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

Han River Control System

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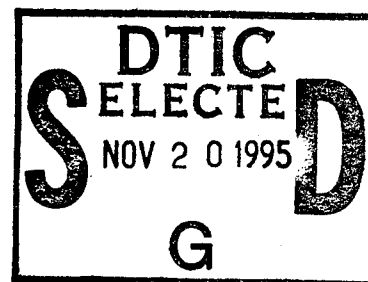
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Preface

The work reported herein was sponsored by the U.S. Forces, Korea/Combined Forces Command (CFC). The CFC technical monitors included LTC Jon Behrens, LTC William Gevedon, LTC Donald Willhouse, and LTC Gary Pesano.

The study was partially conducted under a contract let by the U.S. Army Engineer Waterways Experiment Station (WES). The study was conducted by Mr. Mark R. Jourdan, WES, Dr. Pedro R. Restrepo, University of Colorado, Boulder, CO, and Dr. Juan B. Valdes, Texas A&M University.

The contract was monitored technically by Mr. Jourdan, Estuaries Division (HE), Hydraulics Laboratory (HL), WES, under the direct supervision of Mr. William D. Martin, Chief, Estuarine Engineering Branch, HE, and under the general supervision of Mr. William H. McAnally, Chief, HE, and Mr. Frank A. Herrmann, Jr., Director, HL.

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

1 Introduction

Purpose and Scope

The purpose of this report is to document the development of the Han River Control System (HRCS). The HRCS is a decision support computer software system which was 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.

An overview discussing the Han River Basin and illustrating the impacts of hydrology on the battlefield is presented initially to highlight the importance of reservoir operations on military strategy and tactics. The development of the HRCS is then discussed, beginning with capabilities present during the Korean War and continuing with details of the Reservoir Analysis Model for Battlefield Operations (RAMBO). The two phases of development of the HRCS are also discussed. The components of the HRCS are then described in detail, including the user interface, the rainfall-runoff module, the reservoir optimization module, the dambreak module, the estuary crossing module, the inundation module, and the trafficability module.

Background

The Han River Basin encompasses about one-fourth of the land area of the Republic of Korea (Figure 1). It has a total area of 25,944 sq km, of which 2,080 sq km are north of the Demilitarized Zone (DMZ). The basin includes the 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 (U.S. Department of Interior 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 from 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 km upstream of Seoul. At this point, the two main branches - the North Han and the South Han Rivers - continue to the
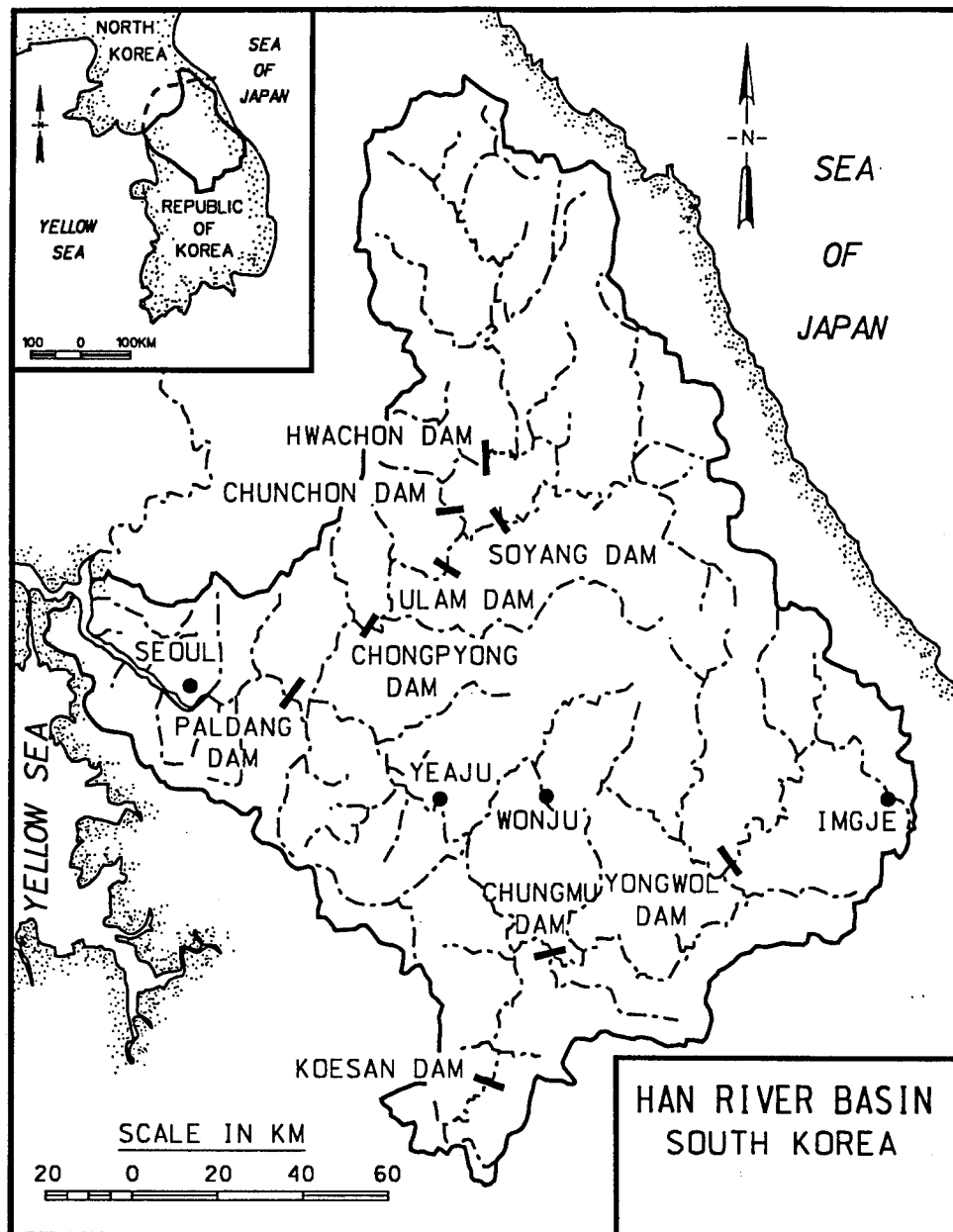
Figure 1. The Han River Basin

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 km. There are 160 river kilometers along the North Han River from its confluence to the DMZ, with an additional 80 km 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 Dams. 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 25, 40, and 41 km 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 were 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 24 km apart, one just below the 38th Parallel and the other near Chunchon (Figure 2). 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 storage to cause a floodwave which could endanger the United Nations floating bridges. On 19 April 1951, the North Koreans opened about one-half of these gates. The resultant floodwave 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 U.N. Command decided to pressure the enemy to move toward peace negotiations by striking at the economic heart of the country -
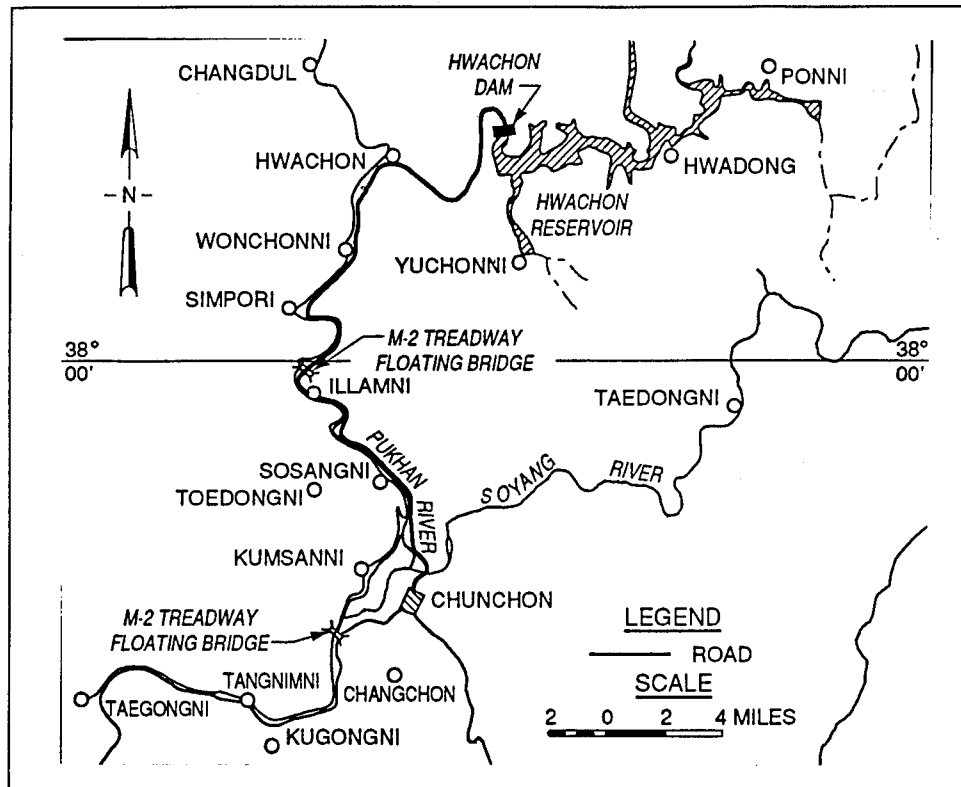
Figure 2. Map depicting location of Hwachon Dam and M-2 float bridge
sites (Fowler 1952)

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 areal 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 2 weeks, and extensive and
irreparable damage was done to the rice crop (Davis 1990).

In addition to the impact that dams had 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

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$250 million (Time 1986). The dam was built in response to construction of a North Korean dam, Kumgangsan Dam, that was to be constructed 18 km 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 20,000,000,000 cu m, might collapse or be demolished by the North Koreans. 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 floodwaters that might be created by such a collapse.

2 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 to rainfall events. Follow-on 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

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.N. forces operated a Flood Prediction Service during the Korean War. The primary mission of this group was the prediction of flooding along the river during the monsoon season. The U.N. 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 upstream flood heights 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 draw down 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 were developed that could provide predictions of drawdown times for specific reservoirs. These methods provided the engineers with estimates that were useful for planning purposes; however, there were several incorrect assumptions behind them. The primary inconsistency was that they assumed constant discharge through the outflow structures of the dam, regardless of the reservoir water surface 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 at WES (Sullivan 1989). RAMBO consisted of an integrated set of procedures for evaluating reservoir drawdown operation. These procedures incorporated military requirements, hydrologic modeling (the HEC-5 Reservoir Operation Model), and statistical analysis techniques into a comprehensive planning process. 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 the potential risk of enemy capture of the basin's 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 U.S. 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 which comprised RAMBO was integrated into a prototype expert system. It was realized that a system with high-resolution graphics, not requiring a great deal of expertise to operate, was necessary for the military 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.

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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 knowledge 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) can simulate any combination of drawdown scenarios involving the seven Han River reservoirs and evaluate critical flow rates at the Indogyo crossing site in Seoul, Korea. The system was designed around the concept of an interactive graphics framework (menu driven), enhanced data entry (mouse device), and rapid interpretation of simulation results using a color graphics monitor. Products of simulations include 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 analysis techniques. Shortfalls with RAMBO-E, though, included: an inability to model complex scenarios (e.g., draw down two reservoirs simultaneously while filling a downstream reservoir and then release this downstream volume of water at some later point in time), inability 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 Digital Terrain Elevation Data (DTED) level I digitized database.

c. Expanded crossing means menu.

d. Incorporation of a dam breach capability to integrate reservoir drawdown and analytical capabilities.

USFK personnel believed that an expert system was ideally suited for serving as the interface between newly assigned staff officers and the technical elements 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 overbank 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 over most of the Han River system. This survey data was then integrated into the Phase II software.

HRCS User

The HRCS was designed to be used by engineer staff officers on the 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, comprised of ROK Army terrain analysts and assigned to the CFC Engineer. During joint exercise and in the case of wartime, the U.S. 33rd Engineering Detachment would be assigned to the CTAT. The 33rd is a U.S. Terrain Analysis Team assigned to the U.S. Eighth Army.

HRCS Databases

The HRCS employs two different types of digital topographic data sets: areal terrain data and elevation data. The areal data is used to compute soil moisture retention in the off-road trafficability module. The digital elevation data is used to identify potential flooded areas during high-water periods.

The Korean Electric and Power Corporation (KEPCO) maintains a system of stream gauges throughout the Han River basin (Figure 3). This system of
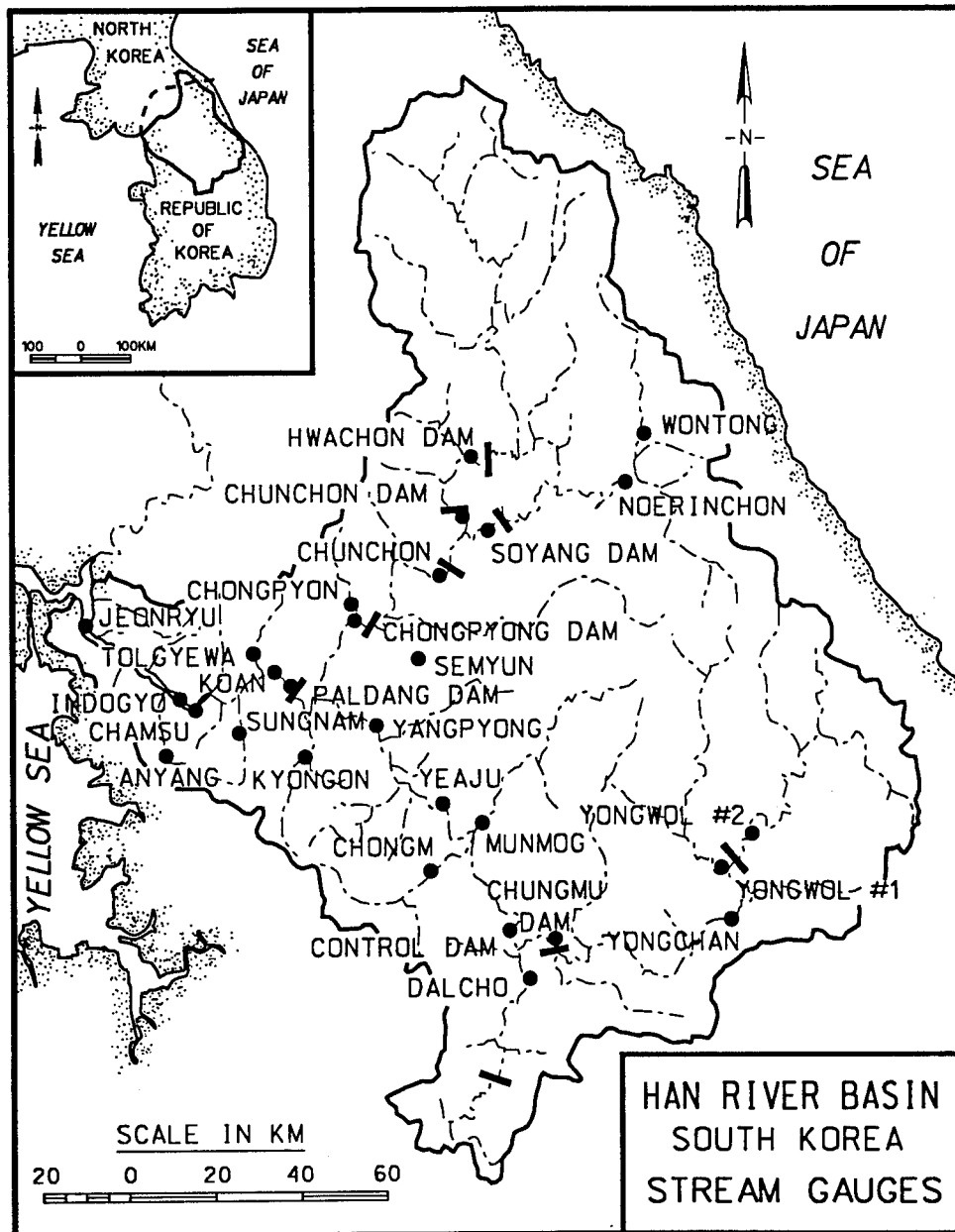
Figure 3. Han River Basin Stream Gauges

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 4) 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.
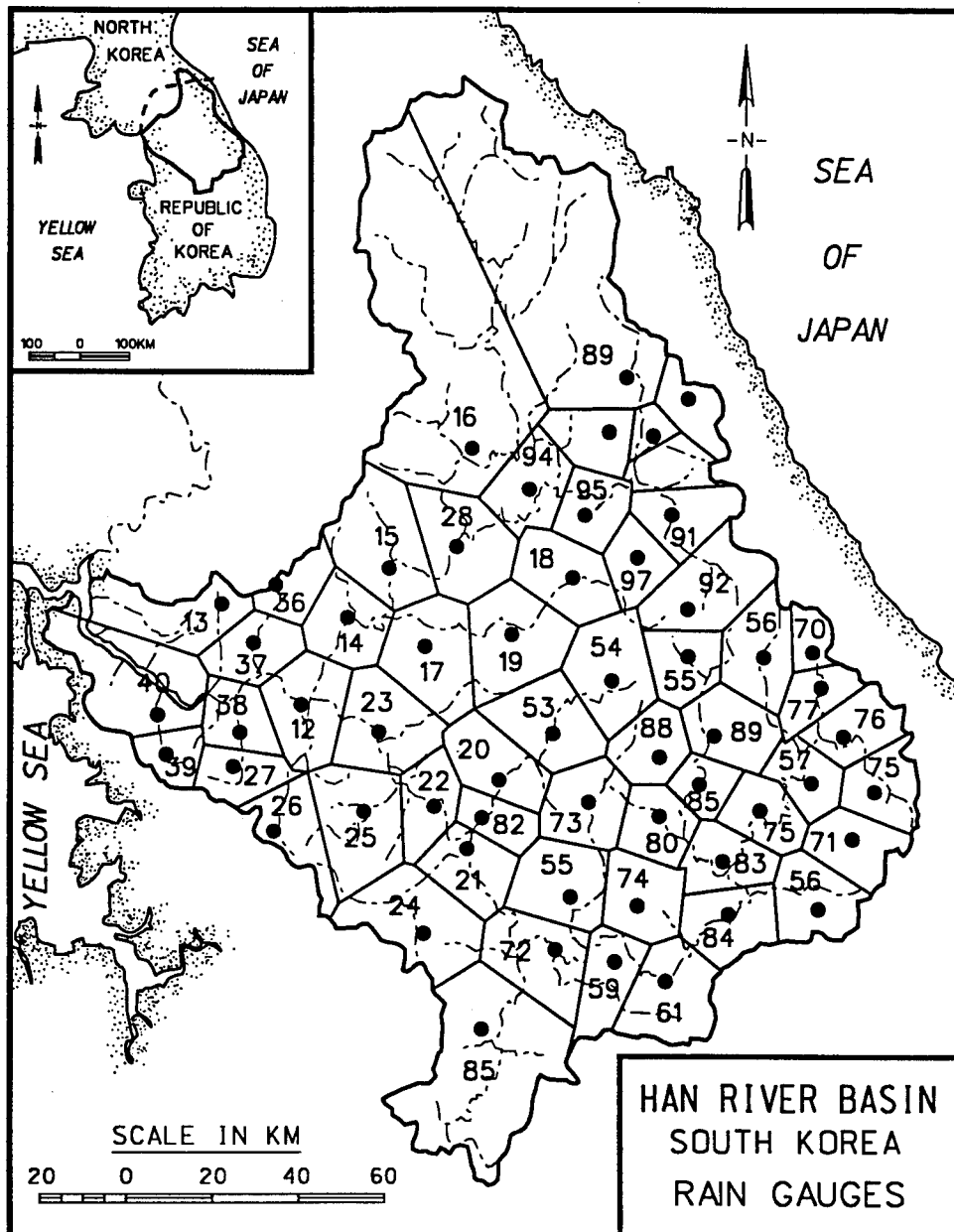
Figure 4. Han River Basin Rain Gauge network

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

3   Model Description

Model Overview

The HRCS is composed of several modules, a user interface, and a software interface that interconnects these modules. Data are input both manually and automatically, by downloading streamflow and precipitation gauge information from the HRFCC. This information is processed to compute mean areal precipitation.

Based on the mean areal precipitation and on the state of the river, the rainfall-runoff module forecasts runoff from each of the 17 subbasins in which the system is divided. This runoff is entered into the reservoir release optimization module, together with user-defined maximum or minimum desired river depth or water velocity at selected cross sections, and desired operation of individual reservoirs. Reservoirs can be set to discharge according to a given schedule, to fill, to dump, or even to fail. Once the optimization module obtains the best set of target releases to meet the user's requirements, the flows are routed through the river by means of CARIMA, a dynamic routing program. This routing produces estimates of water velocity and water depth at over 200 cross sections along the river, for every hour in a 6-day forecasting period.

The resulting water depth values are used to interpolate the high water mark for every day in the 6-day planning horizon, at those sites in which the user is interested. Using GIS techniques, the final extent of the flooded areas is obtained by subtracting the water surface elevation from the digital terrain elevation layer.

Based on this information, the user may decide to change the operating procedure of any of the reservoirs set for fill, dump, or a scheduled release. Moreover, the user can play "what if" scenarios with the forecast precipitation, and find the expected extent of flooding due to increases in precipitation.

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.

A software interface prepares data for one module, in a format that is usable by one or more of the other modules. This advanced software interface allows the background operation of complex software to execute without user interaction.

Rainfall-Runoff Module

HYMO, developed by the U.S. Department of Agriculture, was used to model surface runoff in Phase I of the HRCS. HYMO was developed to obtain a reliable flow forecast in small basins, using very limited data. HYMO's estimate included a base-flow 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 base-flow 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 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 module, 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 (Valdes and Awad 1991). 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, 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 17 subbasins for the TAMU model (Figure 5). Historical records of flows and precipitation were used to develop the model structure for each subbasin. Table 1 provides remarks on the model developed for each subbasin. Flow data on several subbasins was insufficient for development of a model. In these cases, the model structure of similar subbasins was used, with appropriate changes in the structure to reflect the difference in area.

Historical flows were used to develop the model structure and to obtain optimal estimates of the parameters over the calibration period. After the initial values of the parameters are estimated, the model retains a small amount of information that will be necessary for forecasting purposes. This enables periodic updating; that is, as new measurements of the actual flows become available, they can be read into the model to update the forecast states, as well as the parameter estimates. As such, there is no distinction between the calibration stage and the verification stage. After each updating stage, the system develops a new forecasting basis as initial values of the different variables in the model, and there will then be a new cycle of forecasts and updates.

The outflow of each subcatchment is located as an inflow to a reservoir or at a point of interest for which streamflow is required. Graphical output illustrates the flow from each subbasin.

Reservoir Optimization Module

The reservoir optimization module was developed to allow the user the ability to manipulate stored water in the reservoir. The basic principle behind 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/or depth are 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.

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 flood-plain 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 routing model to manage water resources in the reservoirs.
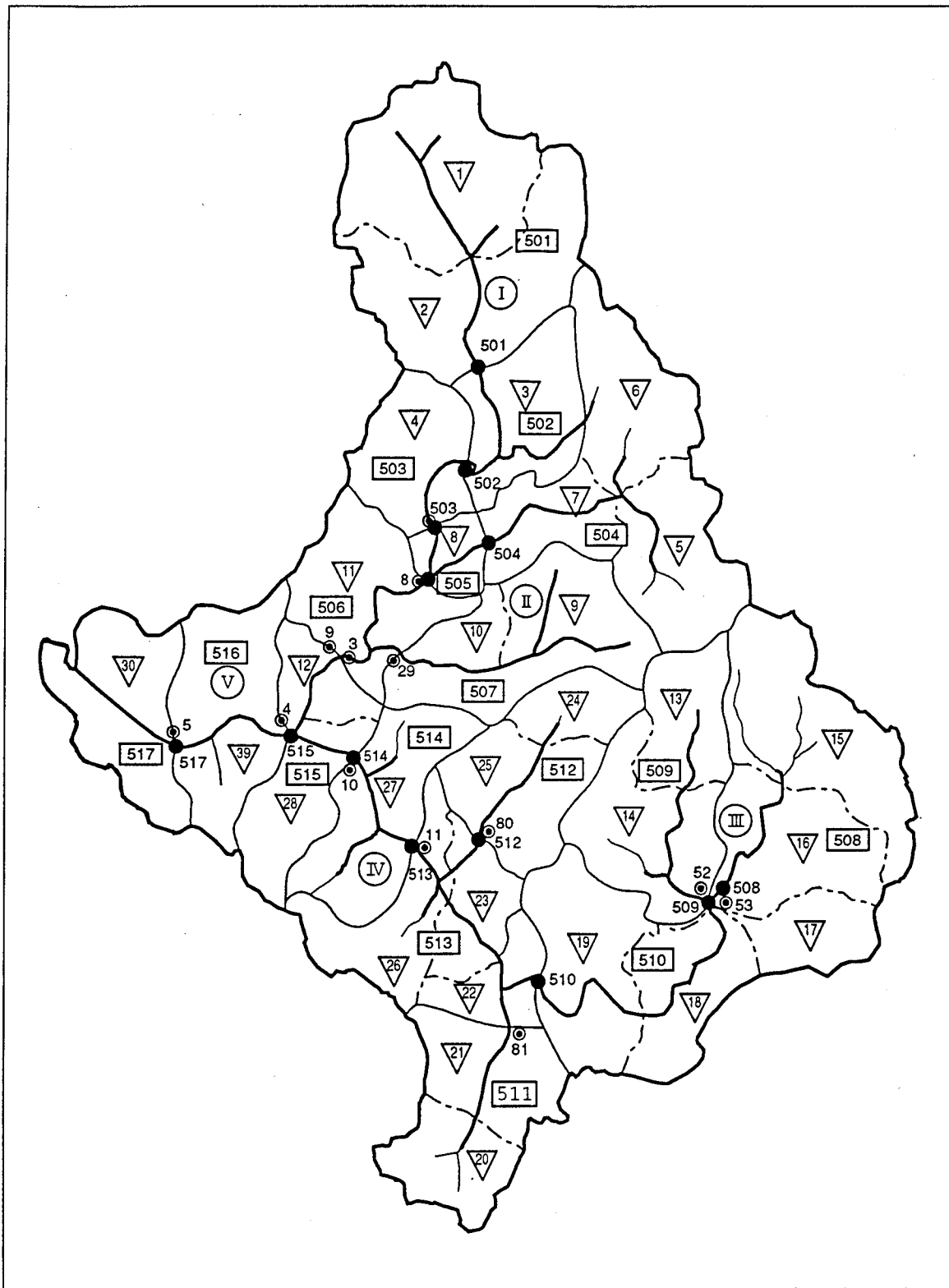
Figure 5. Rainfall-runoff calculation subbasins

Table 1
Basins Used and Status of Structural Model in the TAMU
Rainfall-runoff Module of the HRCS

Subbasin Number	Name	Area (sq km)	Remarks
500	Hwachon Dam	4064	Good records available, structural model complete.
503	Chunchon Dam	784	Good records available, structural model complete.
504	Soyang Dam	2976	No records available. Flows are set equal to flows from basin 50 508 and proportional to the area.
505	Uiam Dam	290	Releases from basin 504, which are required to define observation record, are not available. Model used is proportional to model developed for basin 503.
506	Chongpyong Dam	1007	Records of upstream basin, 507, were too short for reliable model. Basin 507 was set proportional to basin 509.
507	Semyun	1496	Due to short length of record, model is proportional to model for basin 509.
508	Yongwol #2	3010	Good records available.
509	Yongwol #1	1735	Good records available.
510	Chungju Dam	1986	Good records available.
511	Dalchon Dam	1434	Good records available.
512	Munmag	1348	Model proportional to model for basin 509.
513	Yeoju	1725	Basin model from basin 512 was used "as is."
516	Indogyo	1004	Good records available.
520	Paldang Dam	2254	Good records available.

The optimization module accounts for the operation of the system of reservoirs. Given a forecast 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. This schedule will minimize deviations from the flow requirements and from the operation of reservoirs that had either a manual schedule, dump, or fill goal specified.

Floodwave Routing Module

The floodwave routing module uses CARIMA, a dynamic floodwave model developed by the French firm Sogreah (Cunge, Holly and Verwey 1980). CARIMA was selected because it can perform river routing during changing reservoir operations and during tidal fluctuations. CARIMA 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, 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.

Figure 6 is a flow chart that describes the CARIMA simulation in the HRCS. Input requirements are obtained from the HRCS itself, the user, and the TAMU model.

The surveyed cross-sectional data were used to define the channel, except in the estuary where the surveys were not performed. The surveyed data were plotted on topographic maps in the GIS GRASS, and the desired cross sections were selected based on the channel morphology. Only about 30 percent of the cross sections were selected to be used in the simulation to keep the simulation time reasonably short. The selected cross sections were plotted and examined. Some were modified to enable the numerical computations to converge without difficulty. Manning n roughness coefficient values, estimated by the surveyors, were used as preliminary estimates of resistance but can be modified as needed to calibrate the model.

The upstream limits of the model are Hwachon Dam on the North Han River, the Soyang Dam on the Soyang River, and the Chungju Dam on the South Han River. Thus, no crossing sites may be considered that are upstream of these structures. The downstream boundary is the ocean. However, the topology in the estuary is highly uncertain, because surveys were not possible in the DMZ.

Hydrologic inflows (Figure 7) were considered along the complete stretch of the river. Upstream of Hwachon Dam, the runoff from subbasin 500 is the inflow into the reservoir. Upstream of the Chungju Dam, the runoff from subbasins 508, 509, and 510 are lumped together, not routed as the inflow into the Chungju Reservoir. This simplification was deemed justifiable because the Chungju Reservoir is so large that level changes in the reservoir are quite slow, compared with the travel time of the basins. Time of execution was also a factor in this decision. It is assumed that the entire flows from subbasins 516 and 517 enter the Main Han River upstream of the Jamsil Weir. This simplification was made because more specific data on inflow were not available, and this represents a conservative alternative in terms of water surface elevations through Seoul.

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│   │      HRCS        │    │  USER SPECIFIES  │    │      TAMU        │     │
│   │                  │    │                  │    │                  │     │
│   │ Initial Res Elevs│    │  Crossing site   │    │   Inflows to:    │     │
│   │                  │    │                  │    │                  │     │
│   │   Schedule of    │    │    Equipment     │    │    Hwachon       │     │
│   │     Tides        │    │                  │    │    Soyang        │     │
│   │   dt = 6hrs      │    │ Prevent or Allow │    │    Chunju        │     │
│   │                  │    │                  │    │ Lateral inflows  │     │
│   │                  │    │ Crossing time    │    │  · dt = 6 hrs    │     │
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│           │         RESERVOIR  OPTIMIZATION            │                     │
│           │                                            │                     │
│           │       Compute optimal Q(t) schedule        │                     │
│           │        for every reservoir in system       │                     │
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│           │                                            │                     │
│           │    Create CARIMA operational (.CAL) files  │                     │
│           │     to specify initial conditions for      │                     │
│           │                simulation                  │                     │
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│           │            CARIMA  SIMULATION              │                     │
│           │                                            │                     │
│           │     Begin with initial steady-state        │                     │
│           │              condition                     │                     │
│           │                                            │                     │
│           │  Simulate flow at 1-hr time intervals      │                     │
│           │  using interpolated values of reservoir    │                     │
│           │  releases and hydrologic inflows           │                     │
│           │                                            │                     │
│           │  At each computational time step check to  │                     │
│           │  see if reservoir releases violate maximum │                     │
│           │  discharge curves (then release the max    │                     │
│           │  possible) or if the reservoir elevations  │                     │
│           │  meet or exceed the top of flood pool      │                     │
│           │  (then release max)                        │                     │
│           └───────────────────────────────────────────┘                     │
│                              │                                               │
│                              ▼                                               │
│           ┌───────────────────────────────────────────┐                     │
│           │            CARIMA  OUTPUT                  │                     │
│           │                                            │                     │
│           │  FLOW (m/s)    W.S. ELEV (m)    DEPTH (m)  │                     │
│           │                                            │                     │
│           │  Values at every x-section at 1-hour       │                     │
│           │            intervals                       │                     │
│           │  Actual (simulated) reservoir release      │                     │
│           │            schedules                       │                     │
│           └───────────────────────────────────────────┘                     │
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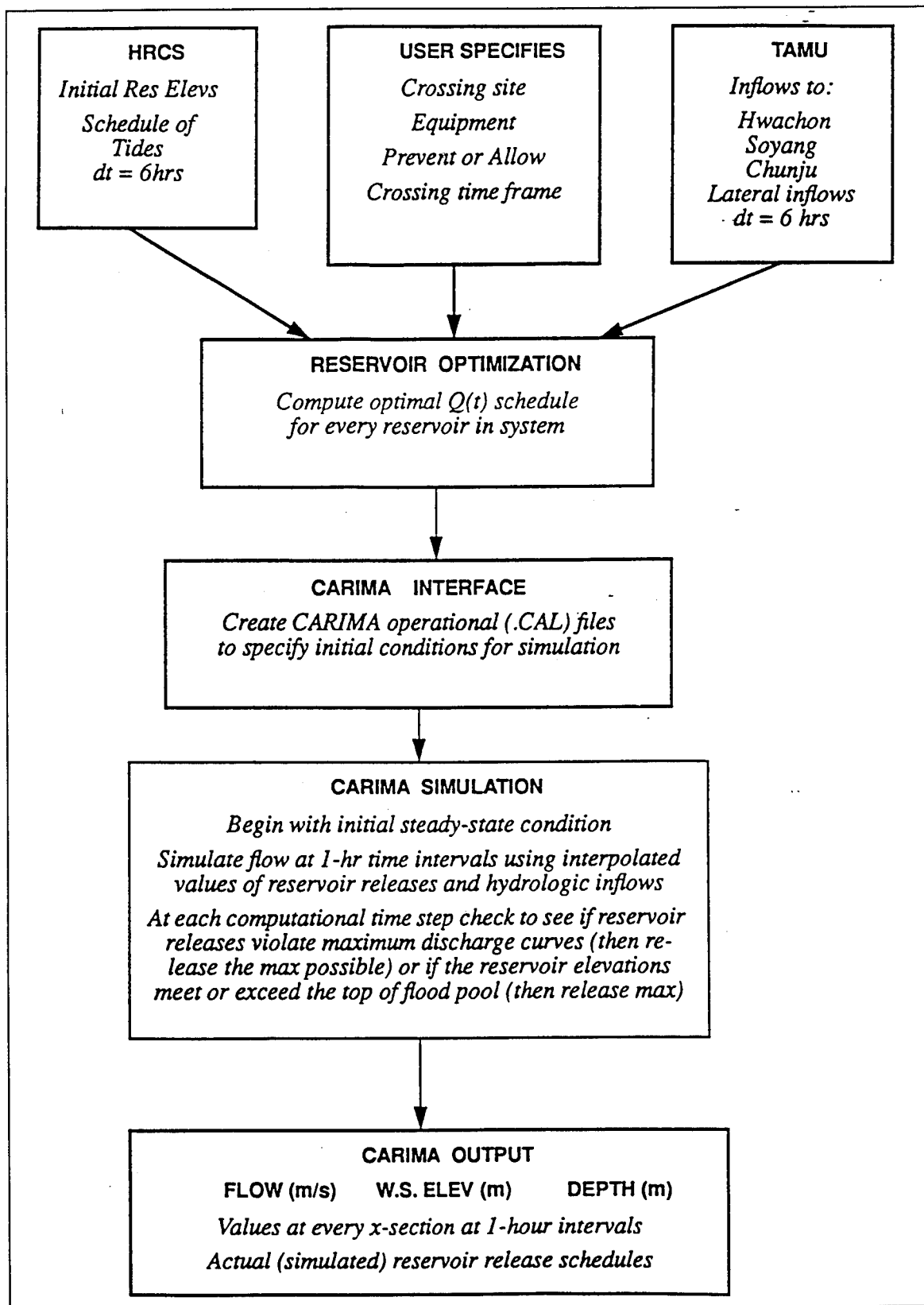
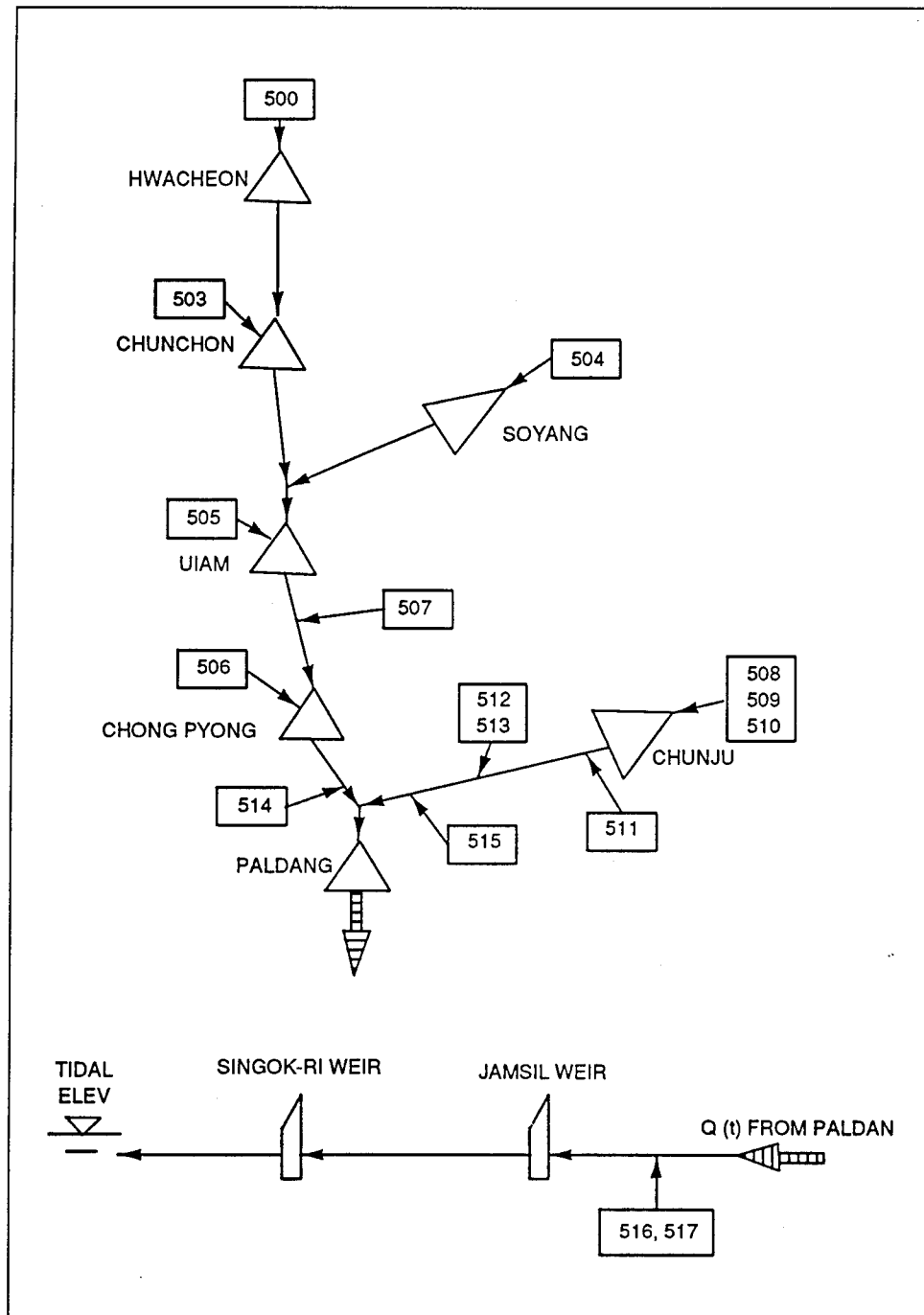Figure 6. CARIMA simulation flow chart

Figure 7. CARIMA simulation - Hydrologic inflows

Figure 8 illustrates the system boundaries used for the CARIMA model. The three upstream reservoirs (Hwachon, Soyang, and Chungju) are modeled as storage basins, thus the flow through them is represented as storage routing, rather than dynamic routing. This decision was made because it was believed that there is more certainty in the head-area-volume relationships than in the cross-sectional data, and because it is not expected that there will be any crossing sites upstream of these dams.
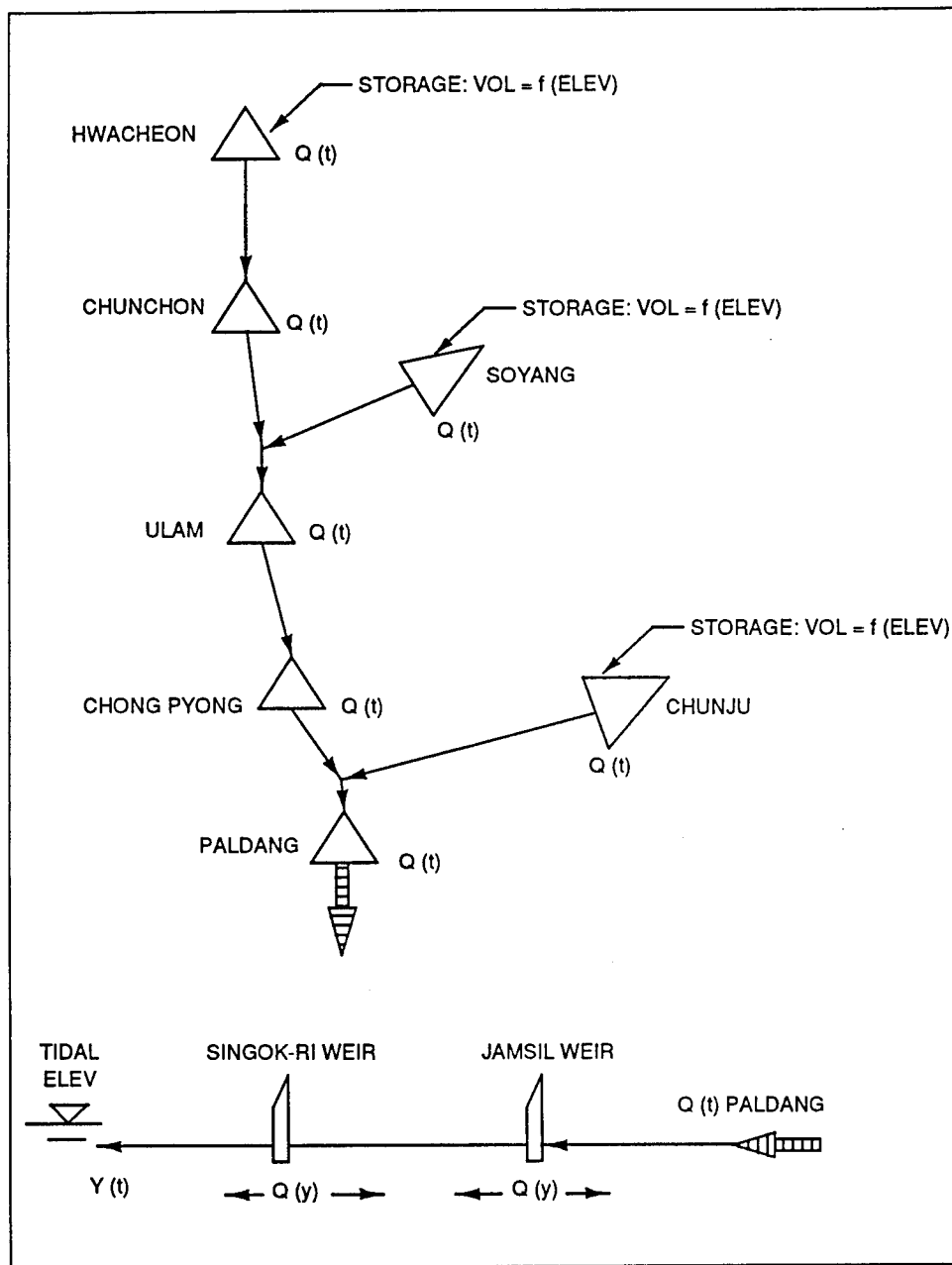
Figure 8. CARIMA simulation-System boundaries (external and internal)

The CARIMA simulation was divided into two separate models. The first model includes everything upstream of and including Paldang Dam. Paldang is a true boundary since downstream conditions cannot affect the flow or depths behind the dam. All the confluences are above Paldang, and all the reservoirs are included in this model, thus all the operational checks and actions are applied to this model.

The downstream model is the Main Han and the Estuary. The cross sections are more closely spaced and the bridge constrictions are modeled. This

model has two internal boundaries which are weirs. The flow can cross the weirs in either direction, depending on the water surface elevations on either side of the structure. The bridge constrictions, the weirs, the effects of the tides and the closely spaced cross sections all were factors which contributed to the decision to model the Main Han separately.

The reservoir optimization routine computes the optimal releases from all reservoirs in the system to meet the requirements of the specified crossing-site operations. However, these computed discharges do not take into account the discharge capacities based on the reservoir levels. Therefore, at the end of every computational timestep, a check is made to see if the scheduled release is possible given the current reservoir elevation. If it is not possible, then the simulation substitutes the maximum possible discharge for that elevation.

A basic flood-control rule is also applied at each computational timestep. The level in the reservoir is checked to see if it equals or exceeds the maximum flood pool level. If so, the scheduled release is ignored, and the simulation releases the maximum possible discharge for the current reservoir elevation. This is done because it is assumed that overtopping the dam should be avoided at all costs. This is also done without regard to any maximum discharge rates that may be used to protect downstream property or structures.

Dambreak Module

The objective of the dambreak module was to provide 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 (Fread 1983), was integrated into the HRCS to provide this capability.

The module allows the user 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.

Figure 9 provides a description of the integration of DAMBRK into the HRCS. The HRCS model provides the initial reservoir levels and schedule of tides. The user specifies the dams to fail, times of failure, and the scheduled discharge from every dam. TAMU provides inflows into the upper reservoirs and lateral inflows into the North and South Han. The DAMBRK model then creates the required input data files and runs two simulations in order. The first simulation is that of the Soyang River. The Han River simulation is then executed using results of the previous run as a lateral flow. Values of flow, water surface elevation, and depth are then provided to the HRCS at a time interval of 1 hour.
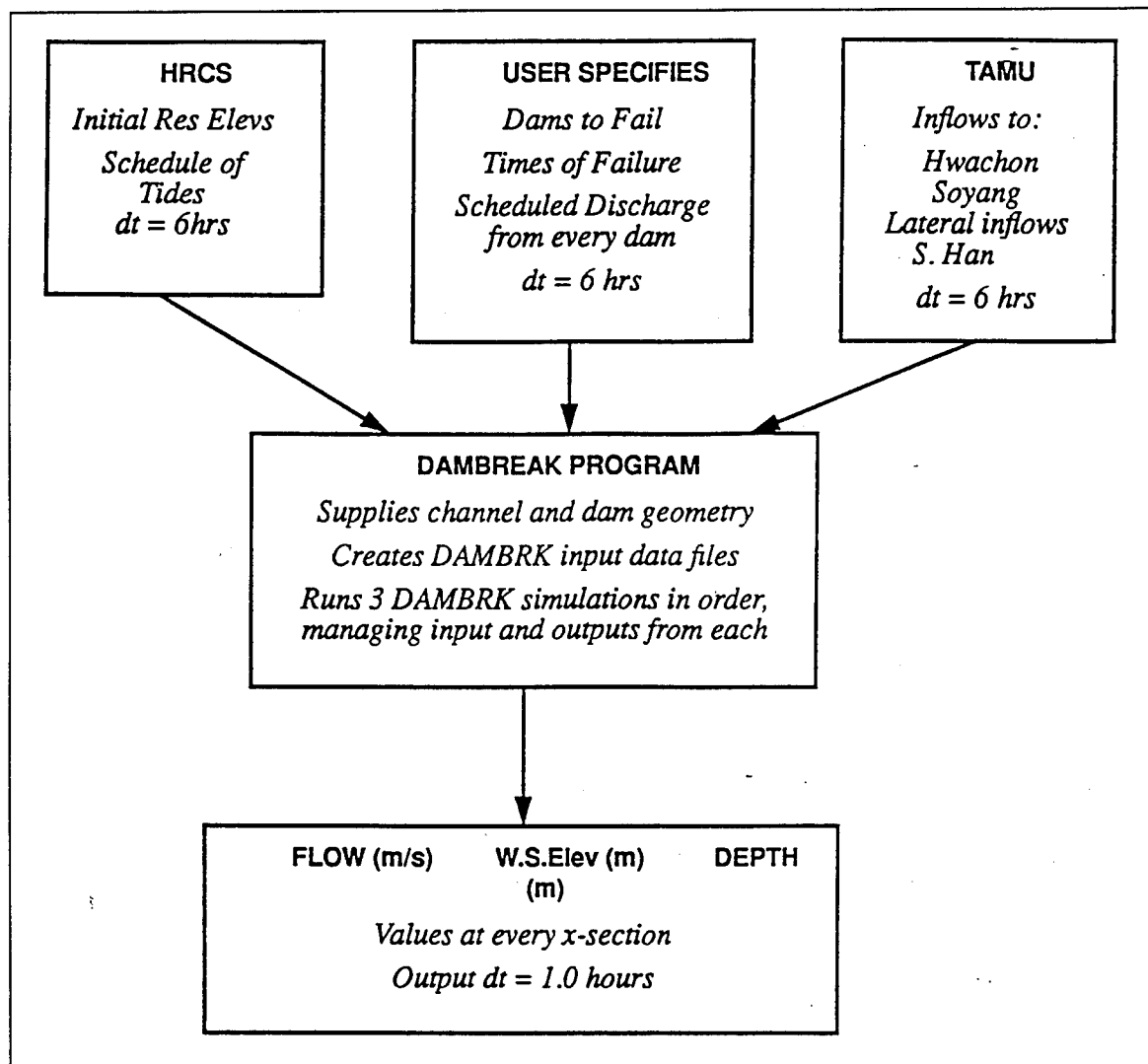
Figure 9. DAMBRK schematic

Figure 10 illustrates the system boundaries used in the DAMBRK portion of the HRCS. The DAMBRK model of the Soyang Reservoir uses level pool storage routing through the reservoir. The cross sections used for this section of the model were obtained from 1:50,000 scale topographic maps. The downstream boundary for the Soyang River is channel control (normal depth). The confluence of the Soyang and North Han Rivers is not modeled dynamically; it is assumed that the level of the North Han does not significantly affect the flow rate from the Soyang Dam entering the North Han and that the level in the Soyang River does not affect the level in the North Han.

In the North Han section of the DAMBRK model, Hwachon reservoir is modeled using dynamic routing, rather than storage routing. The choice of dynamic routing will make it easier to add any upstream dams to the model in the future. The upstream weir (at Jamsil) is not included in the model. Weirs cannot act as internal boundaries in DAMBRK, and the weir characteristics
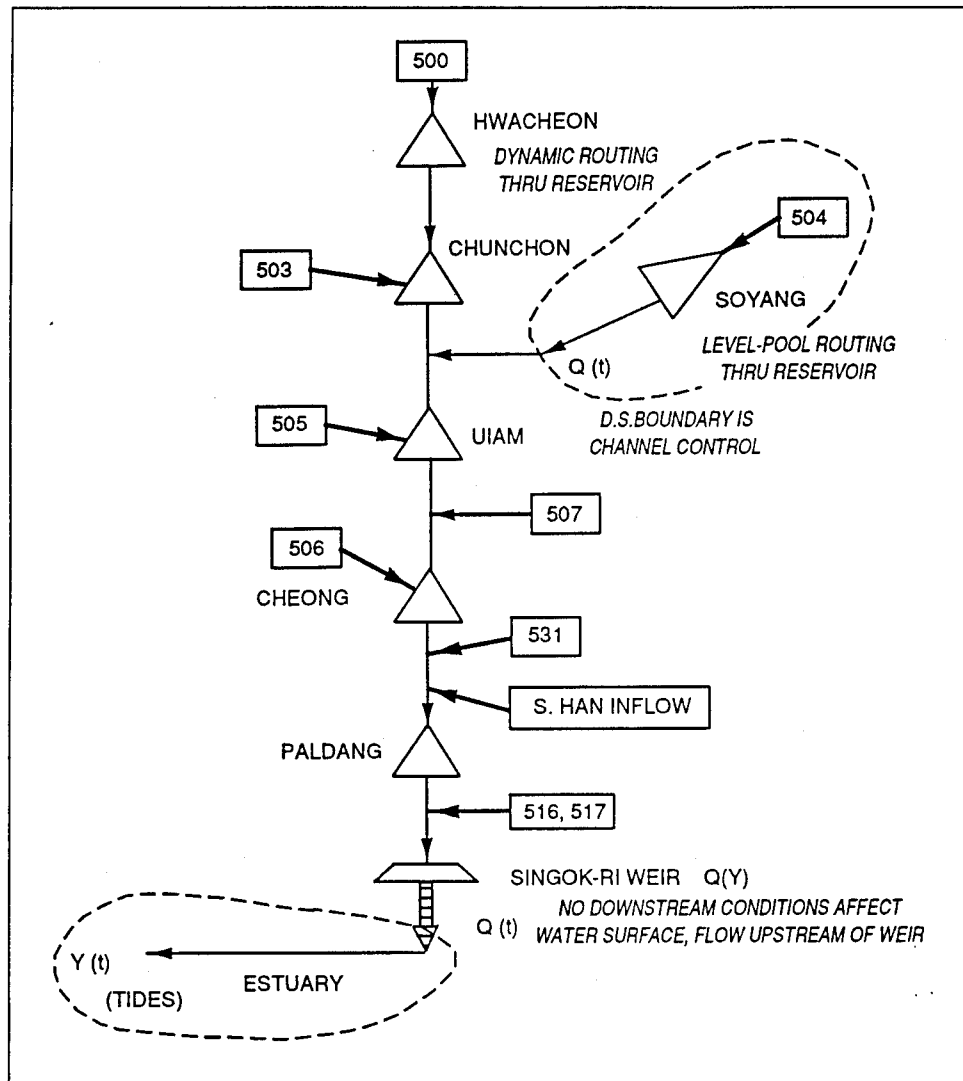
Figure 10. DAMBRK simulation - System boundaries and lateral inflows

were not known at the time of model development. The weir at Singok-ri is
the downstream boundary of the North Han simulation. It is assumed that the
flow is in the downstream direction at the weir, i.e., the tides do not affect the
flow upstream of the weir. In the estuary section of the DAMBRK model,
cross sections derived from 1:50,000 scale topographic sheets were used.
These were modified to have a wide bottom and a constant slope.

There were several assumptions necessary in the development of the
DAMBRK model. The breach of a dam is specified as one-third of the top
width of the dam; its side slopes are 1:5 and its bottom elevation is at
one-third of the height of the dam. The dams, which are all concrete gravity
dams, have significant bottom width, so it is justifiable to assume that an
explosion would not demolish the structure to the bottom.

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The duration of the breach is specified as 1 hour. This is much longer than the few minutes or seconds which it would take in reality if the dam was bombed, but DAMBRK could not reliably simulate a rapid failure in all situations.

Dams which are not failed may be overtopped. Each dam that is not failed has a specified water surface elevation at which the gate structures will fail, and that failure will be simulated. It is assumed that the dam itself will never fail from overtopping.

Estuary Crossing Module

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 implements a solution to this transportation problem using 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, and any waiting time that may occur due to unavailability of docks. The module will also consider 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 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 timeframe, 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 number of trips completed versus time.

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, Champaign, IL. 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 (WES). CAMMS provides a tool for analyzing influential mobility factors (weather conditions, terrain factors, and natural and man-made obstacles) and making mobility predictions for enemy and friendly troops. By using CAMMS, mobility predictions may be made for vehicle mobility (on-road and cross-country traveling, gap and fixed bridge crossing assessment), foot soldier mobility, gap (streams and rivers) crossing, and maneuver damage. The products from these predictions are used by CAMMS to create Tactical Decision Aids (TDA's).

Interactive TDA's include route analysis, tactical bridging, obstacle emplacement, and weapon emplacement. The Route Planning System (RPS) provides a tool to analyze the rates of movement (on-road and off-road) of friendly and enemy troops along a specific route. Tactical bridges may be introduced into an analysis to assist a vehicle(s) in crossing gaps that are otherwise considered impassable. CAMMS also allows emplacement of obstacles and weapons for use by friendly or threat forces. Using CAMMS to evaluate the effectiveness of these emplacements will provide commanders with a tool for making offensive and defensive tactical decisions.

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 nonflooded 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 nonflooded area.

4 Summary and Recommendations

Summary

The purpose of this report was to document the development of 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.

This report documents the development of an expert system capable of forecasting reservoir operation of the Han River system. An overview discussing the Han River Basin and illustrating the impacts of hydrology on the battlefield was presented initially to highlight the importance of reservoir operations on military strategy and tactics. The development of the HRCS was then discussed, beginning with capabilities present during the Korean War and continuing with details of the RAMBO. The two phases of development of the HRCS were also discussed. The components of the HRCS were then described in detail, including the user interface, the rainfall-runoff module, the reservoir optimization module, the dambreak module, the estuary crossing module, the inundation module, and the trafficability module.

Recommendations

System validation is recommended to give the miltary user greater confidence in the system and the results produced. The following steps would be required for proper validation:

a. Verification of the operation of TAMU, using both manually entered and downloaded data.

b. Calibration of the Optimization procedure.

c. Verification of DAMBRK results. This task requires the execution of DAMBRK under various precipitation and reservoir state scenarios.

d. Calibration of CARIMA and verification of CARIMA results.

e. Verification of Estuary Crossing results. The estuary crossing model requires equipment, flow, and location-dependent data. It must be ensured that the model is operating with the correct data and that the results are consistent.

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13. ABSTRACT (Maximum 200 words)

The Han River Basin is the major river in South Korea, with a basin area of more than 26,000 square kilometers. Seven major dams are located in the North Han River Basin. These dams are operated primarily for hydropower generation, although flood control and water supply are also important objectives. The Han River Control System (HRCS) is a decision support computer software system developed by the U.S. Army Engineer Waterways Experiment Station to provide near real-time information on flooding conditions resulting from river operations. The system also provides reservoir operations necessary to meet downstream constraints. An overview describing the Han River Basin will be presented to highlight the importance of reservoir operations within the basin and the significance of a system that assists the user in determining how to operate the different reservoirs to best meet the different objectives. The HRCS components will than be described. These components include the following: TAMU, the rainfall-runoff module; CARIMA, the hydrodynamics module; OPTIMA, the reservoir optimation module; DAMBRK, the dam breach forecasting module; and the inundation mapping module, which uses the graphical information system, GRASS.

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