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# **Intern Experience with the U.S. Army Engineer Waterways Experiment Station**

by Mark R. Jourdan

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Waterways Experiment Station  
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**Final report**

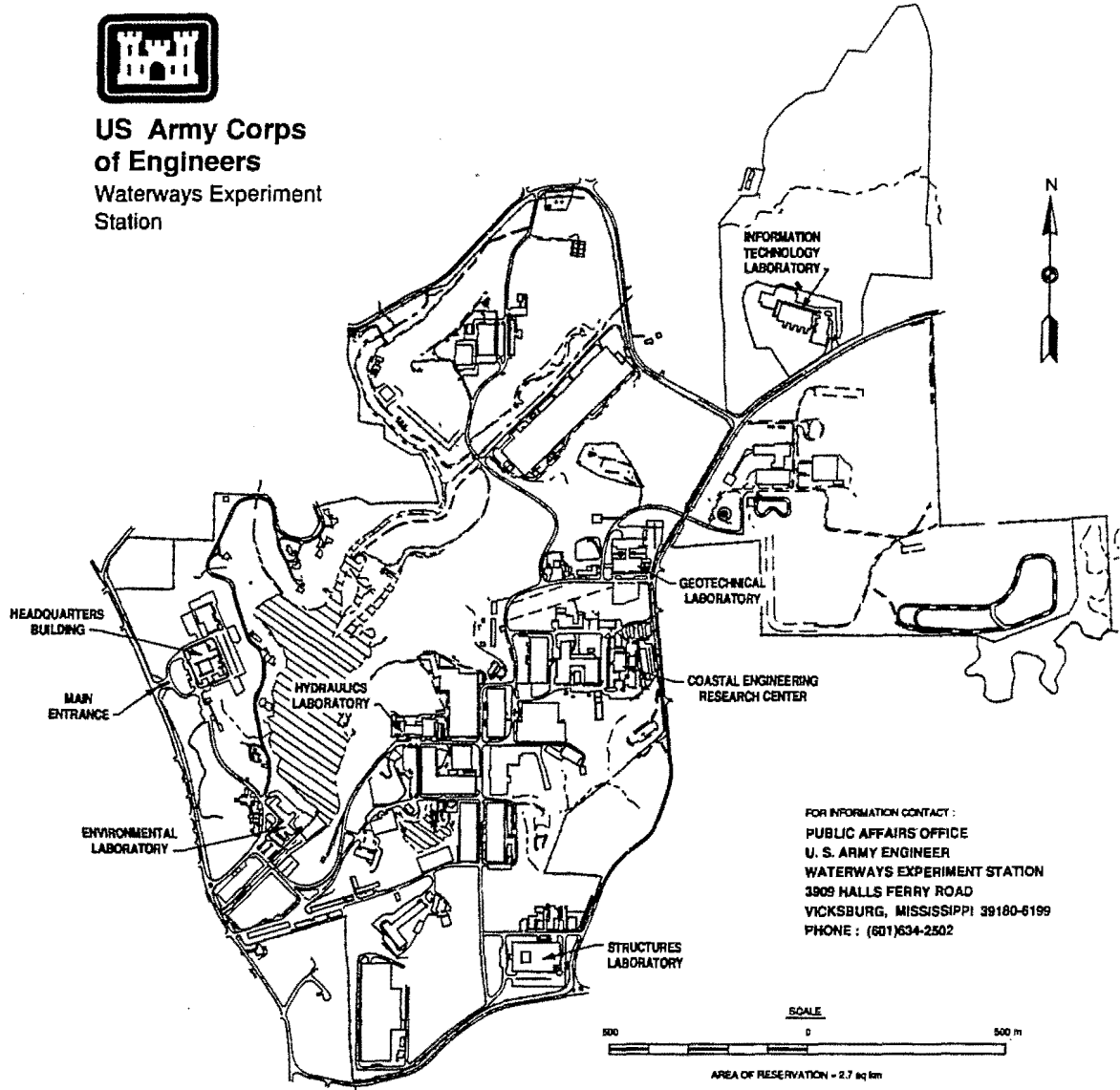
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Prepared for U.S. Army Corps of Engineers  
Washington, DC 20314-1000

Under Work Unit BP-002



**US Army Corps  
of Engineers**  
Waterways Experiment  
Station



### Waterways Experiment Station Cataloging-in-Publication Data

Jourdan, Mark R.

Intern experience with the U.S. Army Engineer Waterways Experiment Station / by Mark R. Jourdan ; prepared for U.S. Army Corps of Engineers.

128 p. : ill. ; 28 cm. -- (Technical report ; HL-95-6)

1. U.S. Army Engineer Waterways Experiment Station. 2. Engineering laboratories.  
3. United States. Army. Corps of Engineers. I. United States. Army. Corps of Engineers.  
II. U.S. Army Engineer Waterways Experiment Station. III. Hydraulics Laboratory (U.S.  
Army Engineer Waterways Experiment Station) IV. Title. V. Series: Technical report (U.S.  
Army Engineer Waterways Experiment Station) ; HL-95-6.

TA7 W34 no.HL-95-6

# Contents

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PREFACE .....	vi
I—INTRODUCTION .....	1
Objectives .....	1
Organizational Setting .....	2
II—KEY PROGRAMS AND PRACTICES .....	17
Army Research and Development Program Structure .....	17
Major Technical Programs .....	18
Resource Accounting Systems .....	22
Relevant Administrative Practices .....	26
Summary of Program and Administrative Setting .....	29
III—THE HAN RIVER CONTROL SYSTEM .....	31
Background .....	31
Development of the Han River Control System .....	37
Han River Control System Concept .....	41
Phase I of the HRCS .....	47
Phase II of the HRCS .....	51
Administrative Duties .....	54
Summary of Involvement in the HRCS .....	65
IV—OTHER ASSIGNMENTS AND CONTRIBUTIONS .....	66
Background .....	66
Integration of TACDAM into ALBE .....	67
Verification of the Reservoir Outflow Model .....	71
Integration of TACDAM and RESOUT into the Obstacle Planner System .....	76
Basin Modeling Comparison .....	89

V—SUMMARY .....	99
Organization .....	99
Assignments .....	100
Conclusions .....	100
REFERENCES .....	102
APPENDIX A. RESOUT CASE STUDIES .....	A1
APPENDIX B. HYDROGRAPHS FROM COMPARISON STUDY .....	B1
SF 298	

## LIST OF FIGURES

---

Figure 1.	USACE districts and divisions .....	6
Figure 2.	USACE military districts .....	8
Figure 3.	USACE R&D laboratories .....	9
Figure 4.	WES organization chart .....	11
Figure 5.	Environmental Laboratory organization chart .....	13
Figure 6.	The Han River basin .....	32
Figure 7.	Map depicting the location of Hwachon Dam and the M2 float bridge sites .....	35
Figure 8.	Han River basin stream gauges .....	44
Figure 9.	Han River basin rain gauge network .....	45
Figure B1.	Precipitation of June 1 .....	B2
Figure B2.	Comparison of measured hydrograph for June 1 to those predicted by both models .....	B2
Figure B3.	Precipitation of July 10 .....	B3

Figure B4.	Comparison of measured hydrograph for July 10 to those predicted by both models . . . . .	B3
Figure B5.	Precipitation of August 4 . . . . .	B4
Figure B6.	Comparison of measured hydrograph for August 4 to those predicted by both models . . . . .	B4
Figure B7.	Precipitation of August 11 . . . . .	B5
Figure B8.	Comparison of measured hydrograph for August 11 to those predicted by both models . . . . .	B5
Figure B9.	Precipitation of September 1 . . . . .	B6
Figure B10.	Comparison of measured hydrograph for September 1 to those predicted by both models . . . . .	B6

## LIST OF TABLES

---

Table 1.	USACE mission changes . . . . .	3
Table 2.	HRCS Phase II contracting issues . . . . .	64
Table 3.	Basin characteristics required for the unit hydrograph procedure . . . . .	95
Table 4.	Basin characteristics required for the SCS curve number procedure . . . . .	95
Table 5.	Soils information for application of the infiltration model to Sleepers River basin . . . . .	96
Table 6.	Comparison of hydrograph peaks . . . . .	97

# PREFACE

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The work reported herein was sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE), under Department of the Army Project No. 40162784AT40, Work Unit BP-002, "Tactical Hydrology."

The study was conducted at the U.S. Army Engineer Waterways Experiment Station (WES) under the direct supervision of Mr. William D. Martin, Chief, Hydro-Sciences Division (HH), Hydraulics Laboratory (HL), and the general supervision of Messrs. Frank A. Herrmann, Jr., Director, HL; and R. A. Sager, Assistant Director, HL. The report was prepared by Mr. Mark R. Jourdan, HH, in partial fulfillment of requirements for the Doctor of Engineering degree at Texas A&M University. Dr. Ralph A. Wurbs served as Chairman of the Graduate Advisory Committee, Texas A&M University.

During the publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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## CHAPTER I

### INTRODUCTION

This document is an internship report submitted by me to the College of Engineering of Texas A&M University.<sup>1</sup> A formal internship in the practice of engineering is one of the requirements of the Doctor of Engineering degree program at Texas A&M. My internship was performed with the U.S. Army Corps of Engineers at the Waterways Experiment Station, Vicksburg, Mississippi, during the period August 1989 through April 1994.

#### OBJECTIVES

A statement of objectives was prepared at the beginning of the internship to provide guidance for the experience and to allow for a meaningful assessment at its conclusion. These specific objectives were developed in support of the overall objective statement of the internship portion of the Doctor of Engineering Program. The program statement states that the purposes of the internship are to enable the candidate to demonstrate his ability to apply knowledge and technical training by making an identifiable contribution in an area of practical concern to the organization in which the internship is served and to provide an opportunity to function in a non-academic environment in which he will learn

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<sup>1</sup>The format and style of this record of study follows the pattern of the *Water Resources Research Journal*.

the employer's approach to problems, in addition to those approaches of traditional engineering design or analysis. The specific objectives of my internship were the following: (1) to learn the organizational structure and understand the role the Laboratory organization plays as a research and development agent for the Corps of Engineers; (2) to develop an understanding of Corps management requirements and techniques that would enable me to effectively act in temporary or permanent assignments at the Group or Division Chief level; and (3) to monitor and guide team members as a technical reviewer of reports, proposals, and similar projects. A copy of my internship objectives is presented in Appendix A.

The remainder of this chapter provides greater detail and background on the internship setting and scope. Subsequent chapters review the specific assignments and accomplishments.

## **ORGANIZATIONAL SETTING**

### **An Overview of the Corps of Engineers**

In order to understand the role of WES and the relationships with its many clients and the Army command, it is necessary to describe the basic organization of the U.S. Army Corps of Engineers. The Corps of Engineers has both civil and military missions. In addition to the military construction and related engineering mission for the Army, the Corps has given the Army a unique engineering expertise that, over the years, has led to missions in the civil works arena for the nation.

## Mission

The U.S. Army Corps of Engineers (USACE) has several different missions. These missions have changed through the years, to include additional tasks (Table 1).

**Table 1.** USACE mission changes

Civil Works Design and Construction	
Navigation	
Flood Control	
<b>Shore Protection</b>	
<b>Environmental Restoration</b>	
Civil Works Operations and Maintenance	
Natural Resource management	
Facilities Operation and Maintenance	
Emergency Operations	
Military Design and Construction	
DoD Facilities	
Mobilization Support	
<b>Installation Support</b>	
<b>Environment</b>	
Real Estate	
Research and Development	
<b>Civil Works Regulatory (Wetlands)</b>	
Support for Other Agencies ( <b>More Diverse</b> )	

NORMAL TYPE:  
Traditional (pre-1960)

**BOLD TYPE:**  
Recent (post-1960)

The USACE Research and Development (R&D) Program is divided into three major programs: (1) The Military R&D Program, consisting of support to the Army in the Field (Military Engineering) and support to the Army in Garrison (Base Support and

Environmental Quality), (2) The Civil Works R&D program, and (3) The Mission Support or Reimbursable R&D Program.

The Military Engineering portion of the Military RDT&E Program is conducted in support of the Army in the Field and covers environmental sciences, combat operations, and echelons above corps support. The major proponent is the U.S. Army Engineer Center and School, other proponents and schools, and Doctrine Command (TRADOC), other TRADOC centers and schools, CINCS, Deputy Chief of Staff for Intelligence, Deputy Chief of Chief of Logistics, Army Material Command activities, other MACOMS and other Army organizations. The program is managed in the Directorate of Research and Development (DRD) by the Assistant Director for Research and Development (Military Programs), CERD-M.

The Base Support and Environmental Quality portions of the Military RDT&E program support the Army's Military Construction, Operation, and Maintenance programs. It supports the USACE districts and divisions, the MACOMS, and the installations' Directorate of Engineering and Housing (DEH). The major proponents are the Military Programs Directorate, and the Facilities Engineering and Environmental Divisions of the US Army Engineering and Housing Support Center, and the Installation Planning Division of the Office of the Assistant Chief of Engineers. This program is also managed by CERD-M.

The Civil Works R&D Program is conducted in support of the USACE Divisions and Districts, the Civil Works (CW) Directorate, and the Engineering and Construction Directorate. The major proponents are the Civil Works and Engineering and

Construction Directorates, USACE. The program is managed in DRD by the Assistant Director for Research and Development (Civil Works Programs), CERD-C.

The Mission Support or Reimbursable program is funded by the user, who provides the technical monitor. Although funded by the user to solve a particular problem, the research must support the Corps' Military or Civil Works missions. The reimbursable program is managed by CERD-M or CERD-C, depending on which R&D mission area the program supports.

### **Organization**

The Chief of Engineers (COE), a lieutenant general position, is appointed by the President of the United States and approved by the Congress. He answers directly to the Army Chief of Staff. The COE actually has two jobs; he serves as an advisor to the Army Chief of Staff, and he is commander of one of the ten major commands within the U.S. Army, namely the Corps of Engineers.

In order to accomplish the civilian mission, the COE had, at the time of this internship, 14 divisions and 39 districts. Figure 1 displays the boundaries of these districts and divisions. The district commanders report to the division commanders who in turn report to the COE, all through the proper chain of command.

With the recent budget difficulties and the end of any great construction projects remaining, there has been much discussion recently on a reorganization of the districts and divisions. The reasons for realignment include the following: fewer traditional projects, shrinking workload, workload/workforce imbalances, high overhead costs, and to enhance technical expertise. The goal of any reorganization is a more cost effective,

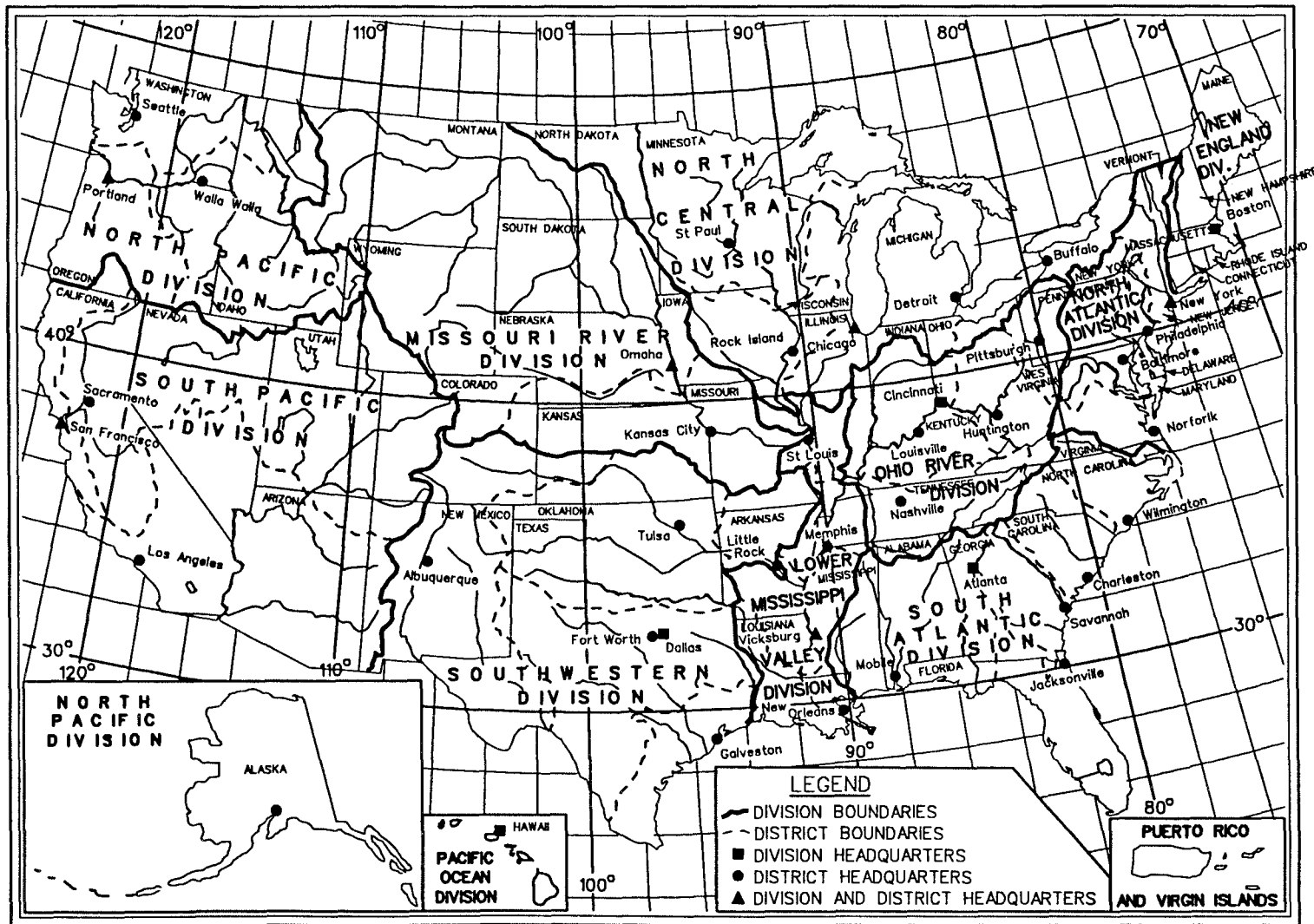


Figure 1. USACE districts and divisions.

competent, flexible Corps of Engineers. Since reorganization discussions occurred near the end of the internship, and the reorganization plans have yet to be approved by the Congress, I will not go into detail at this point.

In order to perform the military mission associated with building and maintaining army bases and facilities, certain districts are assigned an area of responsibility that actually extends beyond the boundaries established for their civil works mission.

Figure 2 illustrates the boundaries of these military districts. For the military mission the district commander reports to the COE. To help accomplish the military and civilian R&D missions, the Corps maintains four research laboratories: Cold Regions Research Laboratory, Construction Engineering Research Laboratory, WES, and Topographic Engineering Center (Figure 3). The four labs report through a civilian Director of Research and Development in the Office of the Chief of Engineers (OCE).

### **The Waterways Experiment Station**

#### **History**

The U.S. Army Engineer Waterways Experiment Station (WES) was established by the U.S. Army Corps of Engineers in 1929 in response to one of the nation's most destructive natural disasters - the Mississippi River Flood of 1927. WES's role as the first federal hydraulic research facility was to help the Mississippi River Commission develop and implement a flood control plan for the lower Mississippi Valley.

#### **Organization and Missions**

The U.S. Army Engineer Waterways Experiment Station is a field operating activity of the Corps of Engineers, operating under the commands of the Commanding

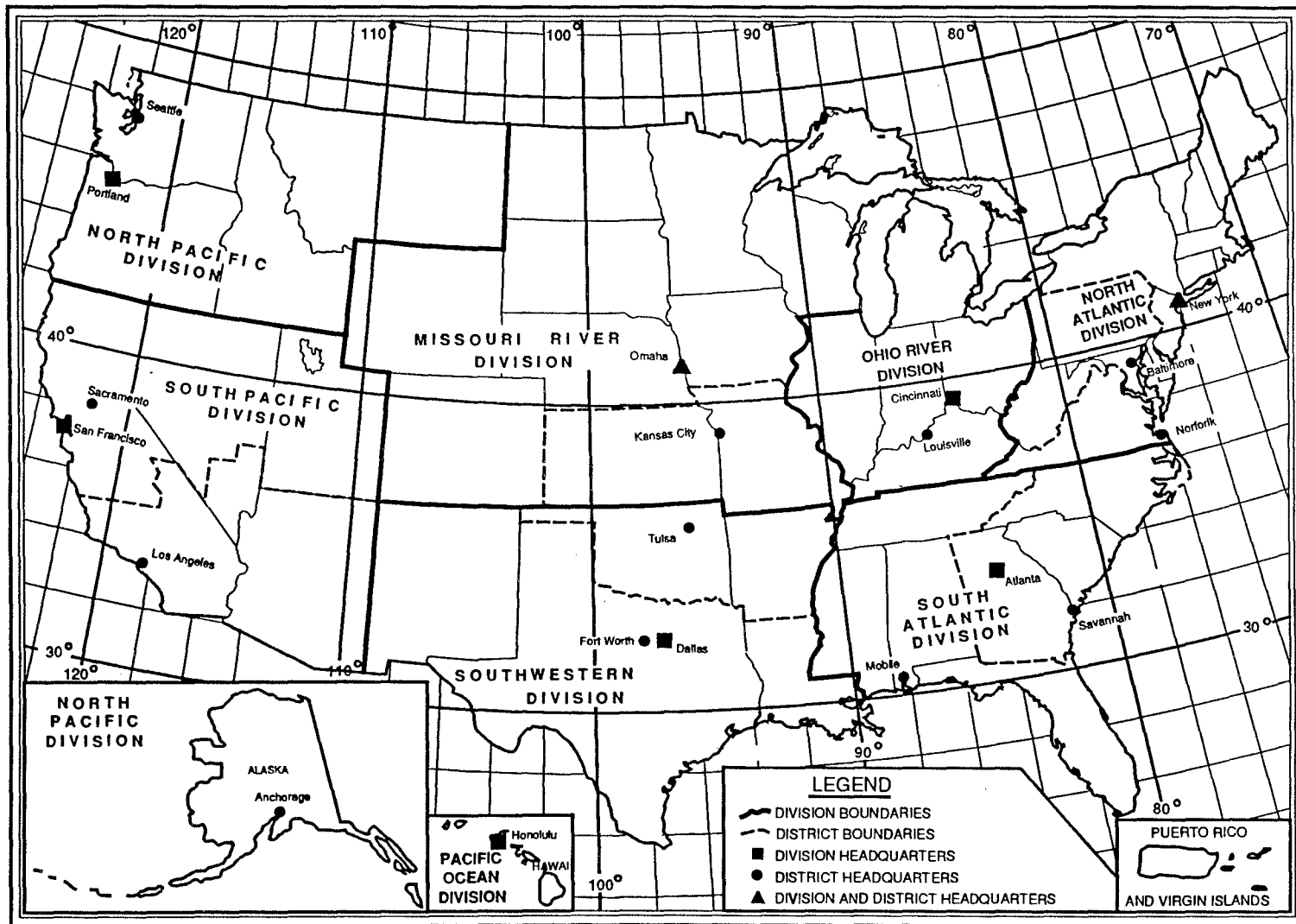


Figure 2. USACE military districts.



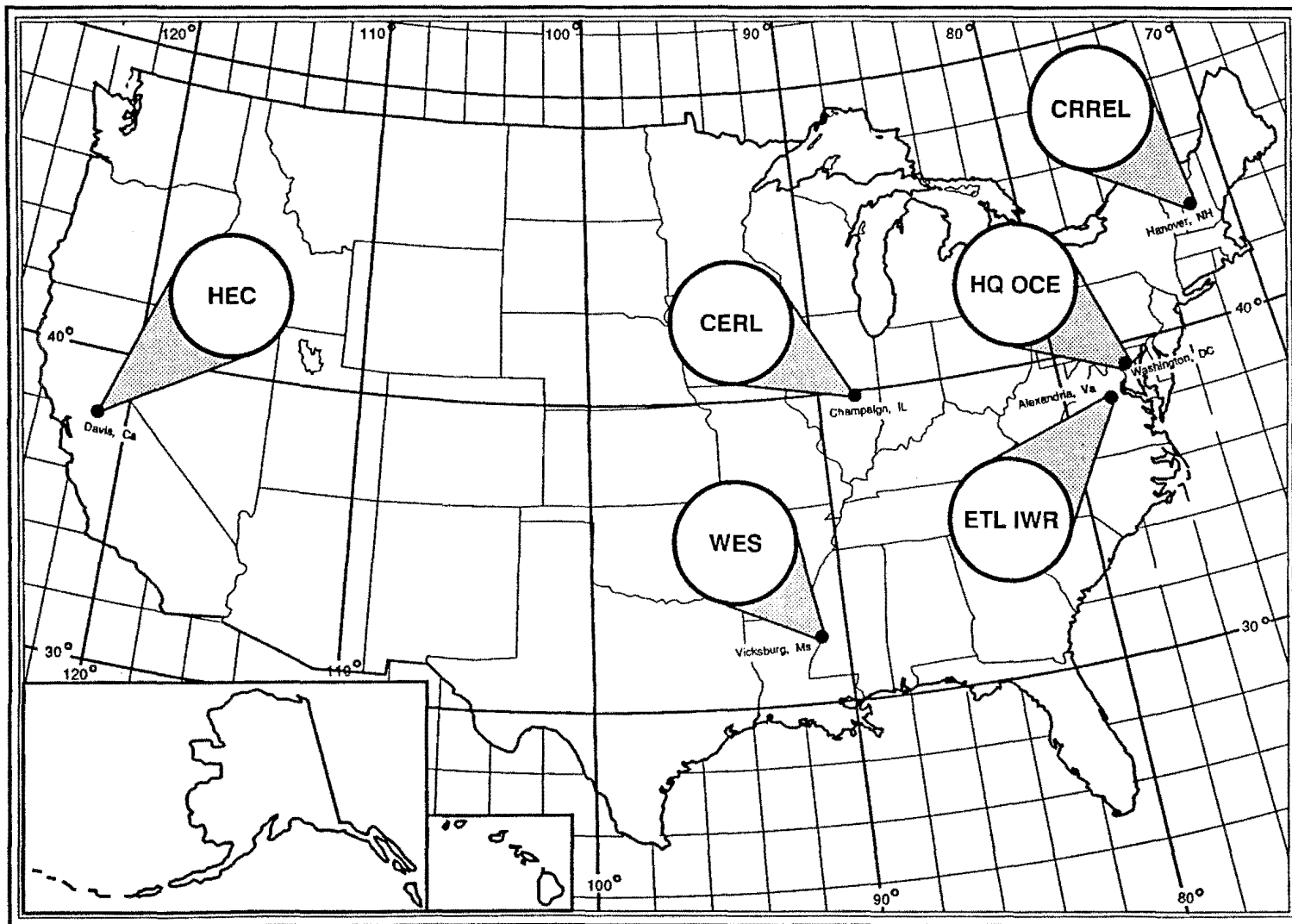


Figure 3. USACE R&D Laboratories.

General, United States Corps of Engineers (USACE), and the staff supervision of the Director of Research and Development. Up until January 1992 the command structure at WES was as follows. The Commander and Director was a regular Army officer with the rank of Colonel. The Deputy Director and Executive Officer was a regular Army officer with the rank of Lieutenant Colonel. The Technical Director was the highest civilian position at WES, with a grade of Senior Executive Service. With the downsizing of the Army and the reduction of regular Army officers, this configuration was changed. The Colonel remained the Commander of WES (and became deputy director); however, the technical director assumed the additional position as Director.

The WES, which was originally started with only one laboratory, now has six (Figure 4). These include the Environmental, Geotechnical, Structures, Hydraulics, Coastal Engineering Center, and Information Technology Laboratory. In addition to the technical laboratories, technical support is provided by the Instrumentation Services Division and the Office of Technical Programs and Plans. The advisory and administrative staff at WES include the Resource Management Office, the Contracting Division, the Engineering and Construction Services Division, and the Logistics Management Office.

The primary mission of the WES is the planning and execution of engineering investigation and research and development in support of the civil and military missions of the Chief of Engineers and other federal agencies.

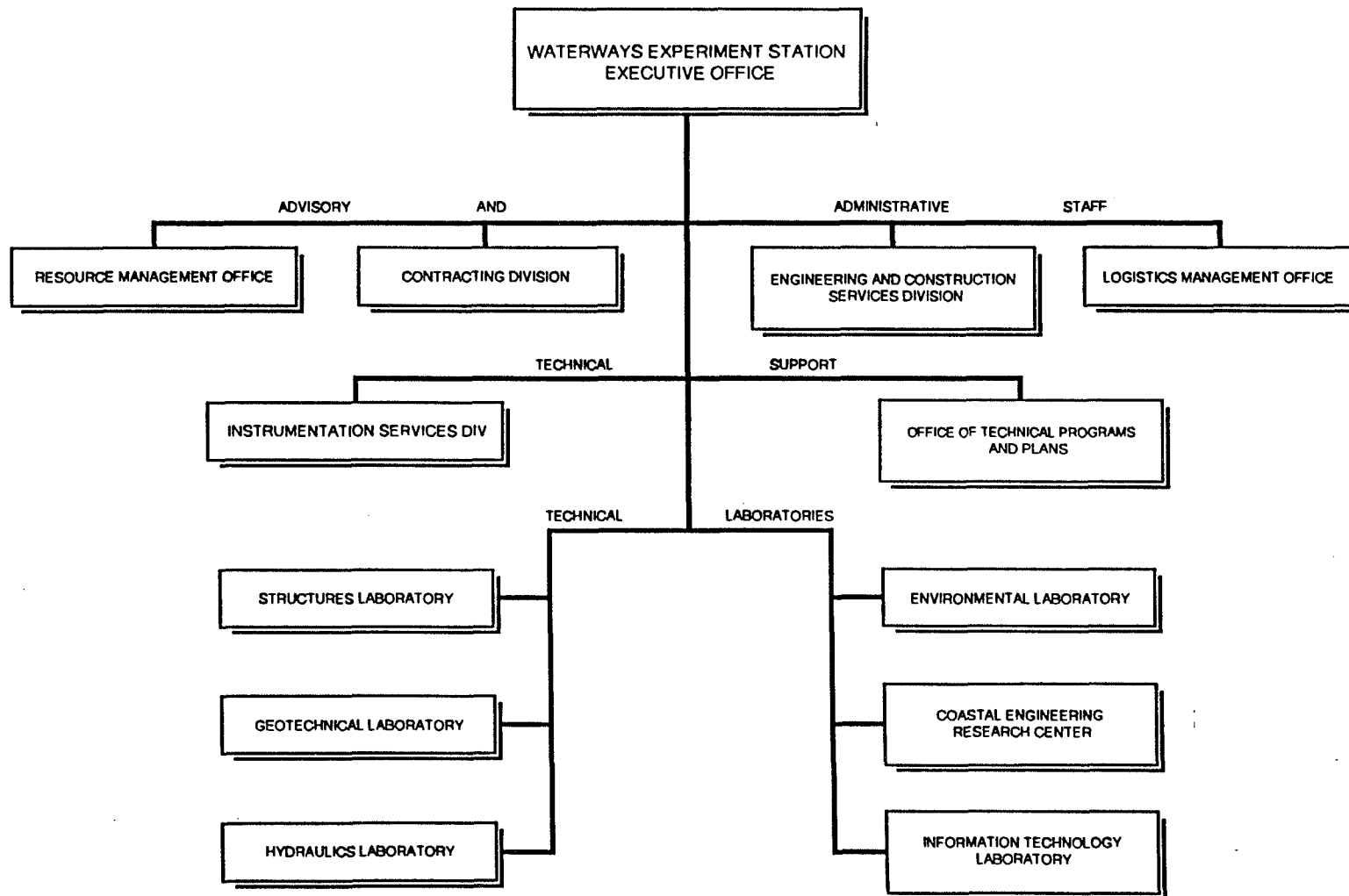


Figure 4. WES organization chart.

## **Operation and Funding**

No direct congressional funding is made available for the operation of WES. All work is performed for the Corps and other sponsors on a reimbursable basis, with the sponsoring office, District, or program paying all costs of the work involved. Under specific priorities and conditions, WES can also perform reimbursable work for other Federal agencies, State agencies, and even private concerns and foreign governments.

WES operates on the standard Federal fiscal year (FY) extending from 1 October through 30 September each year. During FY 91 station funding was approximately 150 million dollars. Just less than 65 percent of the total was derived from civil works projects with the remainder from military sources.

## **The Environmental Laboratory**

### **Mission**

The internship was completed within the Environmental Laboratory. The Environmental Laboratory is one of the larger laboratories at WES, employing approximately 250 personnel and with a FY91 funding level of 45 million dollars. This funding has increased from a level of 35 million dollars in FY87. The Laboratory's present mission is threefold: to predict, quantify, and develop strategies to minimize undesirable effects of water resources development projects and military activities on the natural environment; to develop and test concepts to effect desirable changes in environmental resources at water resources development projects; and to predict and quantify the effects of the natural environment on military operations and materiel.

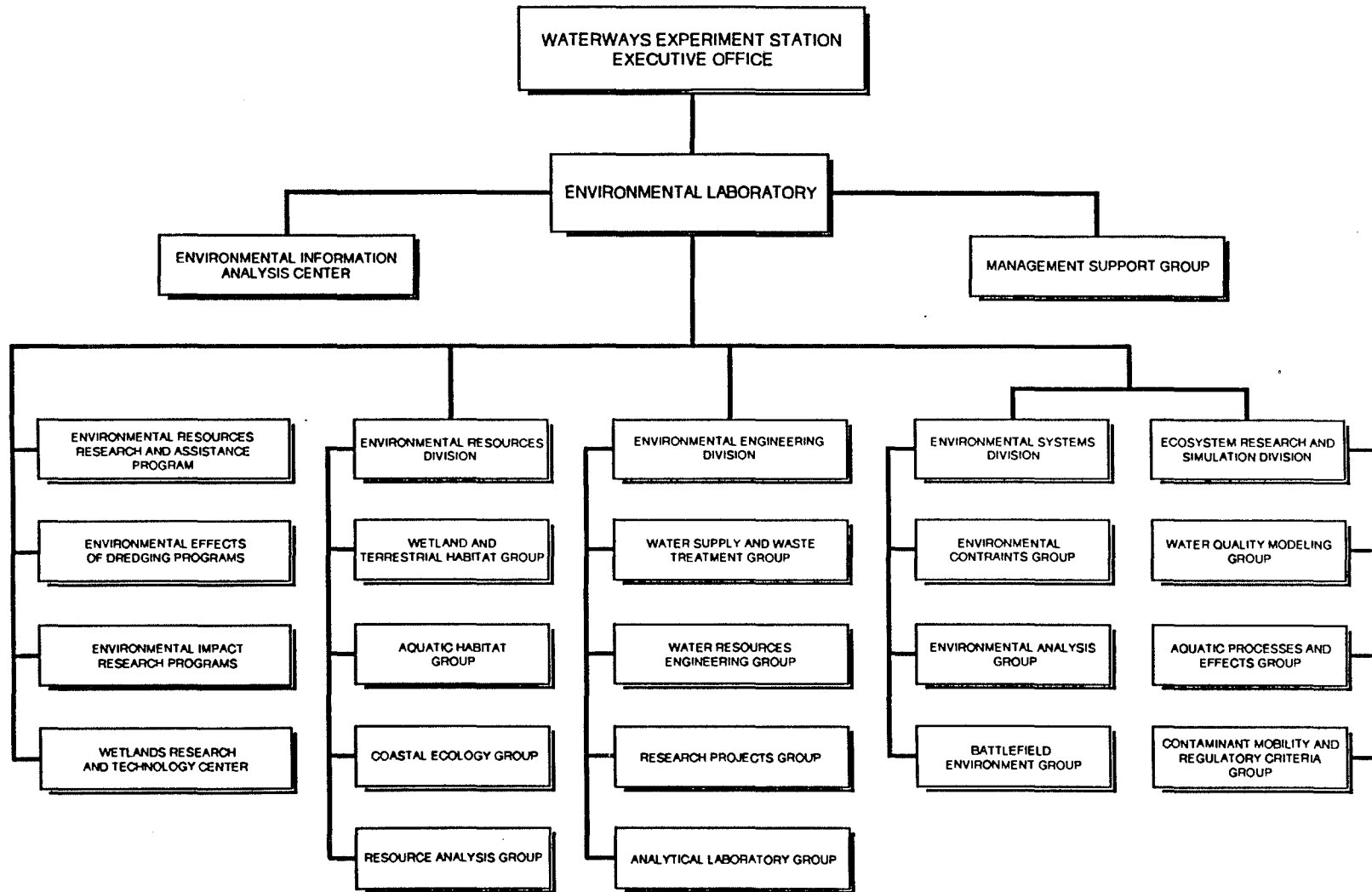


Figure 5. Environmental Laboratory organization chart.

## **Organization**

There are four operating divisions in the Environmental Laboratory (Figure 5) with three of them roughly organized around the technical disciplines of engineering, chemical sciences, and biological sciences (Environmental Engineering Division, Ecosystem Research and Simulation Division, and Environmental Resources Division, respectively). There is considerable simplification in this description since technical areas overlap. The fourth division, the Environmental Engineering Division (ESD), has a broad interdisciplinary technical staff, but is narrowly focused in applications to military engineering. In addition to the operating divisions, the Environmental Laboratory uses a distinct Program Management Office to provide management to programs that stretch over more than one division.

### **Primary Level Internship Organization**

The internship position of the author was located in the Environmental Constraints Group (ECG) of the Environmental Systems Division (ESD). The group is the lowest organizational unit in the chain of command whose chief is vested with full, formal supervisory authority. The ECG is one of thirteen primary groups organized into the four Divisions that make up the Environmental Laboratory.

### **Organization and Missions**

The ECG is involved with several diverse programs spanning technical areas such as camouflage and concealment, scene analysis, and military hydrology.

The ECG is divided into three teams. The Camouflage, Concealment, and Deception (CCD) Team develops procedures and methods for the camouflage, concealment and

deception of fixed facilities to reduce the potential of threat weapons system encounters. The Background Signature Team (BST) develops models to simulate infrared, radar, seismic, and acoustic sensor systems performance and methods for measuring background signatures. Finally, the Military Hydrology Team (MHT) is developing models to improve the Army's tactical hydrologic capability for predicting state-of-the-ground and streamflow conditions.

The ECG is comprised of a professional staff of 23 individuals, with individual specializations that include hydraulics/hydrology, environmental, chemical, electronics, computer programming, agricultural, mathematics, and mechanical. Also, included in the ECG were two secretaries and five technicians.

### **Supervisors**

The Chief of the ECG during the Internship was Malcolm Keown. Mr. Keown was the author's personnel supervisor and also served as the internship supervisor. His academic preparation includes a Bachelor's and Master's degree in Physics from the University of Chattanooga. He also earned a Master's degree in Environmental Engineering from the University of Florida.

Mr. Keown joined the staff at WES in 1968 after working there during the summers of 1966 and 1967 on a graduate student appointment. Prior to becoming a team leader in April 1974, he was assigned to work in the areas of military bridging, test vehicle instrumentation, evaluation of near surface soil properties using radar techniques, development of helicopter landing zones using high yield explosives, and terrain analysis related to siting military supply routes.

Mr. Keown's supervisor and the Chief of the Environmental Systems Division was Dr. Victor L. LaGarde. The Chief of the Environmental Laboratory was Dr. John Harrison. Both have been with the Environmental Laboratory since its beginning and have considerable background in analyzing the effect of the environment on military planning and operations.

### **Summary of the Organizational Setting**

WES is a unique organization both in mission and structure. The diversity of its technical involvement and capability is greater than most large consulting firms and universities. A variety of projects are found including pure research; product, process, and equipment development and testing; and design services. Work is performed under both civilian and military support missions and clients have come from OCE, all Corps Divisions and Districts, most Federal and many state agencies and occasionally foreign governments.

The internship position was located in the Environmental Constraints Group. The Group has been organized into three operational teams. Formal supervision of the staff has been retained by the Group Chief, but work assignments, fiscal responsibility, and technical supervision were accomplished through team leaders, including the author.



## **CHAPTER II**

### **KEY PROGRAMS AND PRACTICES**

Similar to the description in the previous chapter of the organizational framework in which the internship position was located, this chapter describes the program framework in which the internship technical work was performed and the policies and regulations under which the administrative duties were performed. These contexts will be described under the topical areas of Army research and development program structure, major technical programs, resource accounting system, and relevant administrative practices.

#### **ARMY RESEARCH AND DEVELOPMENT PROGRAM STRUCTURE**

Since most of the technical programs were military research programs, it is necessary to understand the general structure of the Army R&D program. Following is a discussion of this program.

The Army research, development, tests, and evaluation (RDTE) program is organized into six categories. These include research, exploratory development, advanced development, engineering development, management and support, and operational system development. USAEWES only receives funds in the first three of these categories.

Research, or Category 6.1, includes scientific study and experimentation directed toward increasing knowledge and understanding in those scientific fields related to national security needs.

Exploratory development, or Category 6.2, is directed toward solving specific problems from fundamental applied research to sophisticated prototype hardware, study, programming, and planning efforts.

Advanced development, or Category 6.3, is divided into two parts. Category 6.3.a includes advanced development involving nonsystems, characterized by the development of generic components and subsystems, and demonstrations of simulation. Category 6.3.b includes advanced development efforts involving a unique or specific, well-defined system objective, in response to an approved requirement.

## **MAJOR TECHNICAL PROGRAMS**

### **General**

The internship was performed in the Military Hydrology Team. 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. The Military Hydrology Research Program was reinitiated in 1978, with management responsibility assigned to the Environmental Laboratory of the WES. One of the initial efforts was to review Army doctrine on Military Hydrology to determine its relevance to modern Army needs (Stinson, 1981). It was found that many of the documents that were reviewed incorporated TOE'S, doctrinal concepts, and technologies

of the 1950s. However, companion reviews of hydrologic capabilities existing in the civil sector indicated that improved techniques and methods were available. As a consequence, the policy generally followed has been to adapt existing technologies to match the equipment and manpower capabilities of Army Terrain Teams -- Terrain Teams being the primary users.

The work performed in the Military Hydrology Team is grouped under several work units. These work units extend over periods of several years and are established with specific tasks, finite lives, and variable funding. The work units have a degree of technical focus (although overlap occurs) and their products are coordinated.

For research purposes, three military hydrology thrust areas are recognized. The thrusts included are Induced Flooding, Streamflow Forecasting, and Weather-Hydrology Interactions. Each of these work areas is discussed in the following paragraphs, including objectives and research efforts.

### **Induced Flooding**

The objective of the induced flooding work unit is to develop procedures for evaluating barrier effectiveness of dam outflows for forecasting downstream flood flows resulting from controlled/uncontrolled releases from dams. Emphasis is placed on adapting existing capabilities for forecasting flood discharge, depth, lateral extent, duration, and velocity. Dynamic wave routing methodologies were evaluated, and as appropriate, adapted for military applications. Existing methods for estimating outflow hydrographs from dams were evaluated. Flood routing and outflow hydrograph components are to be integrated and the combined procedures tested and refined. The

various procedures are to be programmed for personal computers and workstations, and documented in manuals for transfer to Army terrain teams.

One of the initial efforts in this work unit was a state-of-the-art review of dam breach flood forecasting techniques (Wurbs, 1985). As a result of this review, the National Weather Service Simplified Dam Break (SMPDBK) Model was adapted for use by the military and called the Tactical Dam Analysis Model (TACDAM).

It was eventually realized that the efforts should not be limited to dam breach, but should include other forms of induced flooding. A state-of-the-art review of reservoir regulation technology and modeling capabilities was conducted in preparation for the development of expert systems to control reservoir releases in tactical scenarios. Drawdown procedures optimized to meet civilian requirements (electric power, water supply, and navigation) and military needs were developed for a strategically important stream and reservoir system. Subsequently, the procedures were provided to the theater command for evaluation and incorporation into planning documents.

Current R&D efforts in induced flooding include the capability to use GIS systems for predicting the extent of flooding. These efforts will be discussed in later chapters.

### **Streamflow Forecasting**

The objective of the Streamflow Forecasting work unit is to develop improved methods for forecasting parameters such as velocity, width, depth, and flooded area from natural events for mobility/countermobility operations. Emphasis is placed on a near real time capability as well as computational ease and reliability. The various procedures are

to be programmed for personal computers and workstations, and documented in manuals for transfer to Army terrain teams.

The Military Hydrology Model (MILHY), was developed to forecast streamflow parameters (velocity, depth, width) which are important for bridging and river crossing. This model, originally implemented on the HP-9825A computer, and later the MICROFIX computer and the IBM PC, has been delivered to field units. The MILHY model required channel and basin parameters, information on antecedent soil moisture conditions and current meteorological conditions.

A two-week course was developed for the Defense Mapping School as inclusion in the Advanced Terrain Analysis Course. This course covered basic hydrology terms and concepts and described the inputs and outputs required for the MILHY model.

Current R&D efforts in streamflow forecasting include the development of a distributed rainfall-runoff model and the inclusion of this capability in an Army GIS. These efforts will be discussed in later chapters.

### **Weather/Hydrology Interactions**

The objective of this work unit is the development of procedures for using remotely acquired precipitation data in forecasting state-of-the-ground and streamflow conditions. Precipitation is an important driving force for many of the Army's battlefield prediction models. Because of the stochastic nature of storm systems and the limitations imposed by point measuring devices, it has proven difficult to determine the areal extent of precipitation. The ability to accurately detect the occurrence and movement of severe weather systems, predict their potential precipitation intensities, and forecast hydrologic

and trafficability effects in real-time, is essential so that battlefield prediction models can generate products for effective battlefield planning and operations (Engdahl and Collins, 1987).

An investigation of procedures for estimating rainfall from satellite imagery was begun. Collaborative efforts were carried out with the National Oceanographic and Atmospheric Administration (NOAA) concerning automated techniques for estimating convective rainfalls and satellite applications in estimating rainfalls associated with cyclonic systems.

### **Reimbursable Work**

In addition to the direct-allotted research discussed above, the Military Hydrology Research Program at WES has also performed reimbursable work. This is research and development that is not directly funded, but is funded from other sources.

Some examples of reimbursable work include the development of the Han River Control System for the U.S. Forces, Korea, incorporation of the TACDAM model into a suite of software designed for Terrain Teams, and development of techniques for use of radar precipitation rates in Corps of Engineers rainfall-runoff models.

### **RESOURCE ACCOUNTING SYSTEMS**

Because of the varied sources and types of projects at WES, and the diversity of organizational and individual involvement in those projects, resource management and accounting have traditionally received a great deal of emphasis. Managers at all levels

and Principal Investigators are expected to monitor organizational and project funding status and effectively manage resources.

### **The Corps of Engineers Management Information System**

Unlike private enterprise firms, WES is not free to choose the methods by which the monitoring and accounting will be done. The principal method used during the internship is the Corps of Engineers Management Information System (COEMIS). COEMIS is used Corps-wide by all districts, divisions, and field elements. It was designed as a broad upward reporting system to keep OCE managers aware of the status of all aspects of Corps projects and operations.

As in any accounting system used for large corporations, COEMIS includes tracking of obligations, disbursements, accounts payable, and costs. Obligations, which occur upon issuance of a purchase order or award of a contract, are a legal liability against the U.S. Treasury. A disbursement is equivalent to a check being written. Accounts payable are equal to undisbursed invoices plus accruals. Costs are equal to disbursements plus accounts payable.

Because of problems in determining weekly funding balances, there have been several attempts during the internship period to replace COEMIS. The most infamous attempt was called PCMIS, which would have allowed each Principal Investigator access to the data base. All PIs would have been expected to enter any charges against their jobs, as they occurred. Because of problems with the data base and network, which were identified during testing of the system, this management information system was not implemented.

### **Accounting View of Funding Sources**

The distinction between the civil and military missions of the Corps is nowhere more prominent than in the accounting system. Separate accounting is made of civil monies and military monies, and within those classes, a further separation is made between direct allotted and reimbursable funds. Thus, there are four distinct classes of money and a considerable body of regulations governing what and how specific types of charges can be made against each class. The basic separation among funding sources has always been a part of Corps resource management. COEMIS, however, has made the separation more visible and is less tolerant of mismatches in types of funds and types of charges.

One thing that is different, depending upon the source of the funds is the expiration date of those funds. For instance, military, direct allotted, funds are actually two year money. That is the PI has two years to spend the money. However, in these times of budget cut backs and intense scrutiny, these funds must be obligated in the first year. The reason for enforcement of this "unwritten" rule is to eliminate forward financing, where this year's funds are used to pay for work next year.

Many types of reimbursable money may be carried over to the next fiscal year. The transfer document will specify when the money expires. The specified date is either when all the money should be disbursed or when no more obligations can be made against that job.



### Accounting View of Labor

Labor expended on military-funded work is accounted for by an Annual Funding Target (AFT) unit. One AFT is the labor effort available for a "unit," average salary. Labor utilization at any point is reflected by the total current charges to a project divided by the unit salary. Labor allocation, or ceiling, is the total funds available for charge divided by the unit salary. AFT does not correlate well to the actual number of employees present, only to the labor charges made by them. AFT does, however, clearly and rapidly identify shortfalls (or excesses) in funding versus obligations for salary. As such, it can be a valuable tool for preliminary project planning.

The number of military slots at laboratories and divisions is determined at OCE. For much of the duration of the internship, a hiring freeze existed. This was not a complete hiring freeze, but a partial freeze that varied from hiring one employee for every two vacancies to one employee for every five vacancies.

Labor expended on civil work is based on the Full Time Equivalent (FTE) unit for counting strength. An FTE is the equivalent of one person working 40 hours per week for one year. The term "equivalent" is used to accommodate the use of part-time or temporary employees. A part-time employee working 20 hours per week is counted as one-half FTE, and two such employees are one FTE. Authorized strength in a laboratory or division is based upon an allocation of FTE (a ceiling).

The overhead rate differs for civil and military work. The primary difference is that military jobs are not charged for base operations. Therefore, the overhead rate is slightly

lower. At one point during the internship the overhead rate for military jobs was 231 percent, while the overhead rate for civil jobs was 281 percent.

## **RELEVANT ADMINISTRATIVE PRACTICES**

There are a number of different administrative requirements, reports, and duties that must be accomplished by the Principal Investigator. It is no overstatement that the regulations, policy statements, and implementation guidelines governing these administrative requirements fill volumes. The following paragraphs provide a brief overview of general administrative practices in which the author was required to participate.

### **Recurring Reports and Reviews**

Progress reports, which details accomplishments of an R&D effort are required at different intervals, depending upon the requesting authority. Direct personal contact is considered the basic means for the technical monitorship of ongoing research projects between R&D performing elements and proponents. However, management requires progress reports either monthly or quarterly.

Program reviews are conducted, as needed, by the Director of R&D. These reviews constitute a detailed review of selected research being performed. The objectives are to evaluate program execution in relation to the approved program, evaluate adequacy and use of available resources, and evaluate technical progress of the research program.

Annual program reviews are also held for users of the R&D. In the case of the research described here, the user is defined as the U.S. Army Engineer School (USAES).

After the annual review, personnel from the USAES rank the research programs based on the linkages to battlefield capabilities and battle dynamics.

Informal program reviews are held at WES on either a quarterly or annual basis.

### **Transferring of Funds**

The execution of a research program often requires the transfer of monies from one organization to another. This can include the receipt of funds to perform specified research or the transfer of funds to another organization. Funds are often transferred to other organizations that are participating in a research effort. The following discussion describes the two primary methods used to transfer funds. These methods are for the transfer of funds to or from WES. Transfer of funds within WES is performed with the assistance of the Resource Management Office at WES.

### **MIPR**

Military Interdepartmental Purchase Request is a U.S. Government vehicle for the transfer of money from one organization to another.

### **2544**

Intra-Army order for reimbursable services, the DA2544 is also a means of transferring monies, but is strictly for U.S. Army use.

### **Contracting Procedures**

Contracts are heavily used vehicles for obtaining goods and services. The type of contract that is required often depends upon the size of the contract and the type of contract. The government is required by law to ensure that all contracts awarded are the result of full and open competition.

**Purchase Orders**

Purchase orders can be used for to obtain goods and services if the cost is less than \$25,000.00. A sole-source justification is required for any purchase order, due to requirements for open competition. However, if the cost is less than \$2500.00, a sole source justification is not required.

**Other Forms of Contracting**

All proposals for contracts that are for an amount greater than \$5000.00 must be advertised in the Commerce Business Daily (CBD) for 60 days. The reason for this requirement is to ensure full and open competition.

**Broad Agency Announcement**

The Broad Agency Announcement (BAA) was implemented in 1986 as a means of soliciting proposal for basic research. The BAA is general in nature, identifying the areas of research interest, including criteria for selecting proposals, and soliciting the participation of all offerors capable of satisfying the Government's needs. The proposals submitted under the BAA are subject to peer or scientific review. Proposals selected for award are considered to be the results of full and open competition. Since the requirement for full and open competition is fulfilled, advertisement in the CBD is not required.

**ADPE Purchases**

The purchase of Automated Digital Processing Equipment (ADPE) is governed by an even stricter set of rules. A justification for purchase, as well as a cost comparison, is required for all ADPE purchases greater than \$5,000.00.

## **SUMMARY OF PROGRAM AND ADMINISTRATIVE SETTING**

### **Internship Position and Duties**

The internship consisted of service as a Civil Engineer, GS-12. My appointment under Federal service was to the Civil Engineering Position (a vacant FTE at the time), based on past education, training, and experience. Basic qualifications for appointment consideration in that series and grade are essentially the same for all positions.

### **General Technical Duties**

A GS-12 engineer is an independent investigator charged with applying judgement and experience to broad areas and studies. Assignments are made by a general problem statement and objectives to be met. The individual is expected to develop the work plan, identify required resources, and coordinate work with other disciplines.

Except in very rare positions, the Office of Personnel Management (OPM) is prohibited from requiring an employee to actually hold a specific academic degree or professional registration. However, a GS-12 engineer is described as typically having training beyond the master's level and experience equivalent to that required for professional registration. The equivalent American Society of Civil Engineers professional grade level is Grade V.

General technical duties on assigned work units or reimbursable projects included:

- Identify and define problems in sufficient detail to prepare scope of work, specify sub-tasks, develop preliminary approaches and schedules, and suggest form of products.
- Conduct literature searches and conduct others in the field to collect information on previous data, experiences, and results.

- Define final approaches including any necessary laboratory testing, field testing, or computer simulation.
- Report results including alternatives and recommendations.
- Serve as technical reviewer of products prepared by other investigators.

### **General Administrative Duties**

As noted, the technical position description presumes minimal administrative duties. The assigned general administrative duties, grouped by subject area, were:

- Work Program
  - Plan and organize workload assigned to team
  - Assign projects to team members, matching skill and capabilities
  - Establish priorities and preliminary schedules
  - Prepare required project/work unit documentation and status reports, and present at periodic program reviews
- Resource Management
  - Develop spending plans and initial programming of funds on new work and/or new FY
  - Ensure funds are productively spent and budget goals met

Chapters 3 and 4 provide specific assignment-related examples of the general technical and administrative duties listed above.

## CHAPTER III

### THE HAN RIVER CONTROL SYSTEM

The Han River Control System (HRCS) is a decision support computer software system which is being developed to support the United States Forces Korea (USFK)/Combined Forces Command (CFC) Engineer Staff. The system is designed to provide information and recommendations to the Commander in Chief's (CINC) staff concerning control of the Han River and possible water induced impacts on both defensive and offensive planning and operations.

I served as Contracting Officer's Representative (COR) for development of the HRCS. Although this assignment required primarily managerial and administrative effort, there were many technical considerations that had to be dealt with during the length of the project. I will discuss the background that led to the development of the HRCS, the HRCS itself, and finally the administrative requirements resulting from a project of this scope and magnitude.

#### BACKGROUND

The Han River Basin encompasses about one-fourth of the land area of the Republic of Korea (Figure 6). It has a total area of 25,944 square kilometers, of which 3,021 square kilometers are north of the Demilitarized Zone (DMZ). The basin includes the

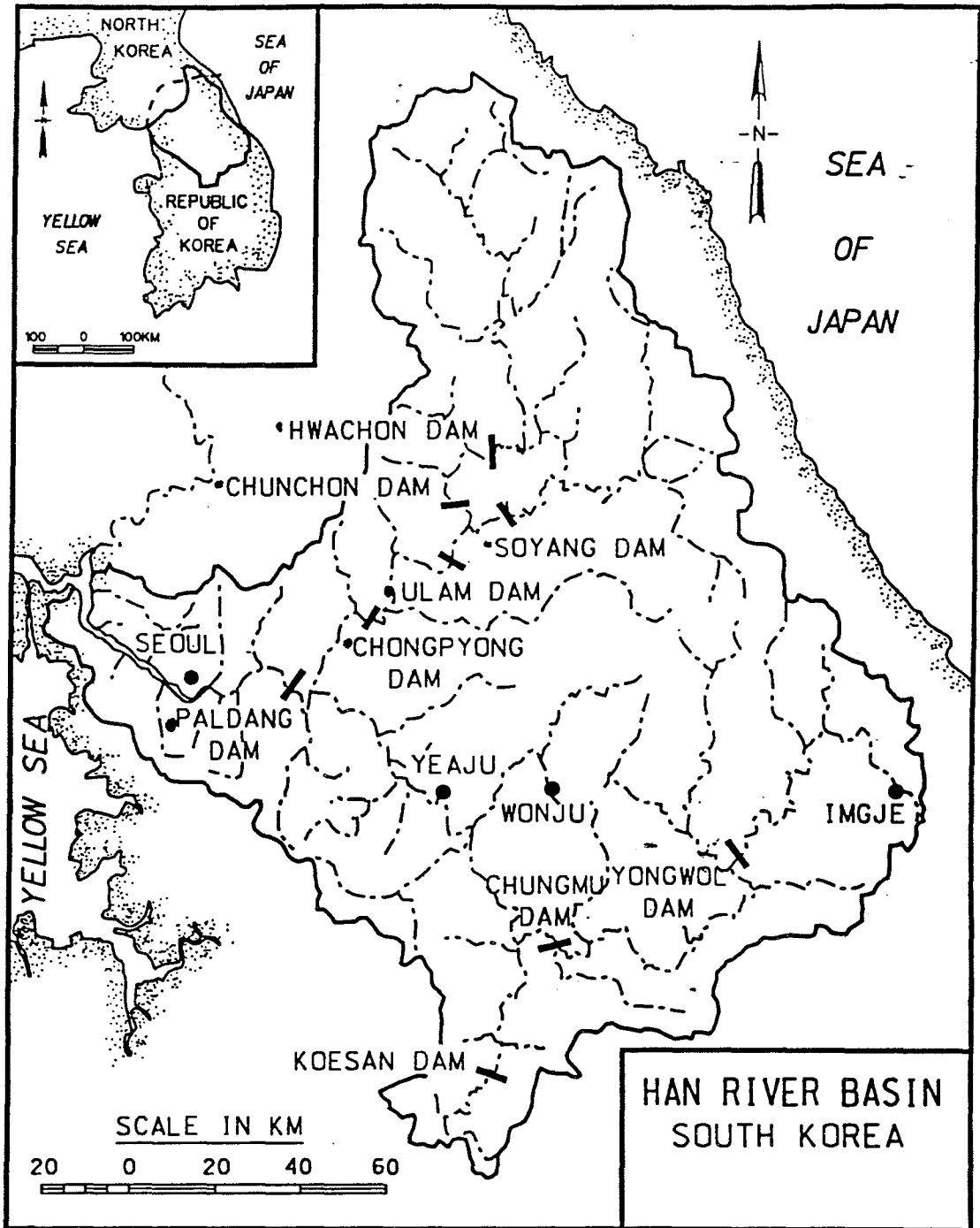


Figure 6. The Han River basin.



most extensive area of rugged terrain in the Republic, with some of the highest mountains on the southern portion of the Korean Peninsula located within its boundaries (Bureau of Reclamation and Geologic Survey, 1971). The basin consists of the Han River Estuary, the main Han River, and the North and South Han Rivers. The Han River Estuary extends for the Yellow Sea to the confluence of the Imjin River. The main Han River extends from the confluence of the Imjin River to a point 35 kilometers upstream of Seoul. At this point, the two main branches - the North Han and the South Han Rivers - continue to the headwaters. The South Han has three main tributaries: the Somgang, the Dalchon, and the Pyonchongang. The North Han River has one major tributary: the Soyang. From the Yellow Sea to the confluence of the North and South Han Rivers, there are approximately 100 river kilometers. There are 160 river kilometers along the North Han River from its confluence to the DMZ, with an additional 80 kilometers from the DMZ to the headwaters in North Korea. On the South Han River, there are approximately 315 river kilometers from the confluence of the North and South Han to the headwaters, all within the Republic of Korea (Bitters, Jourdan, and Restrepo, 1991).

Five major dams are located in the North Han River Basin. Four are on the North Han. From north to south they are the Hwachon, Chunchon, Uiam, and Chongpyong Dam. One additional dam in the North Han Basin, Soyang Dam, is on the Soyang River, which flows into the North Han between Uiam and Chunchon Dam. One major Dam, Chungju, is on the South Han River. Thirty kilometers upstream from Seoul, just below the confluence of the North and South Han Rivers, is Paldang Dam. These dams

are operated primarily for hydropower generation, although flood control and water supply are also important objectives.

Control of the Han River is of specific interest to the military in the Republic of Korea for several reasons. The three northernmost dams--Hwachon, Soyang, and Chunchon--are located approximately twenty-five, forty, and forty-one kilometers from the DMZ. This proximity of these dams to the DMZ creates the possibility that North Korea could rapidly capture these structures with an assault of Special Forces. There are several crossing sites along the Han River that could be jeopardized if these structures were lost to the North Koreans. Since most of Seoul is north of the Han River, and much of the resupply would have to be moved across the river in the case of a conflict, it is important to have the capability to accurately predict flow conditions along the river.

### **The Korean War**

During the Korean War there are several examples of the use of the river to hinder operations, whether military or civilian. In April 1951, the battle was north of the 38th parallel but south of Hwachon Dam, held by the North Koreans. United Nations forces constructed two floating bridges across the North Han about 15 miles apart, one just below the 38th Parallel and the other near Chunchon (Figure 7). The loss of either bridge would have seriously affected United Nations operations in this sector, since they were the only available crossings on the important Chunchon-Hwachon highway leading north.

Intelligence reports to U.N. troops in the North Han valley below the dam indicated that if the North Koreans should open the spillway gates of the dam, enough water was in

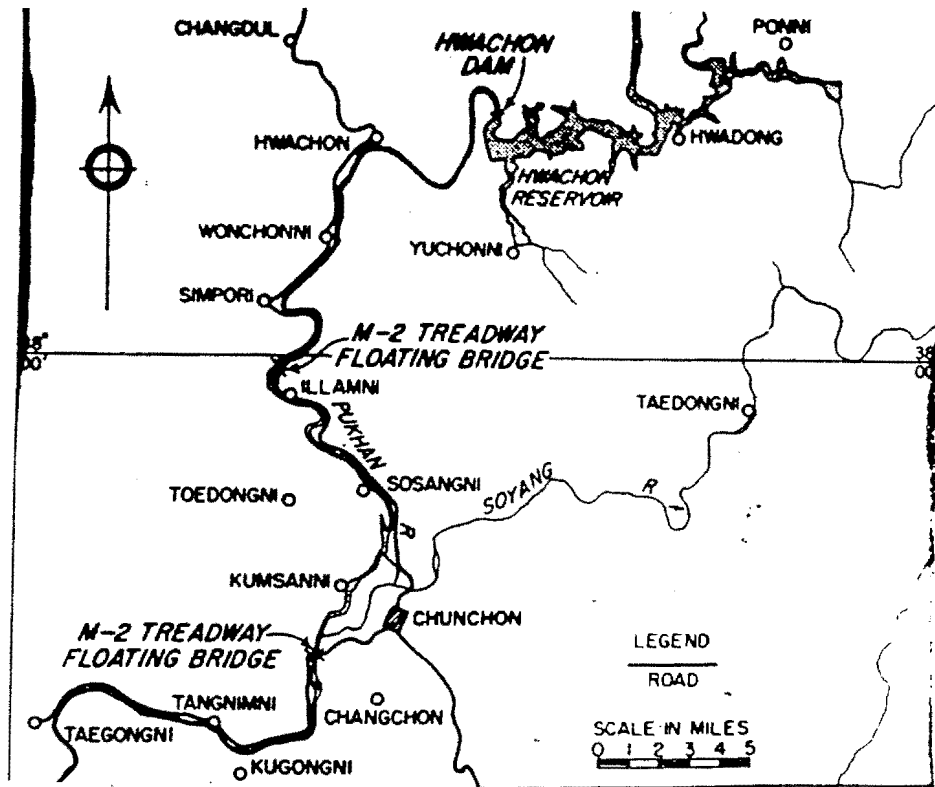


Figure 7. Map depicting the location of Hwachon Dam and the M2 float bridge sites.

storage to cause a floodwave which could endanger the U.N. floating bridges. On 19 April 1951, the North Koreans opened about one-half of these gates. The resultant flood wave created by this large release of water severed both floating bridges. Ferrying operations were set up at both crossing sites to maintain the supply routes along the river. In late May, U.S. naval torpedo bombers attacked the dam and effectively destroyed three of the spillway gates. At this point the dam lost its tactical significance because induced flooding could no longer be employed (Fowler, 1952).

In early 1952, the UN Command decided to pressure the enemy toward peace negotiations by striking at the economic heart of the country - the food supply. Seventy-five percent of the rice grown in North Korea depended, at that time, on water

supply reservoirs and irrigation networks. In addition, major transportation routes supplying the front lines passed through the valleys below many of these dams. Five dams were selected for attack. Of those five dams attacked, two dams - Toksan and Chansan - were breached by aerial delivered munitions. The resulting floods from these breaches destroyed or damaged miles of railway and highway, rail and highway bridges, many buildings, and silted up many miles of irrigation canals. The main supply routes to the south were cut for two weeks, and extensive and irreparable damage was done to the rice crop (Davis, 1990).

In addition to the impact that dams could have on the Korean War, the United Nations Forces also understood the problems that monsoonal flooding could create. The U.S. forces established the Flood Prediction Service to forecast stages along flood-prone rivers.

### **Recent Concerns**

Prior to the 1988 Olympic games in Seoul, the Government of South Korea started the construction of the Peace Dam, at a cost of approximately \$250 Million (Time, 1986). The dam was built in response to construction of a North Korean dam, Kumgangsan Dam, that was to be constructed 12.5 miles north of the Peace Dam on the other side of the DMZ. South Korea was concerned that Kumgangsan, which was to hold a reservoir of 20 billion gallons, may collapse or be demolished by the North. The resulting flood would be a disaster for the South, threatening the lives and property of millions. The Peace Dam, which is to be operated dry, was built to capture any flood waters that may be created by such a collapse.

## **DEVELOPMENT OF THE HAN RIVER CONTROL SYSTEM**

Capabilities for prediction of river conditions have evolved with technology. Original capabilities predicted the response of the river from rainfall events. Later capabilities allowed for the prediction of reservoir drawdown times and downstream effects of such operations. The Han River Control System includes these capabilities and many others. In addition, the HRCS has been developed in response to requirements of the engineering staff at the CFC.

### **Previous Capabilities**

Limited capabilities for prediction of the state of the river existed before development of the HRCS. Following are brief descriptions of some of these capabilities.

#### **Flood Prediction Service**

As stated above, the U.S. forces operated a Flood Prediction Service during the Korean War. The only primary mission of this group was the prediction of flooding along the river during the monsoon season. The U.S. forces had problems from high water level and velocities at several bridge construction sites. The Flood Prediction Service based their predictions on graphs, prepared earlier, which represented the relation of flood heights upstream to downstream flood heights and the timing of the floodwave.

#### **Reservoir Drawdown Procedures**

After the Korean War, many dams were built in the Republic of Korea. Since several of the dams were located near the DMZ, there was a concern that these dams may be captured by North Koreans before much of the reservoir could be emptied. If the North Koreans captured a full reservoir, they could use the water behind the dam to hinder

operations along the river downstream. The U.S. forces needed the capability to predict how long it would take to drawdown specific reservoirs. With this information, they could then determine if it was worthwhile to try to maintain control of a structure until it was sufficiently emptied.

A set of hand computation methods was developed that could provide predictions of drawdown times for specific reservoirs. These methods provided the engineers with estimates that were very useful for planning purposes. However, there were several incorrect assumptions behind them. The primary inconsistency was that they assumed a constant outflow through the outflow structures of the dam, regardless of the reservoir water elevation. Although these methods did consider both a fast and slow lowering of reservoirs, they did not consider downstream flow conditions.

### **RAMBO**

The Reservoir Analysis Model for Battlefield Operations (RAMBO) was developed in 1985-86 by the WES (Sullivan, 1989). RAMBO consisted of an integrated set of procedures for evaluating reservoir drawdown operation. These procedures incorporated military requirements, hydrologic modeling, and statistical analysis techniques into a comprehensive planning process. These procedures involved spreadsheet calculations, statistical analyses, and computer model simulations utilizing the HEC-5 Reservoir Operation Model. HEC-5 can be used to simulate both real-time and statistical planning drawdown studies. The model can also be used to evaluate basin demands (hydropower, water supply, and irrigation), as well as reservoir drawdown times and flow rates at downstream river crossing locations.

A case-study approach was adopted to evaluate the suitability of the HEC-5 reservoir operation model. The Han River Basin was chosen for the study because of potential of enemy capture of the reservoirs. Six scenarios were evaluated, ranging from slow drawdown of a single reservoir, to fast simultaneous drawdown of multiple reservoirs. The results were based on a statistical planning study utilizing 41 years of historic records.

The model results indicated that the HEC-5 computer model could be adapted for use by Army terrain teams to conduct reservoir drawdown studies and provide commanders with reservoir drawdown contingency planning guidance on a statistically derived historical basis.

#### **RAMBO-E**

In 1987, the set of procedures that made up RAMBO was integrated into a prototype expert system. It was realized that a system with high-resolution graphics, that does not require a great deal of expertise, was required if the military was going to perform complex analyses. Particularly because of the high turnover rate of military personnel, it was unrealistic to expect someone to become an expert on a system as complex as the Han River. Because of these reasons, it was decided that an expert system was required to assist the military in planning for operations along the Han River.

An expert system is defined as a computer application that would require extensive human expertise if performed as separate tasks (Simonovic, 1991). Expertise on control of the Han River is fairly complex and much of the decision process is based on a combination of field and technical expertise. The combination of high-resolution

graphics, artificial intelligence, and geographical information systems (GIS) together on a common platform, the engineering workstation, can make data and results accessible through user-friendly menus (Strzepek and Chapra, 1990). The ability to provide quick, concise results allows more time to explore alternative strategies.

This Reservoir Drawdown Expert System (RAMBO-E) could simulate any combination of reservoir drawdown scenarios with a stream gage in Seoul as the downstream control. The system was designed for non-engineer use and was entirely menu driven. Products of simulations included drawdown time histograms and cumulative distribution plots for each reservoir included in the simulation.

In October 1987, RAMBO-E was demonstrated to USFK (Seoul) personnel. A RAMBO-E analysis, conducted in conjunction with a USFK exercise, revealed that on-site Army estimation techniques provided inaccurate drawdown times.

RAMBO-E represented a significantly improved capability over previous drawdown techniques. Shortfalls with RAMBO-E, though, included the following: an inability to model complex scenarios (e.g., drawdown two reservoirs simultaneously while filling a downstream reservoir and then releasing this downstream volume of water at some point in time later), nonability to translate drawdown flow rates into required gate openings for each reservoir, inactive on-line help features, and cursory user documentation.

As a result of the demonstration in Seoul, USFK requested that additional enhancements be included in RAMBO-E to further increase the effectiveness of the system. These enhancements were:

- A. A real time operational analysis capability.



B. Graphically displayed inundation mapping for the Han River system linked to the DTED level I digitized data base.

C. Expanded crossing means menu.

D. Incorporation of a dam breach into RAMBO-E to integrate reservoir drawdown and analytical capabilities.

USFK personnel realized that because of a frequent turn over of personnel, it was unrealistic to expect someone on the staff to become an expert on the Han River. They believed that an expert system was ideally suited for serving as the interface between newly assigned staff officers and the technical portions of the software. USFK personnel supported further development of an expert system capability for forecasting operation of the Han River system.

## **HAN RIVER CONTROL SYSTEM CONCEPT**

The initial concept of the HRCS was formulated to help engineer staff officers in several ways. A tool was needed so that personnel with little background in hydrology could predict Han River flooding. A capability was also needed to allow the command to use the stored water in the river's many reservoirs to influence both friendly and enemy activity along the floodplain. The ability to predict the long-term effect of over bank flooding on off-road military operations was another requirement for this system. There was a requirement for this software to predict the downstream effect of catastrophic dam failure. Finally, a planning tool to compute time, personnel, and material requirements to perform tactical military river crossing operations was needed.

With these requirements defined, a two-phase development project was initiated. The first phase concentrated on the integration of existing runoff, streamflow, and trafficability software and developing a simplified user interface. The second phase concentrated on the refinement of the first phase software and development and integration of catastrophic dam failure and river crossing algorithms. Also, during the second phase, a detailed hydrographic survey was performed of most of the Han River system. This survey data were then integrated into the Phase II software.

### **HRCS User**

The HRCS was designed to be used by either engineer staff officers on the Combined Forces Command (CFC) Engineer Staff or the Combined Terrain Analysis Team (CTAT). The CFC is a command organization staffed by personnel from all the different arms of the military in Korea, i.e., U.S. Army, Navy, and Air Force, as well as ROK Army, Navy, and Air Force. The Engineer Staff of CFC is responsible for planning all joint operations.

The CTAT is a terrain analysis team, assigned to the CFC Engineer, which consists of ROK Army terrain analysts. During joint exercises and in the case of wartime, the 33rd Engineering Detachment would be assigned to the CTAT. The 33rd is a terrain analysis team assigned to the U.S. Eighth Army.

### **HRCS Data Bases**

The HRCS employs two different types of digital topographic data sets: areal terrain data and digital elevation data. The areal data is used to compute soil moisture retention

in the off-road trafficability module. The digital elevation data are used to identify potential flooded areas during high water periods.

The Korean Electric and Power Corporation (KEPCO) maintains a system of stream gauges (Figure 8) throughout the Han River basin. This system of gauges provides periodic telemetric reporting of river stages over the entire length of the river. In addition, flow at all dams is also reported. These data are available at the headquarters of the Han River Flood Control Center (HRFCC) in Seoul. The HRFCC also maintains a system of 60 telemetric rain gauges (Figure 9) covering the entire basin (with the exception of that portion of the basin that extends into North Korea). A modem link will be established to obtain real-time access to this information. If a telephone link is not feasible, the user will have the ability to input river stage, recent rainfall, and reservoir levels into the HRCS manually.

Cross-section geometry is required for the hydraulic computations. In Phase I, the required cross section were derived from 1:50,000 topographic maps. Phase II development included inclusion of cross-section geometry that was obtained from a stadia survey of the Han River.

#### **Memorandum of Agreement**

A Memorandum of Agreement (MOA) was signed on 8 June 1988 to establish and define ROK/US responsibilities and procedures for the design and implementation of an automated HRCS. This MOA stated that the CFC has the responsibility for operating the HRCS during war and peace. Operations and maintenance cost will be provided by CFC (ROK/US both).

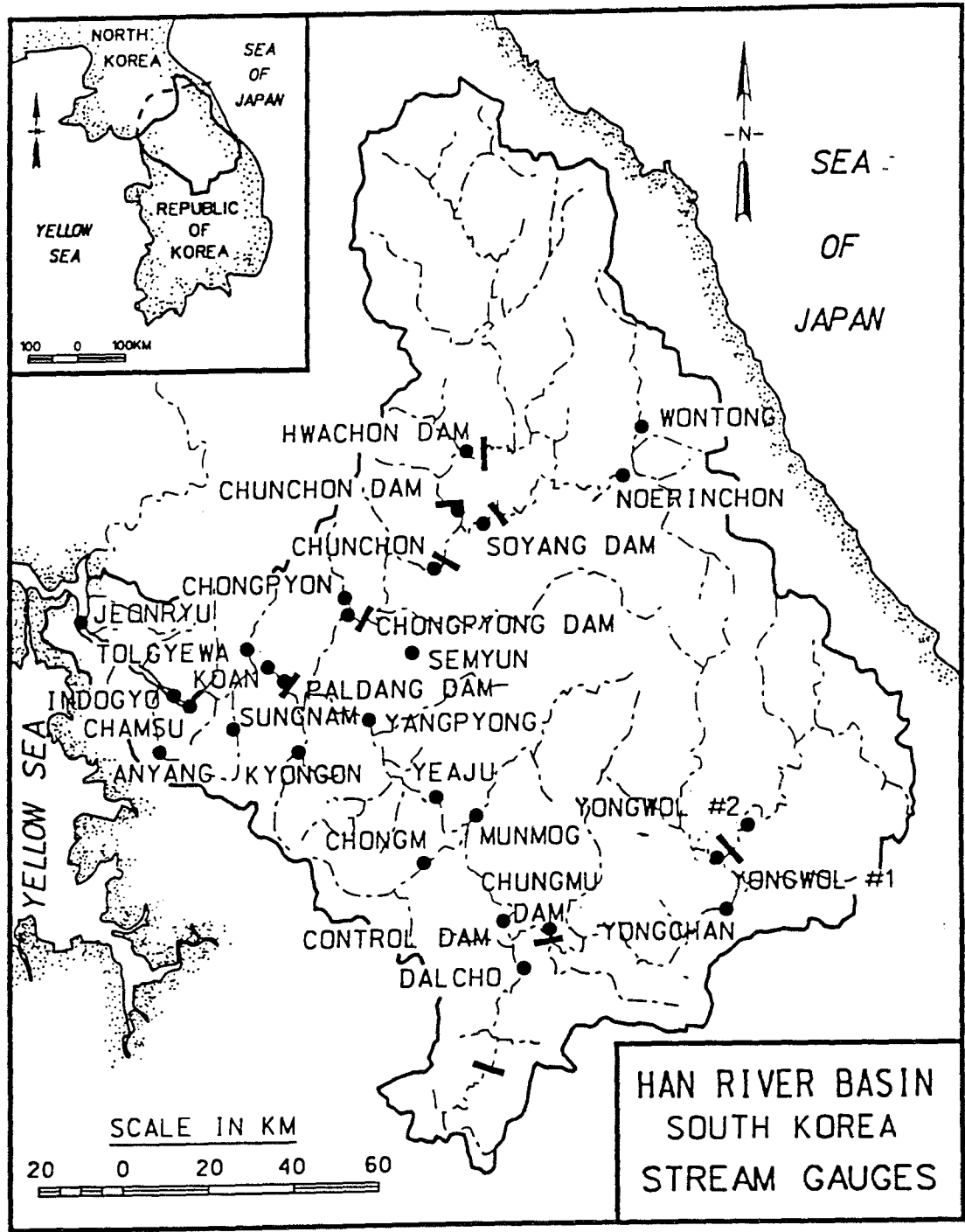


Figure 8. Han River basin stream gauges.

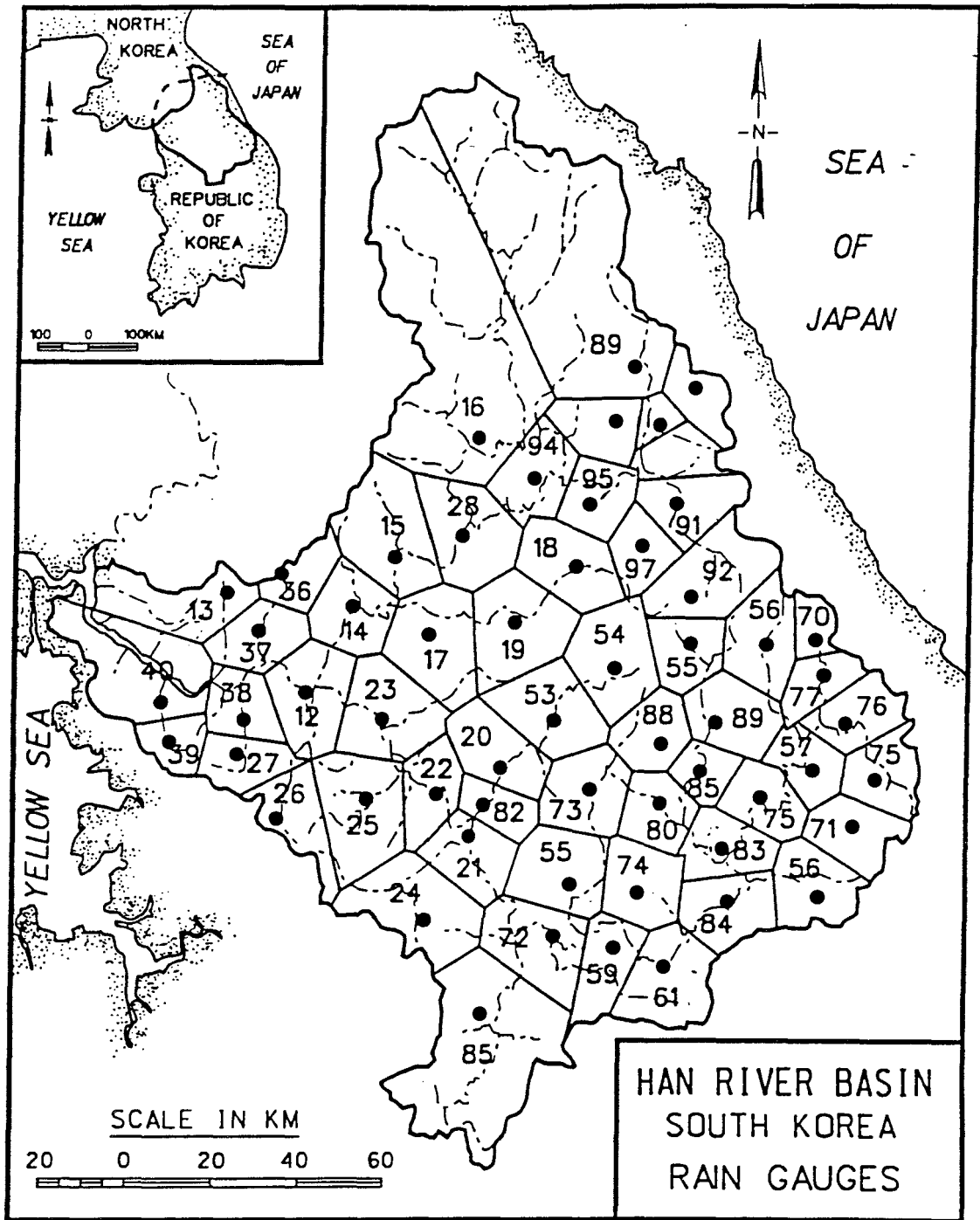


Figure 9. Han River basin rain gauge network.

The MOA stated both ROK and US responsibilities in development and operation of the HRCS. ROK responsibilities included a stadia survey of the North and South Han and the Han estuary. The stadia survey must meet specifications provided by the US. They were also required to: provide three modems for use at the Han River Flood Control Center (HRFCC), CFC Headquarters (Yongsan) and CP Tango; provide a data communication link between the HRFCC and CFC headquarters (Yongsan); ensure release of required over commercial telephone lines when requested by CFC; provide funding for travel and per diem for ROK personnel inspecting the stadia survey and trips to CADSWES and WES; provide and fund one ROK officer to work with CADSWES until the end of the project, assisting CADSWES in developing the software; provide structural data on the Han River dams; and provide the required telecommunications equipment to connect HRFCC computers to the modem.

US responsibilities included the following: providing the computer to operate the HRCS; development of the software that will analyze the data provided by the HRFCC, KEPCO, and historical information that will allow the Han River to be used effectively in military operations; provide a data communications link between CFC headquarters (Yongsan) and CP Tango; provide specifications of the Han River stadia survey to the ROKA; and provide required funding for travel and per diem for US personnel inspecting the stadia survey sites and visits to CADSWES and WES.

The MOA broke down the monetary contribution of each signatory. The ROK was to spend \$470,000, and the US was to spend \$460,000.

## **PHASE I OF THE HRCS**

The HRCS, designed for the nontechnical user, uses an advanced user interface and a complex software interface to connect a series of existing programs. The software interface prepares data for one module, in a format that is usable by one or more of the other modules. This advanced user interface allows the background operation of complex software to execute without user interaction.

### **The User Interface**

The HRCS was developed to provide the power of a computer workstation with minimal user effort. To do this, a user interface was developed around a consistent screen layout. After viewing one screen, all subsequent screens have the same format. This allows the user to easily adapt to the system. The screens feature an interactive overview map, a help window, "pop-up" tables for data input, and "buttons" to control repetitive operations. All screens, except those displaying detailed spatial data follow this format.

### **Rainfall-Runoff Module**

HYMO, developed by the U.S. Department of Agriculture, was used to model surface runoff in the HRCS. HYMO was originally developed for use in ungaged agricultural basins. Though HYMO was developed to model both surface runoff and streamflow, only the surface runoff procedures are employed in this system. HYMO provides an estimate of the runoff as a function of time for each basin in the study area. This estimate is based on a five-day precipitation forecast that is manually entered by the user. The precipitation is distributed over the basin using area-averaged Thiessen polygons

associated to each rain gauge. The resulting runoff estimates are required in both the routing model and the reservoir operations module. Graphic output includes runoff hydrographs for each subbasin.

### **Reservoir Optimization Module**

This module was developed by the University of Colorado to allow the user the ability to manipulate stored water in the reservoir. The basic principle behind either preventing or allowing a river crossing operation by operating reservoirs lies in the depth and velocity of the water at the crossing site. It follows then that there is a critical flow above which the water velocity and depth are such that a crossing is not possible. Similarly, there is also a depth and velocity above which it is safe to cross. Both flow thresholds are determined by the characteristics of the equipment used in the crossing.

This module allows the user to define selected spans of time when reservoirs should be emptied to prevent downstream activity on the river, or when water should be stored to allow downstream activity. One option during the data input phase is to define those spans of time when activity on the floodplain should be denied or allowed. Those user defined guidelines are defined in this model. From these guidelines, target discharge values are computed. These values are computed based on the volume of water required downstream, to increase or decrease flow velocity and water surface elevation. These target discharge values are recommended releases from the Han River reservoirs and are used in the routine model to manage water resources in the reservoirs.

The optimization module accounts for the operation of the system of reservoirs. Given a forecasted inflow to each set of the reservoirs, the flow constraints at the



crossing sites, and the reservoir operating conditions set by the user, the optimization module develops a release schedule that will minimize deviations from the flow requirements and from the operation of all those reservoirs with a manual schedule, a dump or fill goals.

### **Floodwave Routing Module**

The floodwave routing module uses CARIMA, a dynamic floodwave model developed by the French firm Sogreah. This model was selected because it can perform river routing during changing reservoir operations and during tidal fluctuations. The module requires both static and dynamic input data; static data being a detailed physical description of the river channel and dynamic data being runoff and target reservoir discharge. This module predicts reservoir discharges at all dams and water velocity and depth at each cross section. Graphs of flow and velocity versus time for cross sections and flow and volume versus time for dams are available as output.

### **Inundation Module**

The inundation module was developed using an abridged version of the Geographic Resource Analysis Support System (GRASS), developed by the U.S. Army Engineer Construction Engineering Research Laboratory. The primary purpose of the inundation module is to prepare a spatial display of inundated areas. The water surface elevation for each cross section computed in the routing module is used to develop the areal extent of flooding. This is accomplished by interpolating water surface elevation between adjacent cross sections and then subtracting actual terrain elevation from water surface elevation. Actual terrain elevation is obtained from digital elevation data. Output for this module is a

graphic depicting areal extent of flooding overlaid on a large scale shaded relief map. This flooded area overlay is also required in the trafficability computations.

### **Trafficability Module**

The trafficability module uses the Condensed Army Mobility Model System (CAMMS) developed by the U.S. Army Engineer Waterways Experiment Station. It was developed to model on and off-road mobility for military vehicle design and testing. CAMMS was modified for integration into the HRCS. CAMMS performs two major predictions: soil moisture content and vehicle mobility. Using the Soil Moisture Strength Prediction (SMSP) Model, CAMMS computes soil moisture content for points on the ground. These computations are based on past precipitation, soil type, and drainage characteristics of the land (termed the wetness index). These computations account for reported past rainfall, absorption, and evaporation. Using the rainfall record for non-flooded areas and the flooded area overlay generated in the inundation module, SMSP establishes the moisture content of the soil for all points on the ground. This information is used in the mobility model with specific vehicle performance parameters to compute the ability of a vehicle type to travel off the existing highway. Output from this module is a large scale graphic showing the flooded area and a prediction of the cross country mobility of the non-flooded area.

## **PHASE II OF THE HRCS**

Phase II development of the HRCS includes a more sophisticated rainfall-runoff module, an estuary crossing module, and a dam breach module. Phase II also included refinement of Phase I software and incorporation of the surveyed cross section data.

### **Improved Rainfall-Runoff Module**

The rainfall-runoff module that was included in Phase I of the HRCS was developed to obtain a reliable flow forecast in small basins, using very limited data. HYMO's estimate included a baseflow component that is added to the generated surface runoff to produce a total river hydrograph. However the user had to provide HYMO the base flow component which could only be determined by observation when several days had elapsed without precipitation. The lack of baseflow estimation severely limited HYMO's ability to provide sufficiently accurate flow forecasts in the Han basin. Moreover, the single-event approach further limited HYMO's usefulness since the HRCS requires a simulation of several days in duration, during which more than one storm event is likely to occur.

The severe limitations of HYMO suggested that the best way to increase at the rainfall-runoff forecast reliability was by adopting a model that considers base flow, and uses the available rainfall and runoff measurements to estimate the state of the river.

An improved rainfall-runoff model, named TAMU, was developed by Dr. Juan Valdes and Haitham Awad, of Texas A&M University (Valdes and Awad, 1991). TAMU is a stochastic model, developed for short-term forecasting, which incorporates terms for rainfall inputs and reservoir releases. The parameters of the model are

continuously calibrated using a Kalman filter, based on the differences between historical records and the values predicted by the model for the same record. Therefore, it is important, although not necessary, to provide the model information of the recent past rainfall runoff, in order to allow the model calibration procedure to update the model parameters to reflect more accurately the current basin conditions.

The Han River Basin has been divided into seventeen subbasins for the TAMU model. The outflow of each subcatchment is either an inflow to a reservoir, or a point of interest at which streamflow is required. Graphic output illustrates the flow from each subbasin.

### **Estuary Crossing Model**

The estuary crossing module permits the analysis of crossing operations in the estuary area. The estuary area of the Han River is subject to very large tidal fluctuations, and changes in the magnitude and direction of the flow. The beaches along the estuary are covered with a thick layer of mud. Until procedures are developed that allow the mud blanket to support personnel and equipment, crossing operations are limited to those times when the tidal elevations are sufficiently high enough that the bottom of the crossing vehicles does not touch the mud layer. Moreover, crossing operations are only possible if the water speed is slower than the boat speed.

The estuary crossing module, which was developed by Dr. Restrepo of the University of Colorado, implements a solution to this transportation problem based on an event-based simulation. The module considers the amount of equipment that must be transported across, the number of boats and loading docks, time to load, cross, and

unload, any waiting time that may occur owing to unavailability of docks. The module also considers sunrise and sunset, in case the analyst is interested in crossing only under daylight conditions.

There are two types of simulation using the estuary crossing model. In the first type, the system computes a crossing time, given the amount of equipment, number of boats, and any other constraining factors. In the second type of simulation, the system computes the percent of equipment crossed, given the amount of equipment, number of boats, and a required time at which the simulation must be completed. In this simulation, if all equipment was not transported across within the given time frame, the module will increase the number of boats and repeat the process. This iteration continues until all equipment is crossed in the specified time.

The graphic output from the estuary crossing module includes cumulative percentage of equipment crossed versus time, cumulative waiting time versus time, and the number of trips completed versus time.

### **Dambreak Model**

The objective of the dambreak module was to develop a system that will allow the CFC engineer to evaluate the flooding conditions in the Han River caused by one or more dam failures. The Dam Break Flood Forecasting Model (DAMBRK), developed by the National Weather Service, was integrated into the HRCS to provide this capability.

The module allows you to select one or more reservoirs for simulation. At present, only the reservoirs on the North Han River can be modeled. This system was integrated with the inundation module to produce maps of flooded areas. Data from these maps are

then passed to the trafficability module to determine the effect of that downstream flooding has on mobility through the floodplain.

### **Additional Capabilities**

The HRCS has the flexibility to perform analyses other than those for which it was designed. One example of an additional capability is ice break analysis. The question arose during an exercise in Korea on whether ice could be prevented from forming on the Han River. Personnel from the Cold Region Research Laboratory gave me rule-of-thumb relationships that could be used to answer this question. These relationships provide the required sustained flows necessary at the desired cross sections to prevent ice formation.

Other capabilities include analyses of standard operating procedures that call for drawdown of particular reservoirs, depending upon the threat of war.

### **ADMINISTRATIVE DUTIES**

A project the size and duration of the HRCS requires constant administrative attention. USAEWES served as the primary developer of the system, with much of the work contracted to universities. I served as Principal Investigator of this work effort at USAEWES. Administrative requirements included the issuance of contracts, acceptance of funds, contract negotiation, and a general buffer between the sponsor and developers. Following is a description of these administrative duties, and the role I played in development of the HRCS.

### **Duties of a Contracting Officer's Representative**

As the Contracting Officer's Representative (COR) of these contracts, I was responsible for providing direction and control of technical work under the contract. I was required to inspect and monitor contract performance to:

(1) Assure technical proficiency and compliance with the technical provisions of the contract.

(2) Assure that the contractor utilizes caliber of personnel required by the terms of the contract.

(3) Assure that the "quality of brain power" promised is not diluted by the excessive use of lower caliber personnel.

I was also required to inspect, review, and verify satisfactory performance of work accomplished for the purpose of recommending acceptance for payment by the Government. Acceptance for payment was granted by placing my signature on the voucher for purchases. Since this contract was amended several times, using different job numbers, I also had to specify which job number should be used.

I was also required to review and evaluate the contractor's progress and recommend to the Contracting Officer, in writing, changes desired in scope and/or technical provisions of the contract, with justification for the proposed action. When the contractor proposed a change, I had to obtain a written statement from him to that effect and forward it to the Contracting Office, together with my recommendation. The contractor could not proceed with these changes until proper action was taken to effect contract modification.

## **The Phase II Proposal**

Development and acceptance of the proposal for Phase II development of the HRCS were a long and tedious process. The two biggest problems were distance and personnel turnover. Army personnel in Korea, which is literally on the other side of the world, wanted development of the HRCS to continue. They also wanted personnel at WES to monitor the contract and provide technical assistance, advise, and guidance. Most of the work was performed in Boulder, Colorado or College Station, Texas. The distance problem required faxes that were not answered for a day or two and many late phone calls.

The problem with personnel turnover is primarily due to changes of the point of contact in Korea. Army positions in Korea last only one or two years. This frequent turnover requires that new personnel become familiar with ongoing projects, such as the HRCS. With each change of personnel, different perceptions of what the HRCS should look like were encountered.

### **Background**

Phase I of the HRCS, as used in this paper, refers to the development of the HRCS from the start of CFC funding to the beginning of Phase II. The original development of the RAMBO Model and RAMBO-E was developed with USACE RDT&E funds. CFC provided \$20K in March 1988 to add additional enhancements to RAMBO-E and to convert the model to run on a MicroVAX II GIX work station. The reason for conversion to a MicroVAX was the accessibility to such a machine in Seoul. An



additional \$55K was provided in July 1988 for development of software to map flooding in the Han River valley as a result of dam drawdown operations.

Finally, \$150K was provided in October 1988 for the following tasks: development and integration of a rainfall/runoff module and data base to provide rainfall input for the HRCS, based on forecasted precipitation in the Han River Basin; and development and integration of a trafficability module (incorporating the CAMMS model) and data base to provide vehicle performance prediction criteria within the Han River Basin. This scope of work was modified in May 1989 to include an improved reservoir module that will provide (1) a dynamic routing capability for complex scenario analysis, (2) reservoir outflow information translated into required gate settings for each reservoir during computer simulated drawdown operations, (3) a hydrologic routing capability that would be used during numerical instability conditions, and (4) a capability to modify basin river cross-sectional files; a tactical module, developed by CFC personnel; on-line help facilities; and user documentation.

In addition to changes in scope of work and additional requirements, personnel changes also occurred during Phase I. Dr. Pedro Restrepo took charge of the CADSWES portion of the development in August 1989, and LTC Gevedon replaced LTC Behrens as the HRCS point of contact at the CFC in July 1989.

In April 1990, Phase I was delivered to the CFC. LTC Gevedon was not satisfied with the product delivered. Some of the problems with the HRCS at that time included the following: the manual input screen and supporting software did not operate properly; the "Print Screen" option was not functional; the user did not have the capability to input

digitized terrain data; the system did not provide the user with the capability of determining how long it would take for rapid draw-down of one or more dams or provide the recommended release rates for the dams that would meet the objectives of the basis model; the initial version of the HRCS was not fully operational, thus CFC did not have the opportunity to fully exercise it.

This initial delivery of Phase I greatly impacted the negotiations for Phase II development. The following section explains some of the problems and how they were rectified.

### **Key Issues**

There were several key issues that had to be addressed during negotiations of the Phase II proposal. After initial delivery of Phase I, LTC Gevedon sent a letter to Ken Strzepek, Director of CADSWES, expressing his dissatisfaction with the product (reasons are listed above) and listing the remedies CADSWES must provide before Phase II development would even be considered.

One key problem that I recognized at this time was the inability of LTC Gevedon to understand the risks involved in research and development. His military background had taught him that when someone said he or she were going to deliver a product on a specific date, he could expect delivery. However, research and development of a new software product involves many uncertainties. I explained this to LTC Gevedon, and we offered solutions that were finally acceptable to all parties.

Another key issue that was addressed at this time was the proper lines of communication and responsibility. The fact that LTC Gevedon had sent the letter to

CADSWES, rather than through me, as COR, caused some problems that could have been rectified. Because of this incident, it was agreed that all communication between CADSWES and Korea would pass through me. It was also agreed that CPT Eom report to Dr. Restrepo, instead of being tasked by ROK officers back in Korea.

Another issue addressed at this time was one of responsibility. In addressing the inadequacies of the Phase I software, CADSWES was responsible for correcting some of these and Korea was responsible for others. For example, one problem that LTC Gevedon had with the software was that the "Print Screen" option did not work. However, since Korea did supply a printer to send data to, CADSWES could not be held responsible. Another example was the capability to determine drawdown times for one or more dams. Since this capability was included in earlier versions of the software, it was agreed that CADSWES was responsible for ensuring that this capability was included. Responsibilities were finally properly assigned.

### **Project Team**

The personnel involved in the development of the Phase II proposal included myself as COR; Pedro Restrepo, University of Colorado, CADSWES project engineer; Juan Valdes, Texas A&M, rainfall-runoff model; LTC Gevedon, CFC POC; CW2 Barry Bitters, Commander of the 33rd Terrain Team in Seoul, responsible for specifying the equipment requirements; CPT Eom, liaison ROK officer assigned to work at CADSWES on development of the HRCS; and Henry Horsey, acting head of CADSWES at the time of contract negotiations.

Most of the negotiations involved me, LTC Gevedon, and either Pedro Restrepo or Henry Horsey. Horsey played a significant part during this process, due to the fact that Restrepo was in Austria for the summer. Valdes had input into the proposal, since he was responsible for the incorporation of a different rainfall-runoff model. Eom did not have any real role in the negotiations, but since he personally knew the project team, he helped by providing suggestions and comments on the proposal.

### **Proposal Development**

The actual development of the Phase II scope of work and contract with CADSWES took several months. The initial proposal given to LTC Gevedon was delivered in April 1990. The final contract was not signed at WES until September 30, 1990.

The reasons for the delay in the award of the contract include the issue of what was to be included, responsibilities for discrepancies identified in Phase I, and communication difficulties, arising from the distance of the parties involved. Restrepo spent the summer of 1990 in Austria, further complicating the communication issue.

One of the primary problems during negotiations was the inclusion in the proposal of the following statement:

The research funded under this project will be communicated through software prototypes and reports. Section 3.0 specifies these deliverables. However this work is research and as such is subject to the risk associated with the development of new knowledge, and applications of state of the art technologies to real-world problems. The budget and scope of work in this proposal represents CADSWES's best estimate of the needs of the project. As more information is gained during the

project development, should changes in the scope or budget be required, CADSWES will immediately inform U.S. Army Engineer Waterways Experiment Station.

CADSWES insisted that this statement be included, in order to protect themselves from some of the problems that occurred at the end of the Phase I development.

The proposal was sent back and forth several times for minor modifications. All parties finally agreed to the terms of the agreement in September 1990. Since the funds that had been set aside for execution of the contract expired at the end of the fiscal year (September 30), the contract had to be signed by that time. The contract was finally completed at approximately 5:15 P.M. on 28 September (which was a Friday, making it the last working day of the fiscal year).

### **Phase II Project Execution**

Phase II included many interesting technical, managerial and contracting issues. Some of these issues are detailed in the following sections.

#### **Technical Issues**

As COR of this project, I was required to address many different technical issues. These include assisting in development of the dambreak rainfall-runoff, and flood routing modules.

I provided data necessary for development of DAMBRK model, which had been selected as the model to use for the dam breach module. Data provided included which dams to analyze, failure scenarios, initial hydraulic conditions to be considered, and failure mode (breach shape and time). I also provided much of the geometric data

necessary for the DAMBRK model. I provided the valley geometry and a geometric description of the estuary. The remaining geometric data were obtained by a stadia survey performed by ROK contractors.

I assisted in identification of the basins to be modeled in the rainfall-runoff module. One of the problems with this development was data gaps. There were several subbasins for which little or no data were available. We determined which basins were most like the basins lacking data, and used the relationships developed for those basins, accounting for differences in area, to provide data for those basins.

The developers at CADSWES had difficulties getting the flood routing module to execute. In December 1991, I visited CADSWES to assist in completing software development. Prior to my arrival, they were having problems running CARIMA on the main Han. I was able to identify the problems with the data set and CARIMA is now operating.

### **Managerial Issues**

AS COR of the contract with CADSWES, I was responsible for managing the technical and monetary issues. I also had to ensure that proper communication was maintained between the developers at CADSWES and the sponsor in Korea. In order to maintain communication, several meetings were held prior to and during the execution of the contract. There were several trips to the U.S. by the Korean sponsors. In July 1991 LTC Willhouse visited CADSWES to discuss final development of the HRCS. In November 1991 LTC Gevedon and BG Shin visited CADSWES to discuss and review the completion of the HRCS. The primary purposes for the meetings were to bring BG

Shin up to date on the status of the project and to plan for the training and workshop that will accompany installation of the system in Korea.

In July 1992 Restrepo, Valdes, and I traveled to Korea to install Phase II of the HRCS on a CFC computer, conduct training on the system, demonstrate the system, and conduct a workshop describing the system to U.S. and ROK military officers and South Korean academia.

In addition to the trips and correspondence, I had to obtain a Security clearance for Restrepo, handle CADSWES request for additional funding, and submit a proposal to CFC for training of a WES programmer.

### **Phase II Contracting Issues**

The original contract was issued in response to a proposal submitted via the Broad Agency Announcement, which was described in Chapter I. This contract, which was awarded the final working day of the 1991 fiscal year, provided for the development of the Phase II software.

There was a total of nine modifications to this contract. These contracting actions are listed in Table 2. Most modifications were relatively easy, at least for the COR. Typically, all that was required was a letter from CADSWES requesting a unilateral modification, and a letter from me (as the COR) justifying the modification and the sole source award.

The one modification that required additional effort was the first one, in which approval and funds were provided for purchase of a numerical modeling work station and peripherals. In particular the purchase was for a 2-dimensional graphics workstation,

Table 2. HRCS Phase II contracting issues.

DATE	MONIES RECEIVED	CONTRACT AMOUNTS	DESCRIPTION
30 APR 90	\$230,000		Phase II of the Han River Control System
28 SEP 90		\$205,249	Contract with CADSWES for software development
20 DEC 90	\$75,000		Procure hardware for Phase II
13 FEB 91		\$66,521	Modification 1 - Authorize contractor to purchase ADPE
13 May 91		\$16,013	Modification 2 - Dynamic model development and calibration for the HRCS
20 SEP 91		\$6781	Modification 3 - One additional trip to Korea
24 SEP 91		\$8689	Purchase software products from DEC
17 OCT 91		\$27,036	Modification 4 - Calibration of CARIMA Porting CARIMA to VAX Porting CAMMS to VAX Interface debugging Final testing Final Documentation
22 JAN 92			Modification 5 - No Cost time extension
3 APR 92			Modification 6 - No cost modification to extend contract through June 30, 1992
25 Aug 92			Modification 7 - No cost modification to extend contract through 31 Aug 1992
28 AUG 92		\$6,039	Modification 8 - Contract extension for one month and funds to complete model verification
23 APR 93	\$95,000		Funds to train a system programmer
6 JUN 93		\$7,040	Modification 9 - Assist in Ulchi Focus Lens
30 JUL 93		\$3,200	Purchase of Generalized Algebraic Modeling System



supporting software, a plotter, a digitizer, a color graphics printer, and a dot matrix printer.

Because of strict Federal regulations concerning the purchase of computers and related items, I had to write a detailed justification describing how the workstation was to be used and why other equipment could not be used, and list other projects for which this workstation could be implemented. A cost comparison was also required to ensure that requirements would be met at the lowest overall cost to the government. Three sources were found that met or exceeded most of the requirements

There were three modifications that were made simply to extend the period of performance. There were several reasons for the delays in contract performance. These include delay in receipt of stadia data from Korea, cancellations of trips to Korea, and time required to test and validate the system.

#### **SUMMARY OF INVOLVEMENT IN THE HAN RIVER CONTROL SYSTEM**

The HRCS is a decision support computer software system which was developed to support the United States Forces Korea/Combined Forces Command Engineer Staff. The system is designed to provide information and recommendations to the Commander in Chief's staff concerning control of the Han River and possible water induced impacts on both defensive and offensive planning and operations.

As COR of this effort, I was responsible for technical issues, management of the development and contracting.

## **CHAPTER IV**

### **OTHER ASSIGNMENTS AND CONTRIBUTIONS**

#### **BACKGROUND**

As described in Chapter II, the internship organization, (MHT) participates in a variety of project types covering a diversity of topics. The following projects were selected as part of the internship assignment to provide experiences representative of that variety. A brief explanation of the basis for each of the four specific assignments is presented below. Discussions of the projects follow in subsequent sections.

#### **Basis for Assignments**

The first two assignments involved the integration of previously developed models into battlefield software systems. The first assignment was the integration of the Tactical Dam Analysis Model (TACDAM) into the AirLand Battlefield Environment (ALBE) hardware/software system. This assignment was selected to provide exposure to a geographic information system (GIS) that integrated many different tactical applications.

The second assignment involved validation of the RESOUT Model. This assignment was selected to provide exposure to the Army's policy on verification, validation, and accreditation of software.

The third assignment involved integration of TACDAM and the Reservoir Outflow (RESOUT) Model into the Obstacle Planning System (OPS). The OPS utilizes a different GIS than the ALBE system, and is designed for use by U.S. Army Engineer officers. This assignment provided the opportunity to pursue additional funding for the MHT. Both of the first two assignments provided interaction with personnel from other COE research laboratories, specifically, the Terrain Engineering Center (TEC), the Cold Region Research and Engineering Laboratory (CREEL) and the Geotechnical Laboratory.

Finally, the fourth assignment involved a basin modeling comparison study to determine the applicability of replacing the curve number procedure used in the Military Hydrology (MILHY) Model with a soil moisture accounting procedure. This assignment was made to provide experience in the testing of hydrologic models.

All assignments were characterized by a need for planning, interacting, and coordinating with other professionals, effective communication and careful managing of limited time, labor, and physical resources. Overviews of each assignment, the contributions made and the consequences that resulted from the experiences are presented in the following sections.

## **INTEGRATION OF TACDAM INTO ALBE**

### **Assignment Objectives**

The AirLand Battlefield Environment (ALBE) Technology Demonstration Program, directed by the US Army Corps of Engineers (USACE) Directorate of Research and

Development, integrated selected capabilities from three USACE research laboratories - Cold Regions Research and Engineering Laboratory (CREEL), Topographic Engineering Center (TEC), and Waterways Experiment Station (WES) - and from the US Army Materiel Command's Atmospheric Laboratory (ASL). ALBE was a 6.3A-funded program that had the purposes of (a) developing application software (prediction algorithms and cause-and-effect relationships produced in the 6.1 and 6.2 RDT&E programs of the above laboratories) for tactical decision aids (TDA) and utilities, (b) demonstration of this TDA software within either a controlled (laboratory-type) or operational (non-laboratory) environment for target US military systems, and (c) distributing the ALBE TDA software to these US military systems (MP GL-92-36). ALBE's basic goal was to provide to the US military the TDA software capability to assess and exploit battlefield terrain and weather effects for maximum tactical advantage.

A work unit was funded in the ALBE program to integrate the TACDAM into ALBE GIS. This integration would provide the user, in this case terrain analysts, the capability to rapidly evaluate the military consequences of a dam breach event.

#### **ALBE Software/Hardware**

To facilitate the ALBE TDA demonstrations a Geographic Information System (GIS)/User Interface (UI)/Graphics software was developed by the WES Mobility Systems Division of the Geotechnical Laboratory that was tailored to the digitized terrain/weather data base requirements of ALBE. The data sets that were required for the different applications include the following: Digital Terrain Elevation Data (DTED), Interim Terrain Data (ITD) Surface Materials, ITD Surface Configuration, ITD

Vegetation, ITD Surface Drainage, ITD Transportation, ITD Obstacles, and Arc Digitized Raster Graphics (ADRG) Image Map. The ALBE GIS provides terrain input for intelligence preparation of the battlefield. The Defense Mapping Agency (DMA) provides a standard digital terrain data base as input to the DTSS. The data base provides the essential data on soil characteristics, vegetation, hydrologic features, etc., for the operational area.

However, the core software required to accomplish the purposes of ALBE is the ALBE TDA application software. This application software is divided into the following ten categories: Army Aviation, Countermobility, Ground Mobility, Maneuver Control, Meteorological Analyses, Nuclear/Biological/Chemical, Terrain Factors, Visibility, Weather Effects, and Weapon System Performance. The Tactical Dam Analysis Model (TACDAM) is included in the Terrain Factors category.

The ALBE hardware is called the Digital Topographic Support System (DTSS). The DTSS is an automated, tactical terrain data system featuring hardware/software modularity and utilizing modern electronic data processing and computer technology. It includes two interactive graphic work stations, a plotter, a digitizer, a printer, video, a disc player, and a data storage media. It allows the terrain analyst to make predictions as to the effects of weather and terrain on tactical considerations such as cross-country movement, concealment, cover and line of sight.

The DTSS is used by the engineer terrain teams at division and the engineer topographic company at corps and Echelons Above Corps. The DTSS is truck-mounted

and fully mobile. It includes the capability to manipulate and reformat digital elevation data bases for use with weapon systems.

### **The Tactical Dam Analysis Model**

The Tactical Dam Analysis TDA can be used to determine downstream effects of a dam breach. The underlying model uses standard DMA Digital Terrain Elevation Data (DTED) and Interim Terrain Data (ITD)-derived drainage data to calculate peak depth, time to peak depth, and time of flooding, each at selected points downstream of a dam.

A table containing peak depth, time to peak depth, and times of flooding at selected points along the river, downstream of the dam is provided. A hydrograph is also plotted that shows the above information, as well as the duration of flooding at the selected points. Finally, the area inundated by the floodwave is overlaid on the map of the area.

The Tactical Dam Analysis TDA uses the short version of the Tactical Dam Analysis Model (TACDAM) to determine downstream flooding below a dam breach. TACDAM computes downstream flooding in three steps: development of the breach, calculation of the peak flow through the breach, and routing of the peak flow through the downstream valley.

The hydrology layer of the ITD contains a map depicting the stream channel. However, this map does not contain information that indicates the direction of flow. A routine was developed that accesses the DTED data and determines the downstream channel and channel elevations. The flow direction is determined through a graphical user interface that allows the user to select the flow path. This routine was incorporated

into both the TACDAM TDA and the Ice Break TDA, developed by personnel at CRREL.

### **Consequences**

A capability for analysis of the effects of a dam breach was incorporated into an Army GIS. This effort was documented in the following two publications.

Jourdan, M.R. and Hayward, K.M. 1992. "ALBE TDA: Tactical Dam Analysis," from ALBE Tactical Decision Aid (TDA) User's Guide (Version 2.0), pp 4-TF-88 - 4-TF-97.

Jourdan, M.R. and Hayward, K.M. 1993. "ALBE TDA: Tactical Dam Analysis," from ALBE Tactical Decision Aid (TDA) User's Guide (Version 2.1), pp 8-TH-7 - 8-TH-18.

The distribution of the software/hardware system provided visibility to the MHT and increased the opportunities for future work.

## **VERIFICATION OF THE RESERVOIR OUTFLOW MODEL**

### **Assignment Objectives**

The Department of Defense has a policy that calls for verification, validation, and accreditation (VV&A) of all models used for studies and analyses, training, combat developments, education, operational planning, testing, and command decision aids. The purpose of a strict VV&A policy is to provide quality assurance for, and establishment of credibility of models.

Verification is the process of determining that a model accurately represents the

developer's conceptual description and specifications. Verification is designed to ensure that a computer program carries out the logical processes expected of it, and that the processes act rationally and are consistent with the mathematical model.

Validation is the process of determining that a model is an accurate representation of the intended real-world entity from the perspective of the intended use of the model. Validation is achieved by a comparison of predicted and observed values for a wide range of conditions. There will always be some events where the model produces satisfactory results. Discrepancies must, however, be small for a wide range of application. Conditions outside the model's range of application must also be defined.

Accreditation is the process of certifying that a model is acceptable for use for a specific application. Accreditation is approval by management - based on experience and expert judgement - that a model is adequate for its intended use.

The primary objective of the work effort was to begin the process of verification and validation of the RESOUT Model. The RESOUT Model is a generalized computer program for determining discharges from reservoirs. Rating curves (reservoir water surface elevation-versus-discharge relationships) can be developed for a comprehensive range of outlet structure types and configurations (Wurbs and Purvis, 1991). This analysis focused on RESOUT's capabilities to create rating curves for ogee crested spillways (weir flow) and spillway gates (orifice flow).

An additional objective was to develop rules of thumb, so that minimum input data would be required to generate reasonably accurate rating curves.



## General Project Description and Results

In general, there is a surprising shortage of verified rating curve data. Theoretical and model rating curves are available, but it is unclear whether or not these curves have been validated for a wide variety of water surface elevations and gate openings.

### Data Sets

Three data sets were located that appeared suitable for this analysis. These data sets included one theoretical data set and two prototype data sets. The theoretical data were Example 14-1 in Open Channel Hydraulics by Chow. The two case studies which were located analyzed the Raystown Dam (Fagerburg, 1979) and the Chief Joseph Dam (Fagerburg, 1987). The shapes of these spillway crests are in general agreement with the WES standard spillway shapes.

Efforts were made to obtain suitable data sets for foreign dams, since it is most likely that RESOUT will be used in overseas locations. Several rating curves were available for reservoirs on the Han River system in the Republic of Korea; unfortunately, the manner in which the rating curves were developed is uncertain. For example, it is unclear if the rating curves provided are theoretical rating curves which have been verified actual flow data. Furthermore, the shapes of many of the older spillways may not be in general agreement with the WES standard spillway shapes. It was decided that these dams could be analyzed in future efforts.

The RESOUT analysis (results presented in Appendix A) varied for each of the three data sets. For the Chow data set, analysis was performed with the weir coefficient specified and the weir coefficient estimated internally. Sensitivity analysis was

performed on approach depth and design head. For the Chief Joseph Dam data set, analysis was performed on both orifice and weir flow. Sensitivity analysis was performed on the following: approach depth, approach width, height of spillway above approach apron, radius of adjacent concrete abutment, weir coefficient, and the number of points generated in the rating curve. For the Raystown Dam, analysis was performed on orifice and weir flow, with sensitivity analysis performed on approach depth and height of spillway above approach apron.

These data sets were used to begin verification and validation of the RESOUT Model and to develop an understanding of the minimum data required. In addition, certain rules of thumb were developed and are presented below.

### **Minimum Input Data Required**

At a minimum, the following characteristics of a given reservoir must be obtained to execute RESOUT: height of dam, length of dam, elevation of spillway crest, type and number of spillway gates, width of spillway gates, and evaluation of downstream submergence (if submerged, extensive downstream channel data required).

Naturally, the following additional data will improve the possibility of an accurate value of predicted discharge: type of piers, design head, characteristics of spillway shape, slope (if any) of upstream spillway face, and any site-specific conditions or unusual construction techniques.

### **Rules of Thumb**

The following rules of thumb were developed to minimize the input data required for a satisfactory RESOUT run. While several runs were completed to investigate the

sensitivity of the parameters discussed below, the following rules of thumb are intended only to be guides to minimize the input data required for RESOUT runs.

The site-specific geometry of the reservoir under consideration must always be analyzed. For example, inflow irregularities associated with complex approach flow geometry or unusually spaced piers can have a significant impact on the capacity of a spillway.

a. Tainter spillway gate orifice coefficient. This coefficient ranges from 0.67-0.73, and increases as the size of the gate opening increases. As a general guide for high spillways, this coefficient can be assumed to be an average value of 0.69. For low spillways, assume a value of 0.67.

b. Approach width. Use the length of the dam for the approach width.

c. Approach depth. Use two-thirds of the height of the dam.

d. Height of spillway above approach apron. Use two-thirds of the height of the dam.

e. Design head. If design flood levels are unknown, use the elevation of the top of the dam minus the elevation of the spillway crest.

f. Type of piers. If the type of pier is unknown, assume type 2 piers. Type 2 piers have approximately average values of pier contraction coefficients.

### **Verification and Validation**

Several logic errors were identified and corrected. However, a complete verification of the RESOUT Model was not conducted. This analysis focused on RESOUT's

capabilities to create rating curves for ogee crested spillways (weir flow) and spillway gates (orifice flow). As such, the remaining RESOUT capabilities were not tested.

The validation of RESOUT showed that for the minimum set of reservoir parameters identified above, RESOUT will generate a rating curve generally consistent with theoretical and empirical rating curves. This is only for WES standard spillway shapes with no downstream submergence. However, RESOUT does not have the capability to model many site specific construction details. For example, on the Chief Joseph Dam, the piers extend approximately 6 ft upstream from the face of the dam; RESOUT cannot model this condition. Therefore, the potential impact of site-specific factors must always be made, and if necessary, adjustments made to the key parameters.

### **Consequences**

As a result of this work effort, the author became familiar with DoD requirements for verification and validation. Although complete verification and validation was not performed, initial efforts resulted in minimum data requirements and rules of thumb, which will be useful when integrating RESOUT into Army software packages.

## **INTEGRATION OF TACDAM AND RESOUT INTO THE OBSTACLE PLANNER SYSTEM**

### **Assignment Objectives**

The primary objective of this assignment was to secure additional funding for the MHT. Once the funding was secured, additional objectives were developed. These

objectives included the incorporation of TACDAM and RESOUT into the Obstacle Planning System (OPS).

### **General Project Description and Approach**

In order to provide guidance to the R&D community, the Army has established a set of science and technology objectives (STOs). A science and technology objective states that a specific, measurable, major technology advancement is to be achieved by a specific fiscal year. The benefit to obtaining funding for work that is linked to a STO is that this funding is then fenced, which means that the funding cannot be cut.

The MHT was able to obtain funding for work under STO II.I.6 entitled "Rapid Obstacle Creation, Reduction, and Planning." The primary objective of this STO is to provide the capability to effectively plan and execute engineer countermobility missions within the maneuver commander's decision window. This STO runs through FY97, when we are to provide a suite of software algorithms that accurately evaluates the effect of different engineer countermobility employment options into the Maneuver Control System.

The work unit, entitled "Tactical Hydrology" called for the incorporation of several different models, in particular, the TACDAM and the RESOUT models, into the Obstacle Planner System (OPS). The author serves as the Principal Investigator of this work unit. Funding averages about \$250,000/year.

### **Obstacle Creation**

The standard techniques of obstacle creation include mine fields and tank ditches. The ability to create a large linear obstacle and the ability to predict the extent of that

obstacle has provided the impetus for the incorporation of reservoir release prediction models to enhance an obstacle planning system. The method currently used to plan and analyze the placement of countermobility obstacles in support of Operation Plans is a manual effort that is labor intensive and very time consuming. Typically, an effective system of obstacles must be based on the commander's maneuver plan and must be considered together with covering fire weapons and the terrain and weather conditions. The purpose of such a system is to disrupt, turn, fix, or block the advance of threat forces.

Although the Army is interested in flooding that results from natural events (rainfall or snowmelt), the concept that it is possible to flood areas downstream of a reservoir has always appealed to them. As stated above, the Army has always been interested in the creation of obstacles. The ability to create a large linear obstacle and the ability to predict the extent of that obstacle has provided the impetus for the incorporation of reservoir release prediction models to enhance an obstacle planning system.

Two capabilities that are of most interest to Army planners are the capability to predict effects of a dam breach event and the capability to predict effects of reservoir regulation through manipulation of the gates. These capabilities can be provided through the incorporation of the Tactical Dam Analysis Model (TACDAM) and the Reservoir Outflow (RESOUT) into the OPS.

### **The Obstacle Planner System**

To assist the officers tasked with obstacle planning as well as to assist the Army in a faster, more systematic way to perform obstacle planning, state-of-the-art software is being developed at the U.S. Army Engineer Waterways Experiment Station (WES). This

automated engineer planning software is titled the Obstacle Planner System (OPS). The objective of this research thrust is to develop automatic procedures to support the engineer officer in the field in the development of countermobility obstacle plans (Doiron and Underwood, 1991). These plans are developed based on the commander's intent for fighting a battle and the engineer resources available to support the commander.

### **The Army Tactical Command and Control System**

The OPS will be integrated into the Army Tactical Command and Control System (ATCCS). The ATCCS consists of five basic nodes - Maneuver Control System (MCS), Fire Support (FS), Air Defense (AD), Intelligence & Electronic Warfare (IEW), and Combat Service Support (CSS). The MCS has several subsystems to supply the maneuver commander and his staff information in support of the development of operations plans. One of the subsystems is for engineers - the Tactical Engineer Command and Control System (TECCS).

TECCS is being designed and developed to support the planning and execution of engineer operations on the battlefield. It will provide automated command and control to engineer forces. TECCS will provide Engineer forces with the capability to rapidly collect and analyze combat information, quickly perform mission analysis and resource management, and make timely decisions consistent with maneuver commanders and planners.

TECCS will expand the scope of the MCS by combining automated engineer and terrain planning with maneuver and fire support planning. TECCS includes capabilities for engineer brigades, battalions, companies, platoons, and the engineer force level staff

representatives within the TAC, main and rear command posts from corps through battalion. TECCS will operate on the Army Tactical Command and Control System (ATCCS) common hardware.

The four functional areas for engineer planning and execution are - mobility, countermobility, survivability, and sustainment engineering. The OPS will supply the countermobility portion of TECCS.

### **Integration of TACDAM**

Integration of TACDAM into OPS began with the incorporation of the ALBE version of the TACDAM TDA. The model was ported from a Hewlett Packard workstation and the code was modified to account for differences in the GIS. Although the GIS used for OPS was similar to the ALBE GIS, in many cases there were some different calls used to access the data.

The ALBE version of TACDAM performed satisfactorily except for the delineation of the downstream channel. The original TACDAM TDA used the hydrology data from the GIS to determine the location of the stream. Elevation data were then used to determine channel slopes. The problem is that the hydrology data and the elevation data are generated from two different sources. The hydrology data are obtained from maps of a 1:250,000 scale, whereas the elevation data were obtained from maps of a 1:50,000 scale. Because of the different origins of the data, they often did not line up correctly. This resulted, when stream locations were mapped on top of elevation data, in the channel frequently going over bluffs and other high areas. In order to resolve these



inconsistencies, the hydrology layer was not used for location. A stream delineation routine was incorporated into the software.

After the stream is delineated, it is necessary to determine the flow path from the dam to the downstream point under analysis. In the ALBE TACDAM TDA, a graphical user interface was used to determine the flow path. This required significant input from the user. In the OPS TACDAM TDA, flow path generation was automated,

Another important addition to this version of TACDAM was the ability to generate cross sections from the hydrology data and the elevation data. In the ALBE TACDAM TDA, a uniform channel was used for the entire downstream channel. The OPS TACDAM TDA uses up to 15 different cross sections to describe the downstream channel:

### **Stream Delineation**

The first step in determining the effects of a dam beach is delineation of the stream network between the two selected points. This delineation is performed using the R. Watershed command (Open GRASS Foundation, 1993, GRASS Version 4.1 Users Reference Manual, Center for Remote Sensing, Boston University) from the Geographic Resources Analysis Support System (GRASS). R. Watershed was stripped from GRASS and modified so it could be used in the OPS GIS.

R. Watershed determines the stream network using digital elevation data. R. Watershed uses the Astar technique, a least-cost search algorithm, described in Ehlschlaeger (1989).

It has been found that R.Watershed will produce reasonable results in steep terrain, but may encounter problems in flatter terrain.

### **Flow Paths**

After the stream network is delineated, the flow path from the dam to the selected downstream point is determined. This is performed by a recursive search of the stream network. The searching algorithm is based on digital elevation data and uses the results from R. Watershed. Every pixel on the stream network is visited, and loopbacks are avoided by marking the pixels already visited.

### **Cross Section Generation**

Cross sections are generated using the hydrology layer of the ITD, the digital elevation data, and the flow path generated as described above. A cross section is generated at both the dam and the downstream point. The positions of additional cross sections are determined, along the flow path, by dividing the total distance between the dam and the selected downstream point by the number of cross sections required.

Cross sections are defined by three elevation top width pairs. The elevation of the first top width pair is equal to the elevation at the point in the DTED. The width of the first top width pair is equal to the channel width, which is obtained from the hydrology layer of ITD.

The second elevation top width pair is determined by adding the average of the left and right bank heights to the bottom elevation for the height and using the gap width obtained from the hydrology layer of ITD. The third elevation top width pair is

determined by extending a perpendicular to the stream until it reaches an elevation equal to the channel bottom elevation plus the dam height.

### **Build TACDAM File**

The TACDAM file is generated using the flow path and cross section data described above and dam characteristics obtained from the hydrology layer of the ITD. Following are the data elements obtained from ITD: dam crest length, dam material, dam height, and reservoir storage volume. These data elements are described in the TACDAM User's Manual (Jourdan, 1983). Using these data, the final breach width and depth, and the time required for breach formation are calculated. The equations used to calculate these data are described in the TACDAM User's Manual (Jourdan, 1983). The Manning roughness coefficient is set at 0.05. The user is given an opportunity to edit all these data elements if better data is available.

### **Execute TACDAM Model**

After the data file is built for TACDAM and the user has been given the opportunity to edit any of the data elements, the TACDAM model is executed. TACDAM computes downstream flooding in three steps: development of the breach, calculation of the peak flow through the breach, and routing of the peak flow through the downstream valley. The model calculates the maximum outflow at the dam, evaluates how this flow will be reduced as it moves from the dam to the downstream point(s) and finally computes the time of travel to the point(s). In producing the dam break flood forecast, the TACDAM model first computes the peak outflow at the dam based on the reservoir size and the temporal and geometrical description of the breach. The computed floodwave and

channel properties are used in conjunction with routing curves to determine how the peak flow will be diminished as it moves downstream. Based on this predicted floodwave reduction, the model computes the peak flows at specific downstream points. The model then computes the depth reached by the peak flow based on the channel geometry, slope, and roughness at these downstream points. The model also computes the time required for the peak to reach each forecast point and, if the user entered a flood depth for the point, the time at which that depth is reached as well as when the floodwave recedes below that depth, thus providing the user with a time for evacuation.

### **TACDAM Results**

TACDAM outputs are the following: (1) peak flow, (2) peak depth, (3) time to peak flow, and (4) time of flooding and deflooding for specified stations downstream of the dam. The peak flow, output in cubic meters per second, is the maximum flow at a specific cross section. The peak depth, output in meters, is the peak depth at that cross section. The time to peak depth, output in hours, is the time after the initiation of the breach that the floodwave peaks at that cross section. The time of flooding and deflooding is output in hours to indicate the time at which the floodwave will go above a recognized problem depth and the time at which the flood will recede below that depth.

A flooded area overlay is displayed. This overlay is determined using the peak depth from the output table. Perpendicular lines at each pixel along the stream are used for determining the extent of flooding at each pixel and to extend the interpolated flood. These perpendiculars are extended until they reach an elevation in the DTED that is equal

to the elevation at the stream pixel plus the peak flood depth at that pixel. Each perpendicular is then used to create a flood polygon that is passed to the OPS.

### **Integration of the RESOUT Model**

Integration of RESOUT into OPS began with the incorporation of the MS-DOS version of the RESOUT Model. The model was ported from a MS-DOS computer to a Hewlett-Packard workstation and the code was modified to account for access to the GIS. The version of RESOUT that is interfaced with the OPS allows analysis of two different structure types. These are tainter gates and vertical lift gates.

In order to predict flooding from reservoir releases through outlet structures, the RESOUT model performs many of the same steps as the TACDAM model, described earlier. The stream delineation, flow path identification, and cross section generation are identical.

### **Build RESOUT File**

The RESOUT file is generated using the flow path and cross section data described above in the section on the TACDAM, and dam characteristics obtained from the hydrology layer of the ITD. Following are the data elements obtained from ITD: dam crest length, dam material, dam height, and reservoir storage volume. These data elements are described in the TACDAM User's Manual (Jourdan, 1983). Using these data, the approach width, approach depth, design height, pier type, slope face correction factors and discharge coefficient are calculated. Many of the default values used in determining these coefficients are described in the following section. The equations used to calculate these data are described in an earlier report (Wurbs and Purvis, 1991).

### **Execute RESOUT Model**

After the data file is built for RESOUT and the user has been given the opportunity to edit any of the data elements, the RESOUT model is executed.

RESOUT computes a series of rating curves for the given configuration. A rating curve is the relationship between reservoir water surface elevation and discharge through an outlet structure. Discharge is a function of head, or water depth, above the spillway crest or outlet opening. A family of rating curves is required to express the water surface elevation versus discharge relationship, as a function of gate opening. Rating, or discharge, curves provide fundamental information for real-time reservoir operation as well as for mathematical modeling studies. Since stage is much easier to measure than discharge, the discharge from a reservoir is determined by applying the measured water surface elevation to the rating curve. For a given measured reservoir level, rating curves are used to select a gate opening or number of sluices to open to achieve a desired release rate.

Rating curve computation procedures are based on weir and orifice equations. Uncontrolled spillways are weirs, modeled using weir equations. Gate openings at gated spillways are orifices. Methods are incorporated into the weir and orifice computations to reflect approach velocity, submergence, and other conditions. These methods are described in Wurbs and Purvis (1991).

### **Build TACDAM File**

After the RESOUT model is executed, the results are used in building a TACDAM file. The TACDAM file is created using the maximum discharge from the rating curve

generated from RESOUT, the flow path and cross section data described in the section on TACDAM and dam characteristics obtained from the hydrology layer of the ITD.

### **Execute TACDAM Model**

After the data file is built for TACDAM and the user has been given the opportunity to edit any of the data elements, the TACDAM model is executed. TACDAM computes the downstream flooding resulting from the reservoir regulation, by routing the peak flow through the downstream valley. Based on this predicted floodwave reduction, the model computes the peak flows at specific downstream points. The model then computes the depth reached by the peak flow based on the channel geometry, slope, and roughness at these downstream points. The model also computes the time required for the peak to reach each forecast point.

### **RESOUT Results**

RESOUT outputs are basically the same as TACDAM results, which were described earlier, including (1) peak flow, (2) peak depth, (3) time to peak flow, and (4) time of flooding and deflooding for specified stations downstream of the dam. As in TACDAM, a flooded area overlay is displayed.

### **RESOUT Analysis**

Proper analysis of reservoir regulation impacts on the battlefield requires an iterative procedure. Since the basic principle behind either preventing or allowing a river crossing operation by operating reservoirs lies in the depth and velocity of the water at the crossing site, it follows that there is a critical flow above which the water velocity and/or depth is such that a crossing is not possible. Similarly, there is also a depth and/or velocity below

which it is safe to cross. Both flow thresholds are determined by the characteristics of the equipment used in the crossing.

The user must define the selected spans of time when activity on the floodplain should be denied. Target discharge values are then computed. These values are computed based on the volume of water required downstream, to increase or decrease flow velocity and water surface elevation. These target discharge values are required to create the obstacle. To determine if an obstacle can be created, the models described above must be run several times. Proper reservoir regulation can then be determined.

### **Consequences**

TACDAM and RESOUT have been incorporated into another ARMY GIS, this one for use by Army Engineer officers. This incorporation provides exposure of tactical hydrology models to a sector of the Army that had not previously been exposed. With the capability of the engineer officer to consider rivers and streams in the obstacle planning process, this part of the environment will be better understood and considered in future planning.

Several of the problems that were encountered in the incorporation of TACDAM into the ALBE GIS were addressed and corrected. The most significant was the use of the DTED to determine the flow paths.



## **BASIN MODELING COMPARISON**

### **Assignment Objectives**

The Military Hydrology Program had a work unit entitled "Tactical Streamflow Forecast Procedures for Mobility/Counter-mobility Operations." This work unit dealt with the development of improved procedures for the near real-time hydrologic prediction and forecasting of hydrologic conditions in the tactical environment. Procedures for forecasting state of the ground and streamflow had been developed.

The Military Hydrology (MILHY) model was developed through this work unit. MILHY is a single event hydrologic floodplain model developed for U.S. Army terrain teams. The model can be used to estimate streamflows, water surface profiles, and water velocities resulting from a storm event. MILHY was originally developed using the Soil Conservation Service (SCS) curve number procedure to predict effective rainfall. The Anderson Moisture Model (AMM) was developed as a possible replacement of the SCS routine.

The objective of this assignment was to determine if the AMM was a suitable replacement for determining effective rainfall. Suitability was to be judged by model performance and input requirements. A basin modeling comparison study was performed to determine the suitability. A basin in Vermont was chosen because of the availability of measured flow, rainfall, and soil data. Five rainfall events were used in the comparison study.

## MILHY

The Military Hydrology (MILHY) model is a single event hydrologic floodplain model developed for U.S. Army terrain teams under the Military Hydrology Program at the WES (James, Miller, Kerr, and Jourdan, 1984). The model can be used to estimate streamflows, water surface profiles, and water velocities resulting from a storm event.

The hydrologic portion of the model is an adaptation of the computer program HYMO written by Williams and Hann (1973). HYMO utilizes a modified two parameter gamma distribution for the development of the unit hydrograph. Rainfall excess is determined by the Soil Conservation Service curve number procedure (Soil Conservation Service, 1972), which limits the application of the program to a single event storm. The rainfall excess is convoluted with the unit hydrograph to produce the runoff from any subbasin. The model utilizes a variable storage coefficient developed by Williams (1969), which adjusts the routing coefficient with respect to changes in travel time of the flood wave through fixed reach lengths. The coefficient adjustment is a function of the water surface slope rather than the energy slope. A storage indication or Modified Puls method is used for reservoir routing.

### SCS Curve Number Procedure

The curve number procedure, which was developed by the Soil Conservation Service, is presented in the "National Engineering Handbook", section 4, "Hydrology" (1985). The procedure is a method of estimating rainfall excess from rainfall. The curve number runoff equation is given as:

$$Q = (P - I_a)^2 / ((P - I_a) + S)$$

where  $Q$  = depth of runoff; set to 0 when  $P < 0.2S$

$P$  = depth of rainfall

$I_a$  = initial abstraction

$S$  = maximum potential retention.

The SCS relates initial abstraction,  $I_a$ , to the maximum potential retention,  $S$ , by the relation

$$I_a = 0.2S$$

and the curve number (CN) relates to  $S$  by the relation

$$S = 1000/CN - 10.$$

The curve number for any given basin can be determined either through a model calibration using historical recorded data or from field or map surveys and the appropriate USDA tables. The curve number is an index based on five factors that relate to the runoff of an area. It represents the net effect of soil type, land use, land treatment, hydrologic condition, and the antecedent moisture condition.

Three antecedent moisture conditions (AMCs) are recognized by the SCS in the use of the curve number. These AMCs are used to index soil moisture as either wet, normal, or dry. AMC I is used, according to the SCS, if, within the last five days, there has been less than 0.5 inch of rain during the dormant season or less than 1.4 inches of rain in the growing season. AMC II is to be used if rainfall has been between 0.5 and 1.1 during the dormant season or between 1.4 and 2.2 during the growing season. AMC III is to be used if there has been more than 1.1 inches of rainfall during the dormant season or 2.2 inches of rainfall during the growing season.

The SCS curve number procedure is simple, quick and easy to apply, and requires data usually available for the ungauged basins. However, many hydrologists believe that the simplicity of application is achieved at the cost of reduced accuracy. Smith (1976) illustrated in a sensitivity analysis of curve numbers that a 10 percent change in the CN produced a 55 percent change in runoff volume and peak discharge rate. Hawkins (1975) identified an accurate estimate of the CN as the weak input link for this method. Hjelmfelt (1991) believes that due to the variation of the curve number from event to event, the curve number procedure should only be used to transform a rainfall frequency distribution into a runoff frequency distribution.

#### **Anderson Infiltration Model**

A soil moisture model was developed by Anderson (1982, 1984, and 1986), and Baird (1989) as a possible replacement for the SCS curve number technique. This infiltration model is a physically based and dynamic model which provides the capability to continuously simulate one-dimensional, near surface, soil water movement. During a storm, water supplied to the surface may either infiltrate or accumulate on the surface, and when a specified surface detention capacity is exceeded, runoff occurs. When precipitation ceases, water is redistributed by drainage and evaporation. The infiltration is described by the Richards' equation, which takes the following form:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left[ K(\theta) \frac{\partial (\Psi(\theta) - z)}{\partial z} \right]$$

Where:

$\theta$  = soil moisture content  
 $t$  = time  
 $K$  = hydraulic conductivity  
 $z$  = gravitational potential  
 $\Psi$  = moisture potential

In order to apply the mathematical infiltration model, each major soil type is represented as a soil column. The soil column is divided into as many as three layers; each layer is permitted to have different hydrological properties. All layers are further divided into cells, and flow between the midpoint of each cell is simulated under both saturated and unsaturated conditions. Detention capacity, expressed as an equivalent depth of water on the soil surface, has to be exceeded by rainfall excess before runoff begins. When precipitation ceases, this store is depleted by infiltration and evaporation. Detention capacity is the only model parameter that is not a measurable characteristic. It is not physically based, but represents the net effect of vegetation, interception, and surface detention. Its value also reflects the antecedent moisture conditions of vegetation and litter.

### **Comparison Study**

#### **Background**

The Sleepers River subbasin, Connecticut River basin, Vermont, is located 8.05 km northwest of St. Johnsbury. This subbasin has been the location of many field studies, including Dunne and Black (1970), and it is considered to represent a typical glaciated upland basin of New England. It is described by the USDA as comprising sloping to steep land at higher elevations. It has a covering of glacial till which exhibits good

surface drainage. The land use within the watershed is divided between permanent hay (17%), pasture (13%), and maple and beech trees (67%).

The basin used in this study had an area of 42.92 square kilometers. The small size of the watershed is not considered a disadvantage in this comparison study because the emphasis in this investigation is of the hydrograph computation procedure used in MILHY. It has not been designed to examine the characteristics of the Variable Storage Coefficient channel routing technique. The selection of a smaller watershed, which can be treated as a single watershed, has allowed the hydrograph computation to be investigated without the complication of the incorporation of the routing procedure.

#### **Data Collection**

Data collection involved securing three sources of information: topography maps of the basin, soils descriptions, and precipitation data. The basin characteristics: area, elevation, elevation difference, and main stream length (Table 3), have been derived from maps of a scale of 1:25,000. Also derived from 1:25,000 maps were the basin characteristics which are required for SCS curve number determination (Table 4). No subdivision of the basin was necessary, so channel cross section information was not required for channel routing operations.

The SCS curve number for the average moisture condition (AMC II) was computed to be 76. Lower curve numbers were used in the comparison study to observe the sensitivity of peak discharge.

**Table 3.** Basin characteristics required for the unit hydrograph procedure.

Area	42.92 square kilometers
Length of main channel	8.7 kilometers
Difference in elevation	1620 meters

**Table 4.** Basin characteristics required for the SCS curve number procedure.

Land Use	Basin Area (%)	Curve Number
forest	67	73
cultivated	17	82
pasture	13	79
idle	2	91
homesite	1	81

There are five major soil types in the watershed. These include sandy loams, silt loams, and loams, and are namely, Colrain, Peacham, Calais, Cabot, and Woodstock. The details concerning soil horizon depths and soil textural characteristics were available from the USDA ARS descriptions of the basin (Table 5). The division of each soil layer into cells was accomplished according to the general rule that cells in the top layer must not be greater than 0.1 meter and in the lower two layers, not greater than 0.15 meter. From the soil texture information, the Brakensiek and Rawls charts were used to define the soil hydrological characteristics. For all soil textures, the centroid position on the

Brakensiek and Rawls charts was used. Detention capacity was assumed to be zero and a uniform initial relative saturation of 80% was assumed.

**Table 5.** Soils information for application of the infiltration model to Sleepers River basin.

Soil Type	USDA Soil Texture	Average Depth (Meters)	Basin Area (%)
Cabot	silt loam	0.46	28
Buckland	loam	0.69	18
Woodstock	sandy loam	0.61	17
Glover	loam	0.69	12
Calais	loam	0.69	12
Colrain	sandy loam	0.84	10
Peacham	silt loam	0.31	3

### Comparison of Calculated and Measured Hydrographs

The precipitation data for all storms applied to this basin were converted into cumulative totals at an equal time interval. Initial moisture conditions used in the Anderson Infiltration Model (AIM) were derived from a volumetric moisture content analysis calculated using the gaged data. This analysis was performed at the CRREL. The measured hydrograph for each storm was also input for comparison. The storms which were used and the runoffs they produced are indicated in Table 6. Figures showing the rainfall and associated hydrographs for each of these events are included in Appendix B.



**Table 6.** Comparison of hydrograph peaks.

DATE	MEASURED (cfs)	CN=76 (cfs)	CN=65 (cfs)	CN=58 (cfs)	AIM	
					Moisture Content (%)	Peak Q (cfs)
Jun 1	1025	1756	310	14	29.0 20.0	1401 700
Jul 10	131	616	45	1	18.9 20.0	0 0
Aug 4	1548	5344	3222	2121	35.3 20.0	1990 1932
Aug 11	557	1693	701	225	20.0 40.0	48 200
Sep 1	409	850	137	1	18.9 20.0	4 9.0

Comparison of the hydrographs predicted by MILHY and the AIM and the measured hydrographs for a range of different storm events, allow examination of the capabilities of each model. Following is a brief description of the results of each storm that was used in this comparison.

The storm of June 1 had a maximum intensity of .56 inch/hour. The AIM predicted the peak discharge closer than the MILHY model. All predicted hydrographs were much steeper than the measured hydrograph.

The storm of July 10 is a complex event, with two peaks, both with a maximum intensity of .22 inch/hour. These peaks were separated by 22 hours. This is the type of event where the AIM should provide better results, due to the capability of infiltration

rates changing with time. However, the MILHY model better approximated the peak discharges.

In the storm of August 4, there was a maximum intensity of .43 inch/hour. In this case, the MILHY model over predicted the peak discharge, in comparison to the AIM.

The storm of August 11 was another complex storm, with a maximum intensity of .31 inch/hour. The AIM demonstrated a closer response to the double peak, but the MILHY model better estimated the peak discharge.

The storm of September 1 was a simple event with a maximum intensity of .34 inch/hour. In this case, the MILHY model provided a closer estimate of peak discharge.

These cases indicate that the MILHY model with the SCS CN procedure over predicts the peak discharge rate, relative to the AIM, for high intensity storm, and under predicts for low intensity storms. It is possible that improved predictions for each storm could be derived using the AIM if a degree of fine tuning of the model parameters were to be undertaken and if actual soil moisture values were available..

### **Consequences**

As a result of this analysis, additional study will be performed to determine if the Anderson Infiltration Model can be used as a replacement of the SCS curve number procedure. However, the additional data requirements do not, at this time, seem to warrant the replacement.

## CHAPTER V

### SUMMARY

This report described an internship completed by as part of the Doctor of Engineering Program at Texas A&M University. My internship was performed as a civil engineer with the Environmental Laboratory of the U.S. Army Waterways Experiment Station (WES), Vicksburg, Mississippi. A statement of objectives was prepared at the beginning of the internship to provide guidance for the experience and to allow for a meaningful assessment at its conclusion.

### ORGANIZATION

The first chapter of this report set forth the objectives and described the organizational setting of the internship. The second chapter described key programs and practices, and the general nature of the duties performed.

WES is a unique organization, both in mission and structure. It operates on a reimbursable basis to elements of the Corps and other agencies, and has a defined "client" orientation. A variety of work is performed, including pure research; product, process and equipment development and testing; and design services. Work is executed through six laboratories at the Station.

The Environmental Laboratory is a multi-discipline organization providing expertise in several program areas. My internship appointment was as Team Leader and Principal

Investigator of the Military Hydrology Team, with administrative and technical responsibilities for the technical progress and individuals involved in several military hydrology-related work units.

### **ASSIGNMENTS**

Five specific technical assignments were selected as part of the internship to provide experience representative of topics addressed in the Environmental Laboratory and the types of administrative roles likely to be encountered in engineering practice. Chapters 3 and 4 of this report described in detail the specific assignments and contributions.

In addition to the five technical assignments, I served as team leader, effectively performing primary management of the work program, personnel, and fiscal resources.

### **CONCLUSIONS**

My internship proved to be a period of continued learning for me. It was an extension of the academic world into the engineering world. The internship period helped me keep up an awareness of learning and an interest in my own development, two things which are sometimes difficult in a nonacademic environment.

I have gained knowledge in several important aspects of my job. First, I gained an insight into the functioning of my organization at WES - how the organization operates and some of the problems it encounters. The courses which I took in the Doctor of Engineering program helped me to be aware of the organization and the importance of the human element in its everyday operation. I also learned some of the workings of the

U.S. Army and WES' fiscal policies through participation in various planning meetings. The financial planning, programming, and accounting which I have performed are a direct result of the principles which I learned in the Financial Management courses of the Doctor of Engineering program. I have also gained further experience in presenting information to the sponsoring organizations or to the public by participating in many conferences and meetings.

The internship was comprehensive in scope, challenging, and fully met the intent of the Doctor of Engineering Program. It resulted in numerous contributions detailed in this report and demonstrated the author's ability to function at high levels of technical competency, professional development and managerial skill. Formal training completed during the Doctor of Engineering Program was relevant and facilitated significant contributions.

In addition, the internship provided me with a valuable base of experience in a number of technical areas, in the integrated administration of a work program and in the relationship between the two. All proposed objectives were met and the internship exceeded expectations.

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# **APPENDIX A RESOUT CASE STUDIES**

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**CASE STUDY 1: EXAMPLE 14-1, OPEN CHANNEL HYDRAULICS, CHOW.****RESERVOIR DATA**

- a. Downstream submergence of spillway: None.
- b. Approach width and depth: 250 ft, 120 ft.
- c. Height of spillway crest above approach apron: 102.3 ft.
- d. Design head: 17.7 ft.
- e. Characterization of spillway (high or low): high.
- f. Number and type of piers: None.
- g. Spillway shape: WES Standard.
- h. Spillway elevation: 982.3 ft.
- i. Number and type of spillway gates: None.
- j. Width of gate: net spillway width of 250 ft.
- k. Number and type of outlet works: None
- l. Remarks: This simplified example was used to ensure that RESOUT properly calculates the discharge from an uncontrolled ogee spillway with no contraction effects.

**Results/Analysis of Results**

The predicted discharge was most sensitive to the weir coefficient of discharge.

- a. Weir coefficient specified. When the coefficient of discharge was specified as the value used in Chow's example (4.03 ), RESOUT predicted a discharge of 75,500 cfs compared to the hand calculated value of 75,654 cfs for a 0.20% error.

This error can be attributed to the manner in which the program reads and subsequently reformats the input data file for later usage. Although this rounding error is larger than usual, it should not become significant given the amount of estimation required in the other input parameters.

b. Weir coefficient estimated internally by RESOUT. An error involving the estimation of the weir coefficient was discovered in RESOUT's uncontrolled ogee spillway subroutine. RESOUT only estimated one value of the discharge coefficient which was associated with the first elevation at which a rating curve was to be evaluated. For subsequent water surface elevations, a new value of the discharge coefficient was not calculated; instead, the initial value was used. Because of this constant weir coefficient, the predicted discharges were grossly underestimated at higher reservoir water surface elevations. Adjustments were made in RESOUT's code to account for this source of error.

When the coefficient of discharge was subsequently calculated internally by RESOUT, RESOUT predicted a discharge of 75,437 cfs compared to the hand calculated value of 75,654 cfs for a 0.30% error. This error should not be significant.

Another error involving the estimation of the abutment contraction coefficient was discovered in RESOUT's uncontrolled ogee spillway subroutine. If the second field of the first UO record is designated as "-1", which indicates that RESOUT will estimate the value of the abutment contraction coefficient, then a

reduction occurs in the effective spillway length even if no contraction is present. This reduction in effective spillway length resulted in a reduction in predicted discharge from 58,783 to 58,450 cfs, a reduction of 0.6%. The code was updated to account for cases where there is no abutment contraction and no piers. The uncontrolled ogee spillway subroutine and the input subroutine still need to be updated to account for cases in which there are no abutment contraction effects and there are pier contraction effects.

#### **Sensitivity analysis**

- a. Approach flow depth. A 15% reduction in the height of the spillway resulted in a 0.2% increase in the predicted discharge. Because the predicted discharge is not very sensitive to the approach depth, as a general rule of thumb, the approach depth may be estimated to be the height of the spillway above the approach channel.
- b. Design head. A twenty-five percent increase and reduction in the design head resulted in a 3.2% decrease and a 2.63% increase, respectively, in the predicted discharge.

#### **CASE STUDY 2: CHIEF JOSEPH DAM, COLUMBIA RIVER**

##### **RESERVOIR DATA**

- a. Downstream submergence of spillway: None.
- b. Approach width and depth: width assumed to be length of dam (5690 ft); depth

assumed to be two thirds of the maximum height above bedrock ( $2/3 * 230 = 153$ ).

c. Height of spillway crest above approach apron: assumed to be two thirds of the maximum height above bedrock ( $2/3 * 230 = 153$ ).

d. Design head: 41.6 ft.

e. Characterization of spillway (high or low): Corps of Engineers high dam shape.

f. Number and type of piers: 18, Type 3 (assumed).

g. Spillway shape: upstream quadrant of crest defined as a compound curve with  $R = 0.2 * Hd$  and  $0.5 * Hd$ ; downstream quadrant coordinates defined by  $X^{1.85} = 2.0 * Hd^{0.85} * Y$ .

h. Spillway elevation: 901.5 ft.

I. Number and type of spillway gates: 19, radial.

j. Width of gate: 36 ft.

k. Upstream face slope: 20V:1H (not accounted for in RESOUT calculations).

l. Number and type of outlet works: None.

m. Rating curves available: Water discharge data based on rating curves established for the gates were provided by US Army Engineer District, Seattle. Since the rating curves of only gates 9 and 10 are provided, RESOUT model developed for these two gates only.

l. Remarks: At a water surface elevation of 956 ft (head = 54.5 ft) and a gate opening of 34 ft, the gate lip separated from the flow. Considerable upstream turbulence was observed with a gate opening of 30 ft. Thus, at a head of 54.5 ft, the transition from orifice to weir flow begins at a gate opening of approximately 30 ft.

### Results

a. Pool elevation of 956 ft; gate 9 open.

GATE OPENING (FT)	RATING CURVE (CFS)	RESOUT (CFS)	ERROR (%)	ERROR(tainter) (%)
0.7	960	1027	+7.0	+3.9
3.8	5430	5494	+1.2	-0.3
8.1	11360	11468	+1.0	+1.0
15.6	21300	21251	-0.2	+1.2
34.0	57500	51988	-9.6	-9.6

ERROR (tainter) indicates results of adjusting the tainter gate discharge coefficient from the rule of thumb values.

b. Pool elevation of 956 ft; gates 9 and 10 open.

GATE OPENING (FT)	RATING CURVE (CFS)	RESOUT (CFS)	ERROR (%)
0.7	1920	2053	+6.9
3.8	10860	10988	+1.2
8.1	22720	22937	+1.0
15.6	42600	42502	-0.2
34.0	115000	97099	-15.6

c. Pool elevation of 951.6 ft; gate 9 open.

GATE OPENING (FT)	RATING CURVE (CFS)	RESOUT (CFS)	ERROR (%)
0.7	920	984	+7.0
3.8	5200	5259	+1.1
8.1	10850	10957	+1.0
15.6	20260	20225	-0.2
34.0	49500	46143	-6.8

d. Pool elevation of 951.6 ft; gates 9 and 10 open.

GATE OPENING (FT)	RATING CURVE (CFS)	RESOUT (CFS)	ERROR (%)
0.7	1840	1968	+7.0
3.8	10400	10518	+1.1
8.1	21700	21914	+1.0
15.6	40520	40450	- 0.2
34.0	99000	86742	-12.4

e. Notes.

The percent error is calculated as the difference between the rating curve values of discharge and the RESOUT predicted value divided by the rating curve value.

The value of the rating curve discharge for two gates open is simply the discharge with one gate open doubled; this appears to be oversimplified.

Unless otherwise indicated, the RESOUT values are calculated with all expedient rules of thumb applied as required.

### Analysis of Results

a. Orifice flow.

RESOUT was very efficient at predicting orifice flow discharges (1.2% maximum error) except at the smallest gate opening of 0.7 ft (7% maximum error). The error can be attributed to using an average orifice coefficient of discharge of 0.69. By adjusting the value of the orifice coefficient based on the size of the opening, the maximum error on the 0.7 ft gate opening was reduced from 7% to 3.9%; otherwise, the rule of thumb results appeared to be acceptable.

b. Weir flow.

RESOUT was only moderately efficient at predicting uncontrolled flow discharges

resulting from the spillway gates being fully open (RESOUT underestimated flows with a maximum error of 15.6%).

RESOUT was incapable of predicting when the transition from orifice to weir flow occurred. RESOUT erroneously assumes that the orifice flow condition is achieved when the head above the spillway is larger than the gate opening. RESOUT fails to account for the significant drawdown which can occur. As a result, the eighth field of the second tainter gate record (TG), the opening at which to compute the routing, and one of the corresponding values in the fifth tainter gate record (TG), the gate openings for which rating curves will be calculated, must be set to a value large enough to ensure that the opening will be larger than the highest elevation at which a rating curve is to be computed (third field of ON record). Otherwise, the opening will be submerged, and RESOUT assumes orifice flow. This procedure, in essence, "tricks" RESOUT to assume weir flow.

### **Sensitivity Analysis**

a. Approach width. A decrease in the approach width from 5690 ft to 1000 ft resulted in less than a 0.01% increase in the RESOUT estimated weir flow at a water surface elevation of 956 ft; no change was observed for the orifice flow.

b. Approach depth. A decrease in approach depth from 153 ft to 75 ft, resulted in an increase of less than 0.01% in the RESOUT estimated weir flow at a water surface elevation of 956 ft; no change was observed for the orifice flow.

c. Height of spillway above approach apron. A decrease in height from 153 ft to 75 ft resulted in no changes in predicted discharge.



d. Radius of adjacent concrete abutment. An increase in abutment radius from 10 to 50 ft resulted in no change in predicted discharge.

e. Weir coefficient. The predicted discharge was very sensitive to the weir coefficient. A specified weir coefficient of approximately 4.6 was required to generate a predicted discharge approximately equal to the rating curve discharge at a pool elevation of 956 ft. A weir coefficient of 4.6 implies that the spillway is much more efficient than predicted. Fagerburg (1991) did identify an increased efficiency in the spillway, but 4.6 appears to be excessively high.

f. The number of points to generate in the rating curves. As the number of points to generate decreased, the corresponding predicted weir discharges increased; no change was observed in the predicted orifice flow. A one foot increment appears to be less sensitive to error (possibly associated with interpolation of internally tabulated data).

### **CASE STUDY 3: RAYSTOWN DAM**

#### **RESERVOIR DATA**

- a. Downstream submergence of spillway: None.
- b. Approach width and depth: 800 ft, 15 ft (estimated).
- c. Height of spillway crest above approach apron: 15 ft (estimated).
- d. Design head: 20 ft (estimated).
- e. Characterization of spillway (high or low): low.
- f. Number and type of piers: not analyzed.
- g. Spillway shape: WES standard (assumed).

- h. Spillway elevation: 768.6 ft.
- I. Number and type of spillway gates: 2 tainter.
- j. Width of gate: 45 ft.
- k. Number and type of outlet works: sluice gate.
- l. Remarks:

### Results

a. Left spillway gate open. RESOUT orifice values computed with tainter gate discharge coefficient of 0.69.

GATE OPENING (FT)	WSEL (FT)	RATING CURVE (CFS)	RESOUT (CFS)	ERROR (%)
2.1	788.00	1996	2242	+12.3
5.4	788.12	4970	5518	+11.0
8.8	788.02	7842	8492	+8.3
15.0	787.00	12178	13463	+10.6

Rating curve data is based upon actual spillway measurements. Orifice flow was observed for gate openings of 2.1, 5.4, and 8.8 ft; whereas, weir flow was observed for a gate opening of 15.0 ft. RESOUT data for a pool water surface elevation (WSEL) of 788 ft instead of 788.02 ft; the difference should be insignificant.

b. Left spillway gate open. RESOUT orifice values computed with tainter gate discharge coefficient of 0.67.

GATE OPENING (FT)	WSEL (FT)	RATING CURVE (CFS)	RESOUT (CFS)	ERROR (%)
2.1	788.00	1996	2177	+9.1
5.4	788.12	4970	5358	+7.8
8.8	788.02	7842	8246	+5.2
15.0	787.00	12178	13463	+10.6

## Analysis of Results

### a. Orifice flow.

Using the rule of thumb values for the tainter gate discharge coefficient (0.69), RESOUT over-predicted the measured discharge with a maximum error of 12.3%. By decreasing the coefficient to 0.67, a maximum error of 9.1% was obtained. The disadvantage of using an average rule of thumb value is that the actual behavior of the coefficient is not constant; consequently, at lower values of head, the actual coefficient is smaller.

To overcome this problem, an interpolation routine should be added to RESOUT to capture this variability in the tainter gate discharge coefficient. Conversely, a more efficient rule of thumb would be a gradual increase in the coefficient with gate opening size.

Although most of the reservoir characteristics had to be estimated from Fagerburg's (1979) report, he did indicate that this was a low spillway. The minimum tainter gate coefficient for high spillways is specified as 0.67 (Wurbs, 1991). Generally, because of negligible approach effects, orifice flow on high spillways will be more efficient than on low spillways. Thus, given that this spillway is characterized as a low spillway, it follows that RESOUT over-predicted the discharge even with the minimum tainter gate discharge coefficient of 0.67 specified.

b. Weir flow. For the spillway, RESOUT overestimated the measured discharge with a 10.6% error. By overestimating the discharge, RESOUT is failing to account for

a general loss of efficiency accompanying low spillways in comparison to high spillways.

### **Sensitivity Analysis**

Approach depth and height of spillway above approach apron. A 47% increase in both of these parameters resulted in a 2.4% increase in predicted discharge. This change in parameters would result in a "high" spillway classification.

**APPENDIX B  
HYDROGRAPHS FROM COMPARISON  
STUDY**

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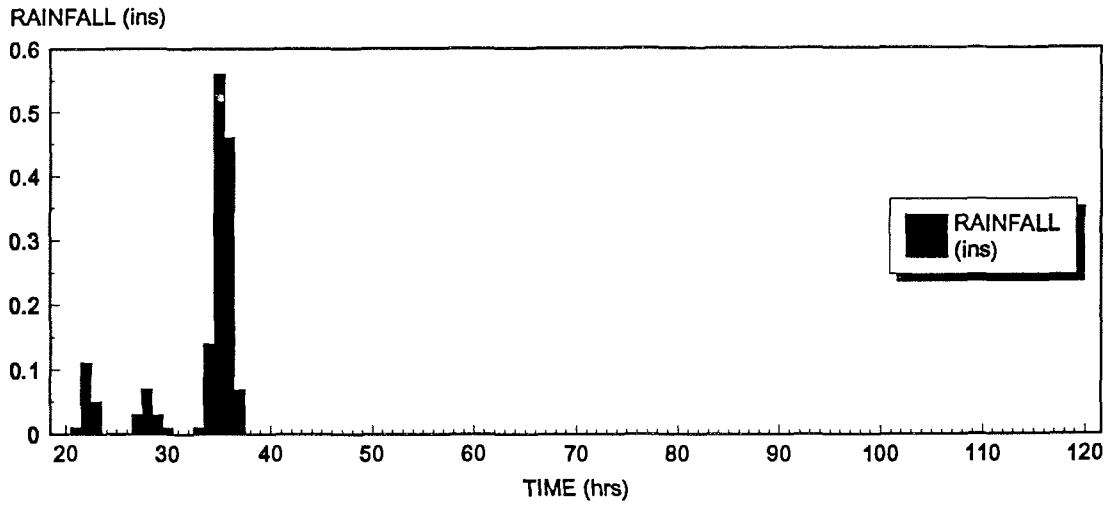


Figure B1. Precipitation of June 1.

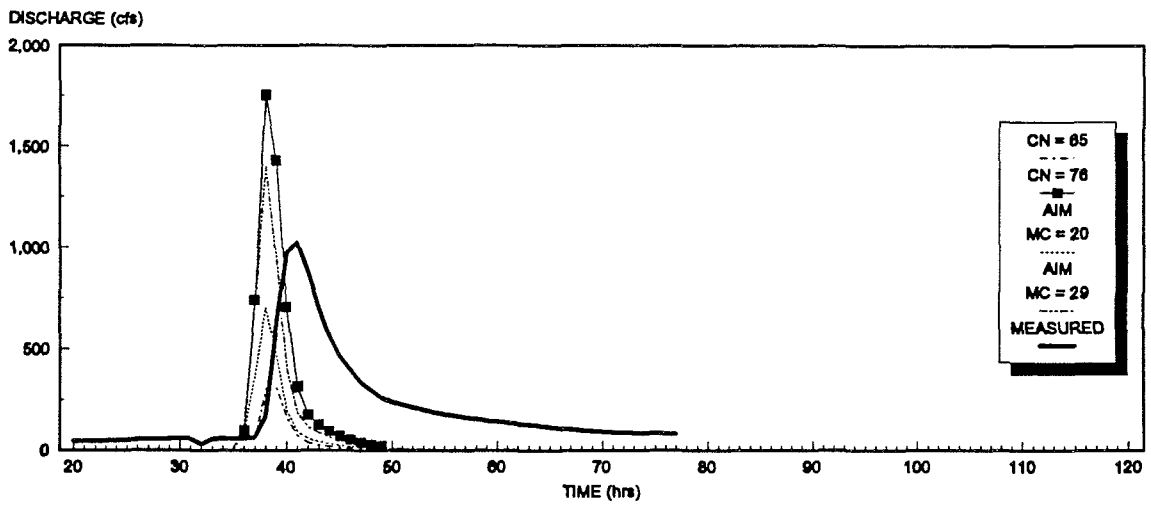


Figure B2. Comparison of measured hydrograph for June 1 to those predicted by both models.

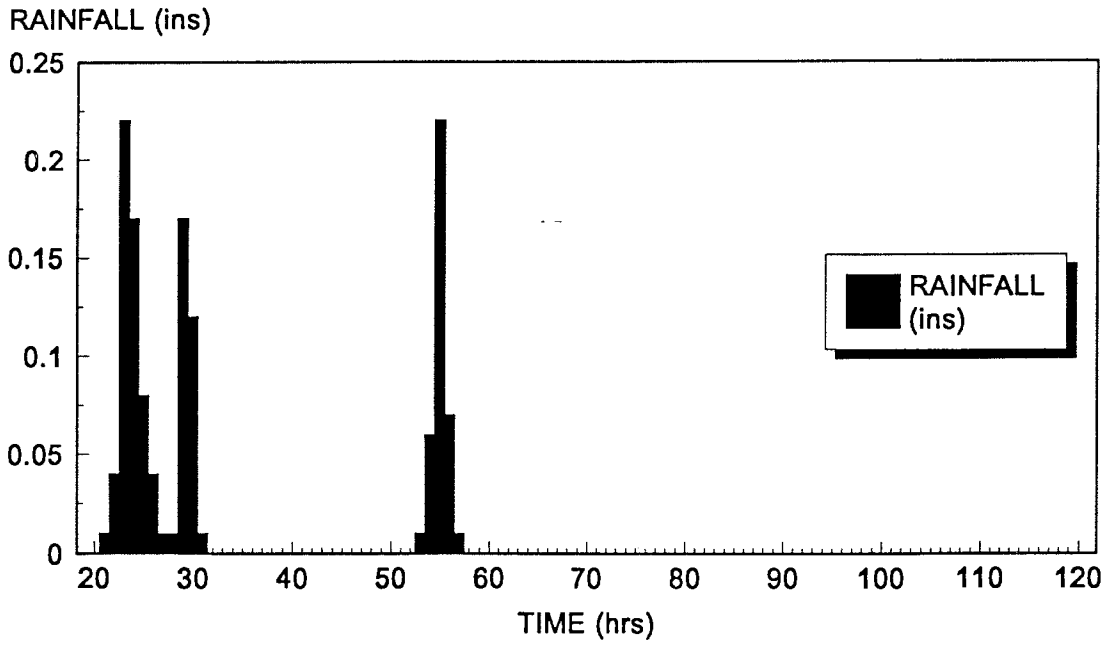


Figure B3. Precipitation of July 10.

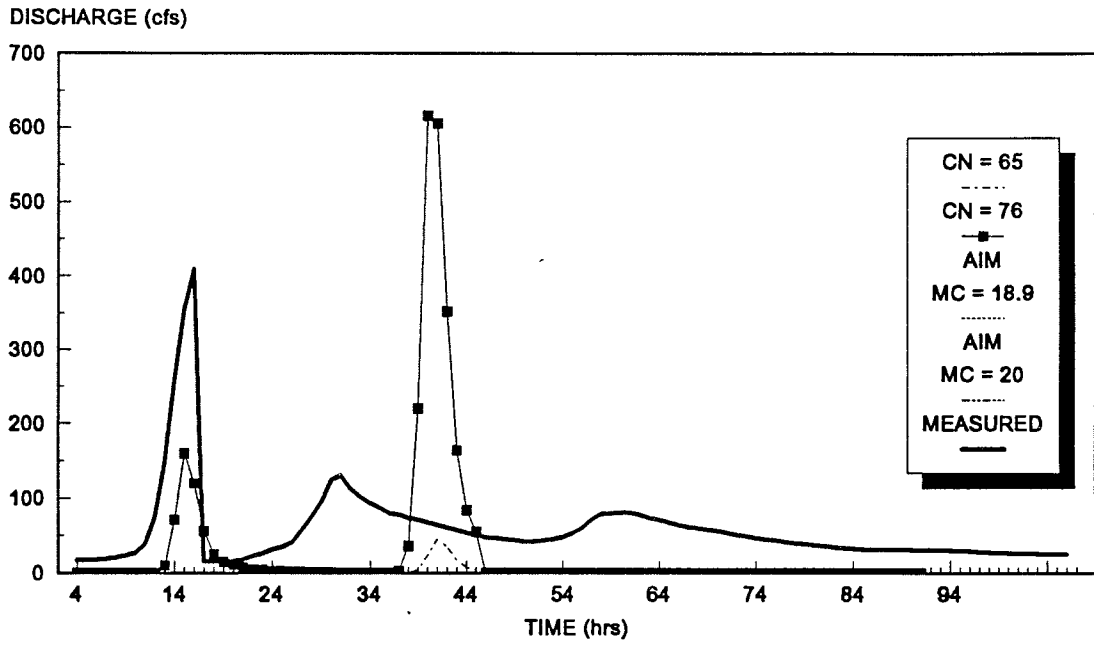


Figure B4. Comparison of measured hydrograph for July 10 to those predicted by both models.

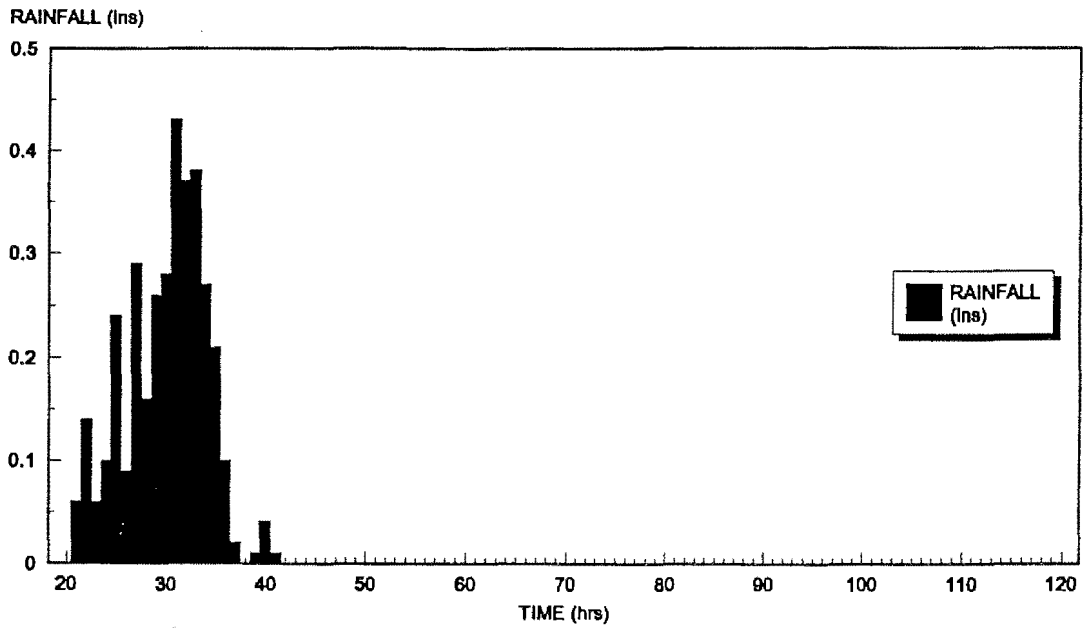


Figure B5. Precipitation of August 4.

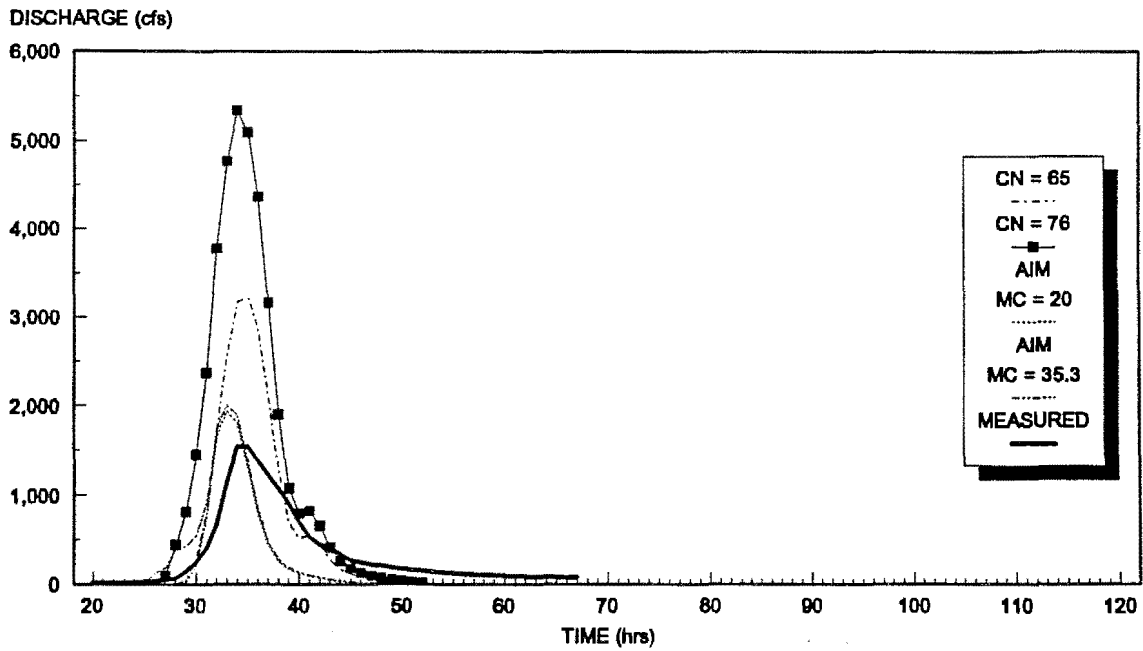


Figure B6. Comparison of measured hydrograph for August 4 to those predicted by both models.



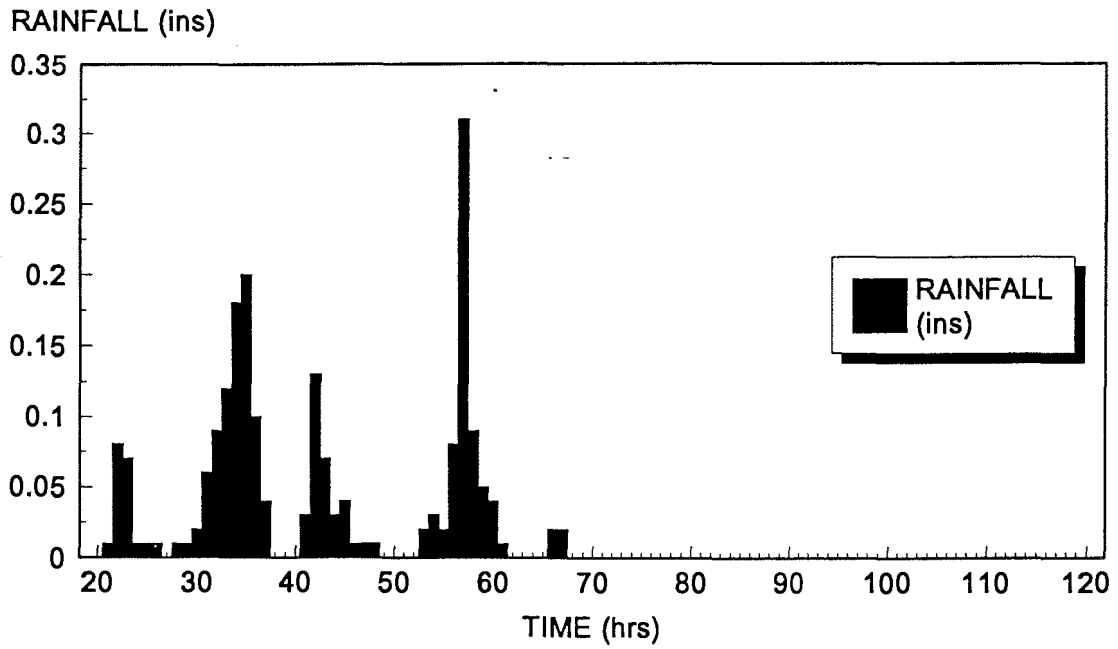


Figure B7. Precipitation of August 11.

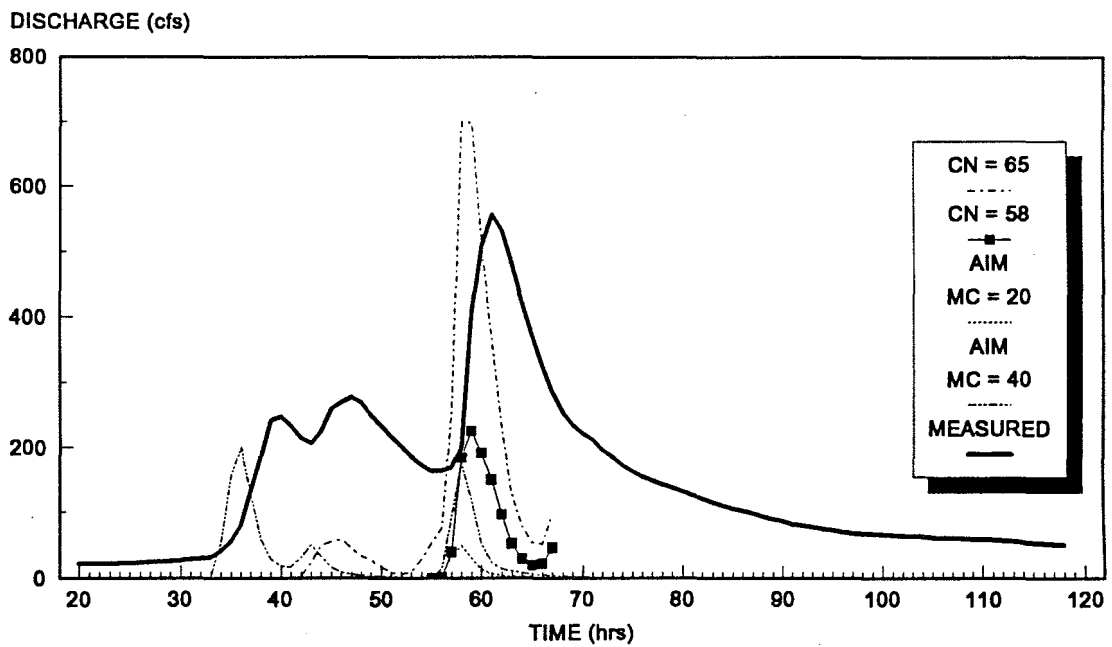


Figure B8. Comparison of measured hydrograph for August 11 to those predicted by both models.

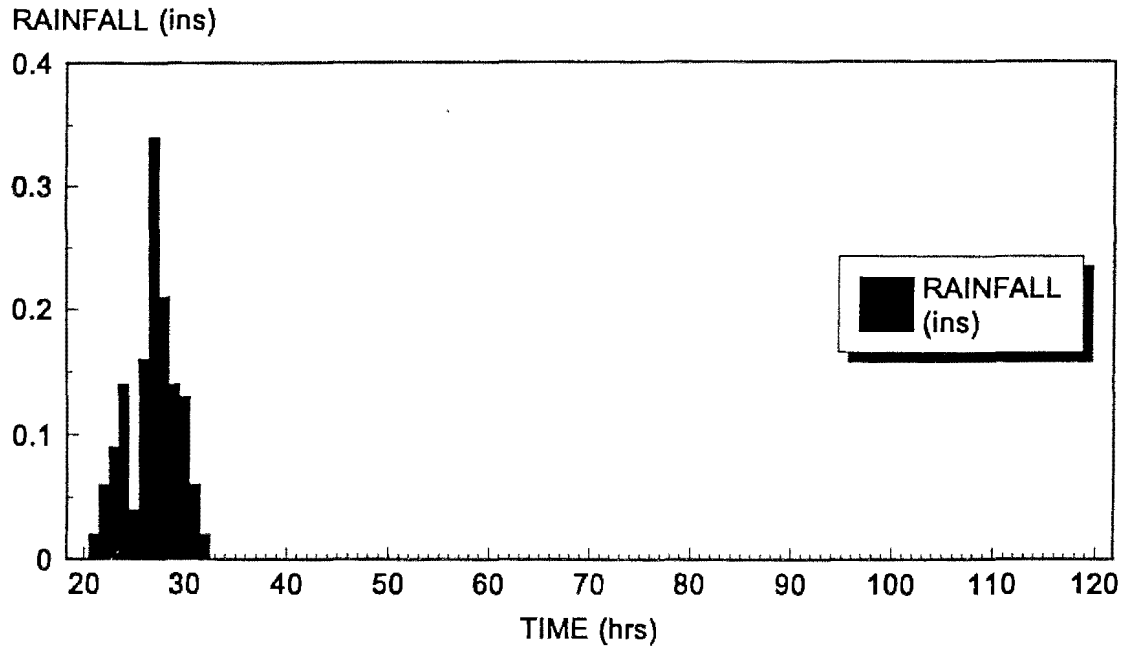


Figure B9. Precipitation of Sepetmber 1.

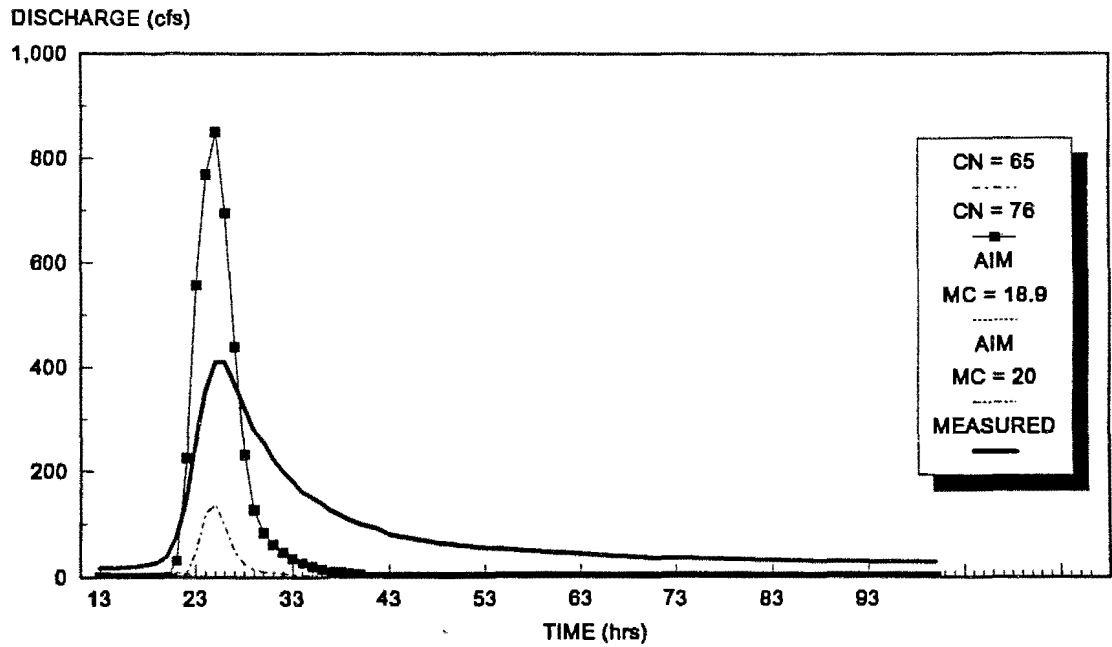


Figure B10. Comparison of measured hydrograph for September 1 to those predicted by both models.

# REPORT DOCUMENTATION PAGE

*Form Approved*  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

<b>1.AGENCY USE ONLY (Leave blank)</b>	<b>2.REPORT DATE</b> September 1995	<b>3.REPORT TYPE AND DATES COVERED</b> Final report	
<b>4.TITLE AND SUBTITLE</b> Intern Experience with the U.S. Army Engineer Waterways Experiment Station		<b>5.FUNDING NUMBERS</b> Work Unit BP-002	
<b>6.AUTHOR(S)</b> Mark R. Jourdan			
<b>7.PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b> U.S. Army Engineer Waterways Experiment Station 3909 Halls Ferry Road Vicksburg, MS 39180-6199		<b>8.PERFORMING ORGANIZATION REPORT NUMBER</b> Technical Report HL-95-6	
<b>9.SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b> U.S. Army Corps of Engineers Washington, DC 20314-1000		<b>10.SPONSORING/MONITORING AGENCY REPORT NUMBER</b>	
<b>11.SUPPLEMENTARY NOTES</b> Available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.			
<b>12a.DISTRIBUTION/AVAILABILITY STATEMENT</b> Approved for public release; distribution is unlimited.		<b>12b.DISTRIBUTION CODE</b>	
<b>13.ABSTRACT (Maximum 200 words)</b> <p>This report describes an internship completed by the author with the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. A statement of objectives was prepared prior to the internship to provide guidance for the experience and to allow for a meaningful assessment at its conclusion.</p> <p>WES operates on a reimbursable basis to support elements of the U.S. Army Corps of Engineers and other agencies and provides basic and applied research, process and equipment development and testing, and engineering design services research.</p> <p>Five specific technical assignments were selected to provide experience representative of work performed in the Environmental Laboratory at WES. The first assignment was the development of the Han River Control System, a decision support system for support of military personnel in Korea. The author was responsible for all technical, administrative, and management issues of this project on a daily basis. The second assignment was the integration of the Tactical Dam Analysis Model (TACDAM) into the AirLand Battlefield Environment (ALBE) hardware/software system. This assignment was selected to provide exposure to a geographic information system (GIS) that integrated many different tactical applications. The third assignment involved validation of the Reservoir Outflow (RESOUT) Model. This assignment provided exposure to the</p> <p style="text-align: right;">(Continued)</p>			
<b>14.SUBJECT TERMS</b> Dam breach                      Hydrology Hydraulics                      Spillways		<b>15.NUMBER OF PAGES</b> 128	
		<b>16.PRICE CODE</b>	
<b>17.SECURITY CLASSIFICATION OF REPORT</b> UNCLASSIFIED	<b>18.SECURITY CLASSIFICATION OF THIS PAGE</b> UNCLASSIFIED	<b>19.SECURITY CLASSIFICATION OF ABSTRACT</b>	<b>20.LIMITATION OF ABSTRACT</b>

**13. (Concluded).**

Army's policy on verification, validation and accreditation of software. The fourth assignment involved integration of TACDAM and the RESOUT Model into the Obstacle Planning System (OPS). The OPS utilizes a different GIS from the ALBE system, and is designed for use by U.S. Army Corps of Engineers officers. This assignment provided the opportunity to pursue additional funding for the Military Hydrology Team. Finally, the fifth assignment involved a basin modeling comparison study to determine the applicability of replacing the curve number procedure used in the Military Hydrology (MILHY) Model with a soil moisture accounting procedure. This assignment provided experience in the testing of hydrologic models.

All the technical work was characterized by the need for a high degree of planning, interaction, and coordination with other professionals and with operational personnel, and careful detailed management of limited time, labor, and physical resources.