring and Forecasting

143. Streamflow monitoring requirements should include in situ,

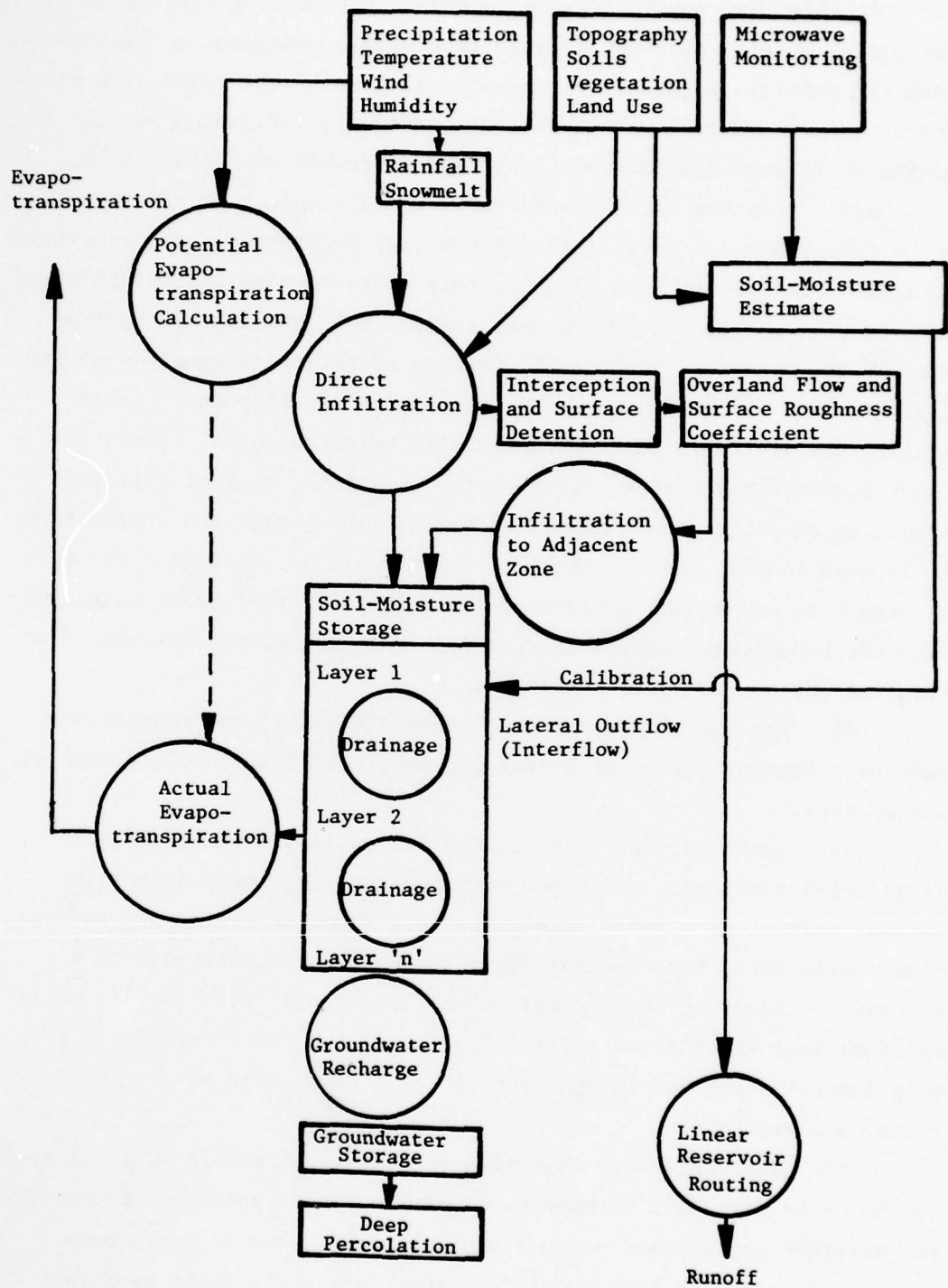


Figure 3. Soil-moisture model

air droppable, and remote sensing methods. Forecasting will require the use of models which could range from simple nomograms to complex computer models. Figure 4, a schematic diagram of the processing of hydrologic information, shows that streamflow is influenced by soil moisture, meteorological conditions, and watershed characteristics.

144. A system using ground radar and precipitation stations is to be developed as a part of the meteorology monitoring and forecasting activity. Satellites with visible, near infrared, and thermal infrared sensors of adequate resolution are assumed to be available. Systems such as the laser or radar profilers used to obtain information on gap crossings and channel cross sections are under development. Other sensors are available but are continually being improved. Since the requirements for altitude, flight pattern, season, time of day, and frequency of flights vary according to both the sensor and application, it is questionable that a single aircraft would be employed. Research is needed to review the various sensors, identify those most compatible with the hydrologic requirements, and develop guidelines for the selection and use of the various sensors.

145. The use of present generation satellites and sensors may require a new generation of hydrologic models to fully exploit remotely sensed data.

146. Advanced streamflow simulation models generally require large volumes of data, and procedures for handling these data from several sources in a short time period are required. Existing streamflow models often take several years to develop and calibrate to a watershed. Adapting these models to military application will require modifications which allow several levels of input data ranging from only general watershed information to detailed data on watershed slopes, soils, and vegetation.

147. The long-range objective of the streamflow forecasting task should be to develop a streamflow simulation model specifically designed for military application using a minicomputer. Time and data constraints distinguish this model from those presently being used for stream forecasting. A deterministic, event simulation model of

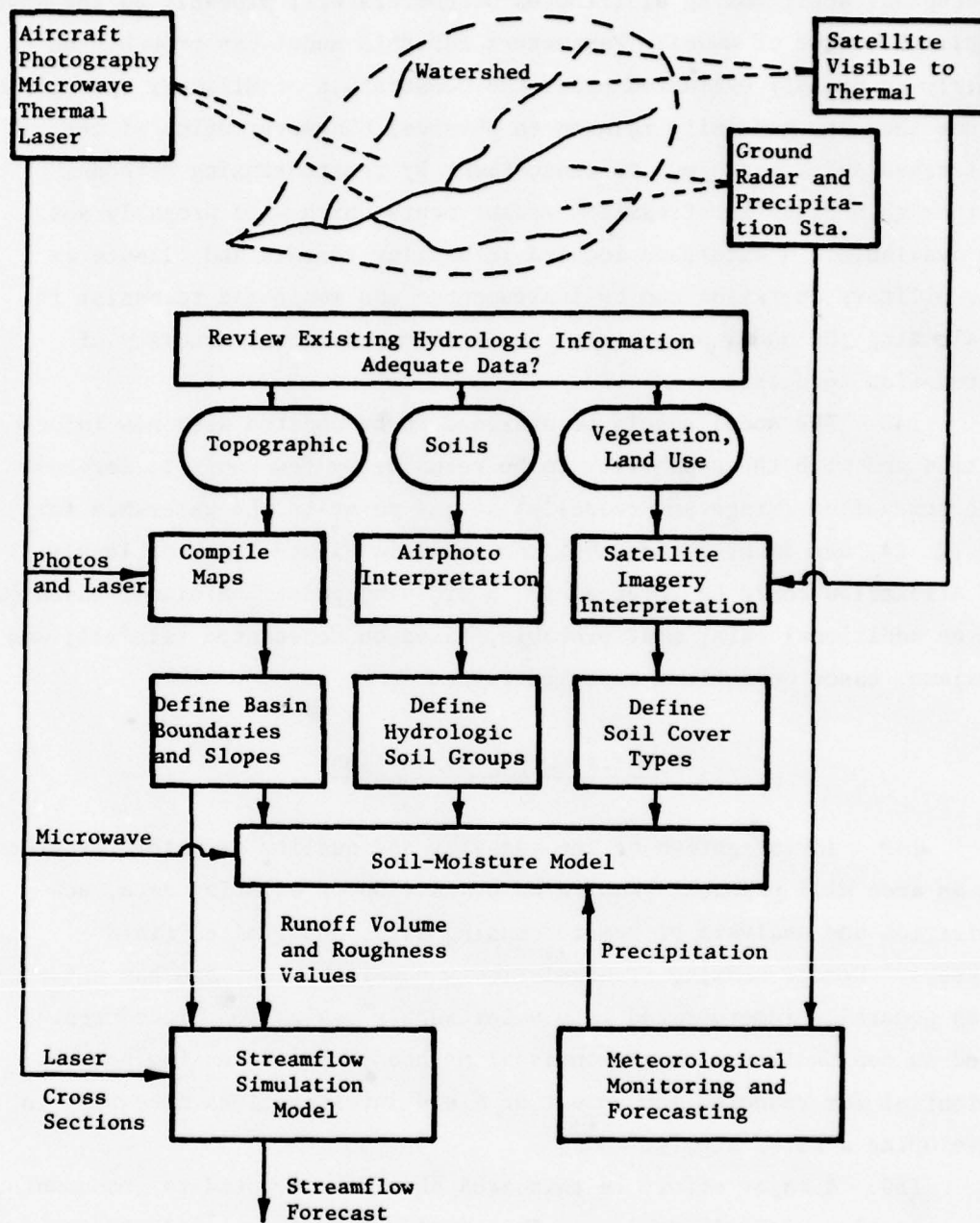


Figure 4. Acquisition, processing, and analysis of hydrologic information

conceptual design using distributed parameters will probably be the most applicable type of model. Parameters for this model can probably be fairly accurately evaluated under the constraints of military operations since they are generally related to physical characteristics of the watershed and are subject to measurement by remote sensing methods, rather than historic streamflow measurements which will probably not be available. A watershed located in similar terrain and climate as the military operation can be instrumented and monitored to assist in evaluating the model parameters and in determining the accuracy of streamflow forecasts.

148. The model should be designed to be updated with new information and with the capability to be rerun every few hours to forecast the streamflow (stage and velocity) at any point in the watershed for 6, 12, 24, and 48 hr in advance. As shown in Figure 5, three levels of streamflow could be forecast for a crossing point: minimum, based on no additional rain; most probable, based on forecasted rainfall; and maximum, based on maximum expected rain.

#### Water Supply Evaluation

149. Investigation of the quantity and quality of water resources in an area will probably require an evaluation of existing data, acquisition and analysis of remote sensing data, and limited field surveys. Remote sensing is a relatively new technology and has not been generally incorporated into water supply evaluation procedures. Used in conjunction with conventional methods, remote sensing has the potential for reducing the amount of field investigations necessary in developing a water supply.

150. A major effort in this area should be devoted to groundwater investigations in arid regions. This could include regional studies using remote sensing, local studies using surface and subsurface methods, and air-droppable penetrometers. Remote sensing technology also appears to have application to surface water quantity and water quality investigations. Microwave, thermal, and visible sensors would probably be

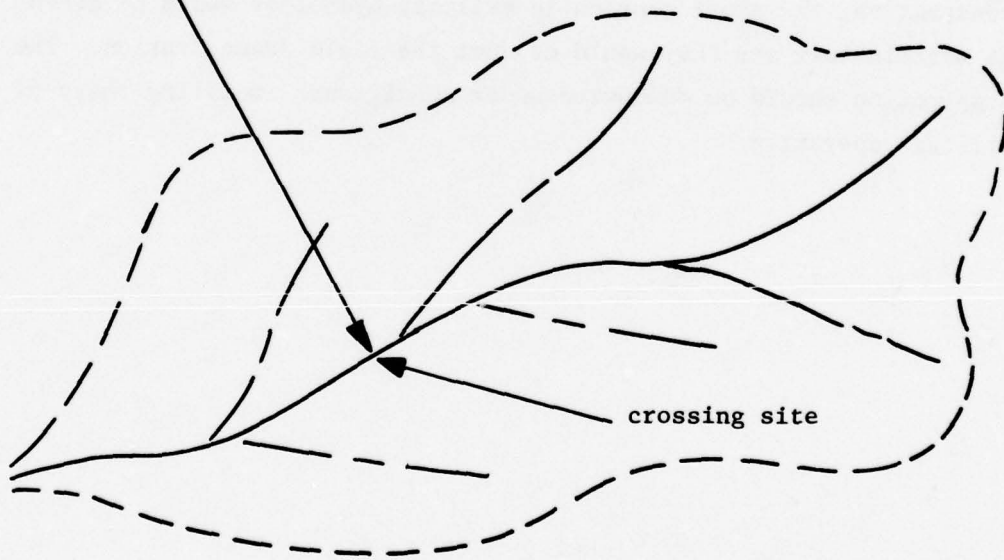
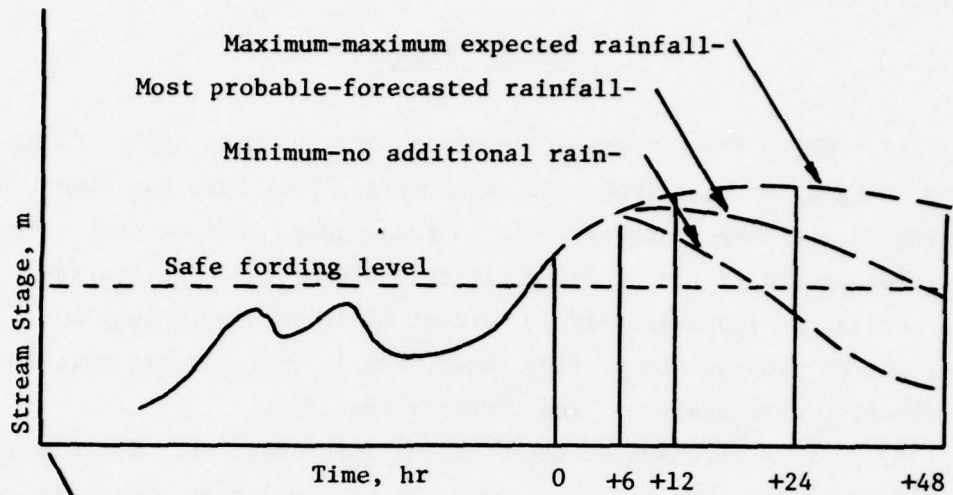


Figure 5. Streamflow forecasting at a crossing site

required to evaluate surface-water supplies. In addition, new methods of storage could be developed or methods from other areas adapted to the water supply field.

#### Technology Transfer

151. While the members of existing terrain teams appear to have strong backgrounds in science and engineering, they have had almost no training in military hydrology. It is recommended that several short courses be developed for study in military hydrology. The courses would consist of approximately 25 percent of lecture on theory and 75 percent on projects to provide experience in hydrometeorological measurements, data analyses, and computer modeling.

152. It is recommended that, during the final year of the project, a field demonstration be conducted to show military officials the advantages, accuracy, and use of the advanced hydrological capability developed by the study. In order to provide a more realistic demonstration, the short courses in military hydrology would be given to a terrain team and they would conduct the field demonstration. The demonstration should be conducted under conditions simulating those of a military operation.

## PART VI: PLAN OF RESEARCH

### Introduction

153. The research plan represented in the following paragraphs strives to provide a short-term update in the Army hydrologic capability based on adaptation of existing technology and a long-term advancement in capability through selected technological advances. The research efforts planned to reach the short-term update capability are, whenever possible, logical initial steps in the sequence of steps that are necessary to reach the long-term advanced capability.

154. The proposed work is discussed under four major "thrust" areas: (a) meteorological monitoring and forecasting; (b) soil-moisture monitoring and forecasting; (c) streamflow monitoring and forecasting; and (d) water supply location and evaluation. One associated thrust area, training and technology transfer, is also discussed.

155. Under each major thrust area, specific work elements are presented to reach the short- and long-term hydrologic capabilities needed. The research plan is designed to produce methodologies and procedures for several levels of technical refinement ranging from simple nomograms to satellite monitoring with computer modeling to match the range of field conditions and available data and facilities expected in military operations. The performance method for each of the work elements is not identified; however, it is intended that private contractors and universities will be used significantly to both supplement and extend in-house capabilities. Other Army agencies, such as the U. S. Army Hydrologic Engineering Center, U. S. Army Atmospheric Science Laboratory, U. S. Army Engineer Topographic Laboratory, and the U. S. Army Engineer Cold Regions Research and Engineering Laboratory, are considered essential participants in their respective areas of expertise, particularly to reach long-term technology advancements.

156. A Military Hydrology Workshop was held in Vicksburg, Mississippi, 17 to 19 May 1978. The purpose of the workshop was to identify research required to develop an improved hydrologic

capability for the Armed Forces. Attendees included fifty hydrologic experts representing eleven Army offices or laboratories, six other Federal agencies, nine universities, one State agency, and a private engineering firm. Recommendations of the workshop were used to formulate the research plan presented in this report.

### Meteorological Monitoring and Forecasting

157. Meteorological factors provide the dominant driving forces for watershed hydrology. The accuracy of hydrologic forecasts will be limited to the accuracy of mesoscale meteorological forecasts. While considerable research is required in mesoscale meteorological forecasting, resource limitations of this project will limit work in this area.

158. Meteorological data are essential for estimating or forecasting soil moisture, runoff, and streamflows. Standard precipitation gage networks may be appreciably in error as a result of inadequate sampling over the watershed. The major effort of the meteorological monitoring task will be to incorporate radar technology, satellite thermal sensors, and ground-based meteorological stations into a system to accurately measure meteorological parameters (primarily precipitation) in the watershed and provide the data on a real-time basis. Digital radar offers advantages for processing the data and developing short-term forecasts.

159. The short-term capability update research requirements are defined below and include adaptation of existing technology into a system for monitoring and forecasting weather over the watershed under military conditions. The long-term technology advancement research requirements listed below are essentially a continuation of the update research requirements with the recommendation that advanced numerical weather prediction capability be developed by the Atmospheric Science Laboratory.

#### Short-term capability update research requirements

160. The short-term capability update requirements are as follows:

##### a. Measurement/monitoring.

- (1) 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.
- (2) Develop improved precipitation-radar return relations.
- (3) 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.
- (4) Develop an integrated methodology for use of presently available satellite-aircraft-remote ground station-digital radar systems for a comprehensive meteorological data acquisition capability.
- (5) Refine existing portable ground-based and air-droppable meteorological stations.

b. Forecasting.

- (1) 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.
- (2) Define and develop initialization procedures for mesoscale forecasting models.
- (3) Adapt existing physically based relations for modeling mesoscale wind fields, temperature, and humidity.
- (4) Develop climatic data base for selected world regions. Data base should include temperature, wind, humidity, and precipitation data to provide essential background information needed for forecasting.

Long-term technology advancement research requirements

161. The long-term technology advancement research requirements are as follows:

a. Measurement/monitoring.

- (1) Upgrade digital radar capability obtained under short-term research to include both hardware and software.

- (2) Develop refined radar return-precipitation relations for global scale.
- (3) 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.
- (4) Develop techniques to quantify precipitation, temperature, and relative humidity by airborne and satellite remote sensing.

b. Forecasting.

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

Soil-Moisture Monitoring and Forecasting

162. The objective of this thrust area is to develop the methodology to estimate soil moisture content to a depth of at least 30 cm for each incremental area in the watershed at any given time and to forecast the soil-moisture content several days in the future based on meteorological forecasts. The task concerns remote and in situ methods of soil-moisture monitoring and modeling. The soil-moisture models will be designed so that, where possible, parameters can be evaluated and the model calibrated by remote sensing methods.

163. The microwave-determined moisture content is usually expressed as percent saturation and represents an average moisture content for a variable depth depending on the moisture content. It is not anticipated that there will be continuous microwave monitoring of the watershed, but only periodical, as required to readjust the model. It should not be necessary to recalibrate the model for all locations in

the watershed since the model can be used to extrapolate soil-moisture conditions between various vegetation, soils, and topographic classes. Drying rates can be determined from repetitive monitoring of soil moisture and this information can be utilized to estimate clay content of the surface soils and to refine the soil classification in the watershed.

164. The short- and long-term requirements for soil-moisture monitoring and forecasting are outlined below.

Short-term capability  
update research requirements

165. Military requirements for soil moisture must be established. In order to rationalize research in either measurement or forecasting of soil moisture it should be determined where soil moisture values are needed and to what accuracy.

a. Measurement/monitoring.

- (1) Examine psychrometric, surface-lying microwave, gravimetric, and tensional thermal and nuclear (to include gamma radiation) techniques to define those most suitable for rapid ground determination of soil moisture.
- (2) 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 day-night, all-weather capability. Included should be an evaluation of current systems designed for other purposes to see if they can be modified or adapted to measure soil moisture.
- (3) Evaluate the effects of surface geometry and 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 effectively 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.
- (4) Based on the evaluations, look critically at future systems that might be constructed.

b. Forecasting.

- (1) Screen existing soil-moisture models (physically based) to establish those most applicable to military operations, bearing in mind the simplification needed at various levels as far as data acquisition and analysis are concerned (Corps, Army, DA).
- (2) 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.

Long-term technology  
advancement research requirements

166. The long-term technology advancement research requirements are as follows:

a. Measurement/monitoring.

- (1) Cooperate in developing air-droppable sensor transponders for soil-moisture measurement with depth. This system should be incorporated in the long-term technology with any air-dropped 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.
- (2) 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.
- (3) Cooperate in the development of low-cost transmitters for in situ soil-moisture measurements.
- (4) Evaluate potential advanced military sensor systems to assess their applicability to military hydrology problems.

b. Forecasting.

- (1) 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 climatic and weather data.
- (2) Evaluate the model and develop guidance for most effective use and for data base generation.

- (3) Identify data that are indispensable for soil-moisture forecasting at the desired levels of accuracy and establish data acquisition systems where these are not available.
- (4) Evaluate and/or develop monitoring and modeling techniques for freezing and thawing conditions in soil.

#### Streamflow Monitoring and Forecasting

167. This thrust area is concerned with measuring and forecasting water levels, current velocities, and flooded areas in or adjacent to streams, lakes, and reservoirs. The methodology, hardware, and procedures developed by this task will be utilized to evaluate such problems as facilities site selection, river crossings, flood prediction, mobility, and artificial streamflow regulation. The short-term update research requirements listed below are concerned with utilization of state-of-the-art technology in the areas of ground-based surveys, air-droppable sensors, satellite and aircraft remote sensors, and hydrologic models. Most of this technology is being applied to similar civilian applications; however, constraints imposed by military operations necessitate additional research. For example, most models used by the National Weather Service to predict flood levels require several years of streamflow records to calibrate. Since these data would seldom be available for streams in foreign countries, research is required to make these methods compatible with the available data. It is anticipated that several methods or models will be provided, having different levels of data and computational requirements to meet the wide range of conditions expected in military operations.

168. The long-term technology advancement research requirements include essentially the same areas as the short-term needs but the research is directed at advancing the state of the art specifically for military application. Operations in real-time will require a mini-computer on-line with the meteorological monitoring and forecasting system.

169. Remote sensing procedures to obtain terrain (vegetation,

land use, soils) and soil-moisture condition data in the watershed are developed under the soil-moisture monitoring and forecasting task.

Short-term capability  
update research requirements

170. The short-term capability update research requirements are as follows:

a. Measurement/monitoring.

- (1) Develop ground-based techniques for monitoring streamflow, velocity, and depth. For example, investigate the feasibility of developing a hydrographic survey drone capable of measuring depth, current velocity, and position in a stream and transmitting the data to a remote receiving station.
- (2) Develop ground-based concepts for rapidly determining stream channel and bank geometry. Investigate the feasibility of developing a range and vertical angle survey instrument with recorder for measuring a stream cross section above the water level from a vantage point.
- (3) Develop procedures to 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 of little hydrologic data. It would enable him to say something about the hydrologic characteristics of such an area.
- (4) Develop procedures to identify channel characteristics from basin characteristics. This is directly related to the discussion of (3) 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 which would be of considerable use to a military hydrologist working in a sparse data area.

b. Forecasting.

- (1) Much is already known about methods for handling the dam break 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 that might be confronted with such a problem as a potential dam break.

- (2) Alternative procedures are another area in which a great deal is known. There are numerous models for forecasting streamflow, ranging from very simple to very complicated techniques. This is also an area in which manuals need to be developed to provide the hydrologists working under field conditions with alternatives for varying levels of computational capability, data availability, and manpower resources.
- (3) Adapting models to sparse data areas is a more difficult problem and is related to (2) above. It is important that the hydrologist recognize models which can be used best in areas having variable topographic and vegetative features and also variable amounts of data. For example, data availability may limit the type of model employed.
- (4) Adaptation and testing of various models for specific areas and military problems is a very important research requirement. More needs to be done in the identification of the goodness of various models and how to adapt 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.
- (5) A lot of work has been done in the area of rain on snow. Unfortunately, more needs to be done since most models do not handle this situation adequately.

Long-term technology  
advancement research requirements

171. The long-term technology advancement research requirements are as follows:

a. Measurement/monitoring.

- (1) 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.

- (2) Develop airborne channel/valley geometry data acquisition systems using modern photogrammetric, laser profilometer, acoustic, and radar altimeter technology.

b. Forecasting.

- (1) The identification of parameters pertinent to stage frequency determination and their functional relationship to basin characteristics and antecedent conditions is of major importance. Parameterization of stage frequency as a function of basin characteristics and antecedent conditions 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 which 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 the evaluation of the goodness of hydrologic output.
- (2) Relation of model parameters to basin characteristics 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 which are utilized in the numerous rainfall/runoff relationships that he might apply.
- (3) Ice problems are 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 breakup and jamming on streams and rivers. However, there are many worthwhile contributions that could be made in a relatively short time frame.

Water Supply Location and Evaluation

172. The main objective of this task is to evaluate and develop water supply investigation methods applicable to military operation. Special emphasis is placed on rapid methods of location and evaluation of groundwater supplies in arid regions. Methods include evaluation of existing geologic and water supply information, remote sensing

techniques, geophysical procedures developed primarily for petroleum and mineral exploration, and subsurface investigations. Correct interpretation of results obtained by indirect methods will generally require supplemental data from subsurface investigation for verification.

173. Short- and long-term research requirements for this task are outlined below. Criteria for evaluating and utilizing local domestic water supply systems and criteria for planning water supply storage and distribution systems will also be developed.

174. Each research item should include modern 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.

Short- and long-term capability  
update research requirements

175. Short- and long-term capability update research requirements are as follows:

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 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 flow and yield augmentation of surface and groundwater sources.

#### Technology Transfer

176. The objective of this task is to transfer military hydrology technology developed by the project to military personnel. Each phase of the study will be documented and the technology will be transferred to military units through a series of manuals and short courses. The task will consist of developing field manuals and short course materials in four areas of military hydrology and conducting a field demonstration on advanced hydrologic technology. The topics for the field manuals and courses are Meteorological Monitoring and Forecasting, Water Supply Investigations, Basic Hydrology, and Advanced Hydrology. Each short course is recommended to be 80 hr in length and will be divided into approximately 20 hr of lecture and 60 hr of laboratory and field exercises. Most of the course material will be developed under other tasks of this project. The courses will be designed for military personnel and will provide training in the application of models, systems, and procedures developed for the military hydrology project. An instructor's manual and daily lesson plans will be developed for each course under this task. In addition, each course will be presented to a group of military personnel for review and evaluation. It is recommended that each course be presented on a routine basis to military personnel under a separate contract by universities or other entities that have

a qualified staff and are adequately equipped.

177. A large-scale field demonstration of the developed technology would be valuable as a means to both provide technology transfer and evaluate research products on a realistic basis by proposed users. A remote watershed will be selected. Assuming that topographic maps of the area are available, all other data will be acquired by remote methods. The models will be developed and calibrated under conditions simulating those of a military operation. A radar station will be established; a satellite receiving station will be installed; aerial photography of the watershed will be flown, processed, and evaluated; a microwave system will be flown at various intervals; and soil-moisture and streamflow forecasts will be made. In order to test the accuracy of the system, streamflow and soil-moisture measurements will be made and compared to those forecasted. The demonstration is to be conducted at a location and season at which it would be anticipated that hydrologic factors would limit field activities. The activity should also include mobility forecasts and vehicle demonstrations.

Short- and long-term requirements

178. Short- and long-term requirements are as follows:

a. Short-term requirements.

- (1) Develop military hydrology field manuals.
- (2) Develop course material for four short military hydrology courses utilizing state-of-the-art hydrology.

b. Long-term requirements.

- (1) Update military hydrology field manuals.
- (2) Update short courses with advanced technology developed by the project.
- (3) Develop and conduct field demonstrations of military hydrology technology.

## PART VII: CONCLUSIONS AND RECOMMENDATIONS

### Conclusions

179. On the basis of this study, the following conclusions were reached:

- a. The existing hydrological capability of the Armed Forces was basically developed during World War II (paragraph 46).
- b. Modern hydrologic methodologies in common usage by the engineering community have not been adopted by the military (paragraph 44).
- c. The 319th Engr Det (Terrain-Hydro) is deficient in hydrologic training and equipment (paragraph 40).
- d. Because of military constraints, short-term capability update research is required to apply modern civilian hydrological methodologies to military problems (paragraph 44).
- e. The application of advanced technology is essential to provide hydrologic information in a tactical time frame (paragraph 47).
- f. Even with the recent changes in the TOE, available resources of the military are not adequate to meet the hydrologic needs of the Armed Forces (paragraph 47).
- g. Hydrologic data requirements of major significance to the mission of the Armed Forces can be placed into four major categories (paragraph 28):
  - (1) Meteorology.
  - (2) Soil moisture.
  - (3) Streamflow.
  - (4) Water supply.
- h. The development of methods and procedures to transfer hydrologic technology to the Armed Forces is an essential part of this project (paragraph 48).

### Recommendations

180. Based on the findings of this study, it is recommended that the research plan outlined in Part VI of this report be implemented.

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APPENDIX A: MILITARY HYDROLOGY, AR 115-21, AFR 105-10

ARMY REGULATION  
No. 115-21  
AIR FORCE REGULATION  
No. 105-10

HEADQUARTERS  
DEPARTMENTS OF THE ARMY  
AND THE AIR FORCE  
WASHINGTON, DC, 24 March 1977

## ENVIRONMENTAL SERVICES MILITARY HYDROLOGY

Effective 15 May 1977

**This is a complete revision of AR 115-21/AFR 105-10 and changes are made throughout. Local supplementation of this regulation is prohibited except upon approval of proponent agency, HQDA (DAEN-FEE) WASH DC 20314.**

	Paragraph
Purpose.....	1
Applicability.....	2
Explanation of Terms.....	3

### APPENDIX A. RESEARCH AND DEVELOPMENT B. OPERATIONS AND TRAINING

**1. Purpose.** This regulation defines the scope of military hydrology and assigns responsibility for providing hydrologic information to the US Armed Forces.

**2. Applicability.** The functions of military hydrology applies as stated below.

*a.* The Chief of Staff, US Army, has been assigned by the Joint Chiefs of Staff, responsibility for military hydrology for the US Armed Forces. The Chief of Staff, US Army, has assigned to the Chief of Engineers (COE) responsibility for performing the functions and activities which are divided into two parts: those dealing with research and development and those dealing with support of operational elements.

(1) *Research and development.* All research and development activities relating to military hydrology are the responsibility of the Chief of Engineers. See appendix A for amplification.

(2) *Support of operational elements.*

(*a*) In CONUS and other territories of the United States, the COE is responsible for providing military hydrology services and functions required for direct support of operational elements. See appendix B for amplification. To this end the COE will use all Army resources as required; exploit all services available from such organizations as the National Oceanographic and Atmospheric Administration, US Geological Survey, US Air Force, and US Navy; and require the

Commanders of the US Army Reserves and National Guard elements to provide such military hydrology services as are available in their commands, to local Army commands or to the COE or designated agents.

(*b*) In theaters of operation and oversea commands, terrain analysis elements of Army forces are responsible for providing military hydrologic information to all deployed units. Where no terrain analysis element is present or available, staff engineers are assigned this responsibility.

*b.* The Chief of Staff, US Air Force, has been assigned responsibility by the Joint Chiefs of Staff to provide meteorological information to the Chief of Staff, US Army. The Chief of Staff, US Air Force has assigned responsibility for providing meteorological data and weather forecasts to the Commander, Air Weather Service. Commanders of Air Weather Service elements are assigned responsibility for such services in a theater of operations.

*c.* This regulation applies to Army National Guard and Army Reserves.

**3. Explanation of Terms.** *a. Hydrology.* That part of the terrestrial environment concerned with the characteristics of surface and subsurface water features.

*b. Military hydrology.* A specialized field of hydrology that deals with these characteristics of surface and subsurface water features that may

\*This regulation supersedes AR 115-21/AFR 105-6, 31 January 1969.

**AR 115-21/AFR 105-10**

affect the planning and conduct of military operations.

*c. Hydrologic services.* Those activities concerned with the collection and analysis of hydrologic data and the dissemination of hydrologic information.

*d. Hydrologic prediction.* A statement about the probable characteristics of surface or subsurface water features at some date in the future, based on historical or engineering analysis.

*e. Hydrologic forecasting.* Determining probable near-time characteristics of surface and subsurface water features, based on current conditions of weather, ground, and water retaining structures.

The above definitions are applicable only to this AR. Any recommendations for changes should be submitted through channels to HQDA (DAEN-FEE-P) WASH DC 20314 for consideration.

## APPENDIX A

### RESEARCH AND DEVELOPMENT

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A-1. The Chief of Engineers (COE) has the responsibility for providing the R&D required to improve the *military* hydrologic capabilities of the Armed Forces.

A-2. This responsibility will be accomplished utilizing COE laboratory resources in the following areas:

*a. CONUS support.*

(1) Research, testing and development to improve the military hydrology capability of the Department of Defense (DOD). This mission is to conceive, plan, and execute engineering investigations and R&D studies in hydraulics, hydraulic prediction and forecasting models, flood assessment and control measures, and telemetry systems for the acquisition of hydrologic data that support both the military and civil missions of the Army, and CONUS requirements of the other Armed Forces.

(2) Research, testing and development as required to meet the special problems found in cold regions. These include but are not restricted to problems related to ice flows, ice jams, snowmelt, and water availability under freeze-thaw regimes, etc.

(3) Research, testing and development of field equipment and analysis techniques to

maintain the effectiveness of military hydrology field teams. This will include test and evaluation of commercially available hardware items, preparation of appropriate instruction manuals, and handbooks, and recommendations for hardware improvements.

*b. Support of operational elements.*

(1) Analysis of military operational requirements to define hydrologic information needed by commanders for planning and conducting both tactical and strategic operations.

(2) Conduct of exploratory and advanced engineering development on systems, techniques, and equipment required to provide hydrologic information in support of field elements including analytical and mathematical or graphical prediction and forecasting procedures involving matters relating to flood heights, times and durations.

(3) Stream and ground water forecasting procedures as required to support the hydrologic information systems required by military elements in the theater of operations.

(4) Analytical and mathematical or graphical prediction and forecasting procedures as required to adequately cope with the special conditions exhibited by cold regions.

## APPENDIX B

### OPERATIONS AND TRAINING

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**B-1.** The Chief of Engineers (COE) is responsible for the collection and analysis of hydrologic data and the dissemination of hydrologic information required by the US Armed Forces. As part of this responsibility, the COE is responsible for insuring that the results of the research and development efforts are made available to field units as quickly as possible.

**B-2.** The Commanding General, US Army Training and Doctrine Command (TRADOC), is responsible for validating the requirements for improved military hydrologic capabilities for the Army, for establishing the doctrine for using the resources available for performing military hydrologic functions, and for training Army personnel to perform these functions.

**B-3.** The Commanding General, US Army Forces Command (FORSCOM), is responsible for the readiness of Army engineer units to perform military hydrologic functions in operational situations.

**B-4.** For providing military hydrologic support to US Armed Forces within the United States and

other US territories, the COE will use the full capabilities of the Corps of Engineers, as well as active and reserve engineer units under the control of the Commanding General, FORSCOM. Requests for hydrologic services should be submitted to HQDA (DAEN-FEE-P) WASH DC 20314.

**B-5.** In oversea commands, Theater Army, Corps, and division level, engineer elements are responsible for providing military hydrologic information to commanders of US Armed Forces units. Engineer elements responsible for terrain analyses, because of their specialized skills, have primary responsibility for performing military hydrologic functions at the tactical level.

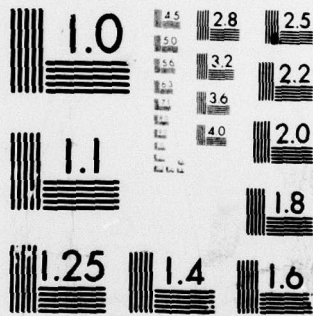
**B-6.** Wherever possible, both in US and foreign areas, engineer agencies will use applicable hydrologic and meteorological data and services that are available from such organizations as the National Oceanographic and Atmospheric Administration, US Geological Survey, and the US Navy.

AD-A081 038 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 8/8  
MILITARY HYDROLOGY. REPORT 1, STATUS AND RESEARCH REQUIREMENTS.(U)  
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The Army office of primary interest in this joint regulation is the Office of the Chief of Engineers. Army users are invited to send comments and suggested improvements on DA Form 2028 (Recommended Changes to Publications and Blank Forms) directed to HQDA (DAEN-FEE-P) WASH DC 20314.

By Order of the Secretaries of the Army and the Air Force:

**BERNARD W. ROGERS**  
*General, United States Army*  
*Chief of Staff*

Official:

**PAUL T. SMITH**  
*Major General, United States Army*  
*The Adjutant General*

**DAVID C. JONES, General, USAF**  
*Chief of Staff*

Official:

**JAMES J. SHEPARD, Colonel, USAF**  
*Director of Administration*

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APPENDIX B: RESPONSES TO WES REQUEST FOR ASSISTANCE,  
MILITARY HYDROLOGIC DATA SUPPORT



DEPARTMENT OF THE NAVY  
NAVAL FACILITIES ENGINEERING COMMAND  
200 STOVALL STREET  
ALEXANDRIA, VA 22332

IN REPLY REFER TO  
0621B/WTH  
Ser 139  
24 MAY 1977

From: Commander, Naval Facilities Engineering Command  
To: Commander, Waterways Experiment Station

Subj: Hydrologic Data Support for Military Operations

Ref: (a) WESFE Request for Assistance of 10 Mar 77  
(b) CEL ltr L54/CEI/mr Ser 772 of 28 Apr 77  
(c) PHONECON 16 May 77 Mr. W. T. Henry, NAVFAC and  
Mr. J. G. Collins, WES

1. Reference (a), which requested information on subject data requirements of engineer and combat units, was forwarded to this Headquarters from the Civil Engineering Laboratory by reference (b).

2. Hydrologic data requirements of the Naval Construction Force (Seabees) fall into two general areas: sizing culverts, and availability of potable water.

3. For sizing culverts, small bridges, and drainage ditches, general data on rainfall intensity versus duration for several return periods would be most helpful. As to level of precision needed, intensity values within about one inch per hour would be adequate. It is assumed that Defense Mapping Agency topographic maps would always be available for determining the drainage area and would provide overall information on runoff characteristics such as slopes, vegetative cover, and development. However, general statements on runoff characteristics of an area would be helpful as part of the hydrologic data.

4. For potable water, general statements are desired concerning the availability and quality of groundwater and water in streams. If guidelines are possible of development, it would be most helpful to list characteristics of terrain and topography that should be looked for to increase chances of drilling successful wells.

5. As was discussed during reference (c), reference (a) has been forwarded to the Commandant of the Marine Corps for further input.

W. M. BASS, JR.  
By direction

DEPARTMENT OF THE AIR FORCE  
AIR FORCE CIVIL ENGINEERING CENTER (AFESA)  
TYNDALL AIR FORCE BASE FLORIDA 32403



REPLY TO  
ATTN OF: DOSC  
SUBJECT: Military Hydrology

84 MAY 1977

TO: Waterways Experimentation Station/WESFE  
Corps of Engineers  
P.O. Box 631  
Vicksburg, Mississippi 39180

1. Reference is made to:
  - a. Your letter of 10 Mar 77, Subj: Request for Assistance.
  - b. Conference telecon on 19 May 1977, held between our Captain Wingad and your Dr. L.E. Link and Mr. J.G. Collins.
2. In contrast to the other military services, the Air Force is in a unique position in that bases which will be used in a contingency environment, have already been identified in appropriate contingency plans. Because the bases are already in existence, the type of information that will likely result from your hydrology work unit will be of only limited value to the Air Force during a contingency situation. Should it be necessary for the Air Force to build a new base at a completely virgin location, however, the efforts of your work unit could be invaluable.
3. The hydrological parameters necessary when evaluating the suitability of a location for an airfield are as follows:
  - a. Availability of water (underground and surface water; non-potable and potable and quantity of each)
  - b. Rainfall (frequency and quantity)
  - c. Surface drainage (susceptibility to flooding)
  - d. Water table level

FOR THE COMMANDER

*Darrell G. Bittle*  
DARRELL G. BITTLE, Lt Col, USAF  
Director of Readiness

Cy to: HQ USAF/PRENC

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.

James, Wesley

Military hydrology; Report 1: Status and research requirements / by Wesley James and L. E. Link, Jr. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.

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Literature cited: p. 85-87.

1. Hydrology. 2. Military hydrology. I. Link, Lewis E., joint author. II. United States. Army. Corps of Engineers. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; EL-79-6, Report 1.  
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100