DISSERTATION

SPATIAL DECISION SUPPORT SYSTEM FOR INTEGRATED RIVER BASIN FLOOD CONTROL

Submitted by

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY KYU-CHEOUL SHIM ENTITLED SPATIAL DECISION SUPPORT SYSTEM FOR INTEGRATED RIVER BASIN FLOOD CONTROL BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT OF DISSERTATION

SPATIAL DECISION SUPPORT SYSTEM FOR INTEGRATED RIVER BASIN FLOOD CONTROL

Flood has caused the most prevalent and costly natural disasters in the world. Flood also causes impacts to society that go beyond cost and facilities; including impacts such as family and community disruptions, dislocation, injuries and unemployment. During the real-time flood events, the operation of water surface system is very important and crucial to minimize the impacts of flood.

This research presents a comprehensive methodology focused on improving current approaches of flood forecasting and control systems using the enhanced technologies, neural network algorithm and multidimensional dynamic programming. The developed methodology has been embedded in a PC based Spatial Decision Support System (SDSS) for integrated river basin flood control. For implementing the prototype of SDSS, several submodules and subsystems have been developed. The SDSS consists of Relational Database Management System, Hydrologic Data Monitoring System, Spatial Analysis Module, Spatial and Temporal Analysis for Rainfall Event Tool, Flood Forecasting Module, Real-Time Operation of Multireservoir System, and Dialog Module with Graphical User Interface and Graphic Display Systems.

The prototype system is intended to demonstrate the potential value of a SDSS to the water resources manager and engineer for operational flood management. The developed SDSS provides an automated process of alternative evaluation and selection within a flexible, fully integrated, interactive, centered relational database management system in a user-friendly computer environment. The river basin decision-maker for the flood control should expect that he could manage the flood events more effectively by fully grasping the hydrologic situation throughout the basin.

The detailed contribution of each module is as follows:

1. The relational database management system serves center of the spatial decision support system and generating the necessary data files for various modules in the system.

2. The GIS module contributes by minimizing the time required for spatial analysis to generate the isohyet of each time period, as well as new information of the spatial characteristics in the basin

3. The rainfall-runoff models can be easily constructed beforehand without a lot of knowledge of the underlying process using a neural network algorithm. The developed rainfall-runoff models can better forecast the discharges in accuracy for the proposed points throughout the basin.

4. The power of using dynamic programming for real-time operation of multireservoir should give the more assurance to the operational decision-maker providing quantitative information rather than qualitative information

5. The graphical user interface should serve the great advantages of time saving, error checking and control, understanding the overall procedures for water resources management problems through driving the user to the task.

6. The case study provides motivation, ease use, understanding the overall operational flood management works to the system developers as well as terminal users.

The results of case study for '1995 flood event in the Han River Basin have provided that the developed methodology and computer based SDSS can operate water surface system to minimize flood impacts at the downstream while maintaining water for next hydrologic period water use during the real-time flood events.

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INTRODUCTION

1.1 Problem Overview

When waters from a river, lake, ocean, or other surface water feature rise above normal limits, it may be defined as a flood event. Flooding has caused the most prevalent and costly natural disasters in the world. Floods often endanger lives and cause millions of dollars in damage. Floods also cause impacts to society that go beyond cost and facilities; including impacts such as family and community disruptions, dislocation, injuries and unemployment (Mays, 1992).

One of the most important aspects of minimizing the impacts of floods is the operation of flood control systems. These systems may include reservoirs. In order to operate these systems, the forecasting of flood events is very important as well. Nemac (1986) classified hydrological forecasts by three characteristics: a) the forecast variable; b) the purpose of the forecast; and c) the forecast period. Many textbooks consult technical aspects of these topics (Linsley, 1979; Chow, 1988; Mays, 1992; etc.). One of the most important criteria in flood forecasting is the lead time which is the interval of time between the issuing of a forecast and the expected occurrence of the forecasted event.

Both developed and developing countries throughout the world have been made an ongoing effort in real-time hydrological forecasting systems. Developed countries are concerned with the expansion and improvement of existing flood-forecasting systems and developing countries are concentrating on the establishment of basic data networks and forecasting capabilities for the prevention of flood damages (Mays, 1992).

The real-time reservoir operation problem involves the operation of a reservoir system by making decision on releases, as information becomes available, with relatively short time intervals such as one hour. Real-time operation of multireservoir systems involves various hydrologic, hydraulic, operational, technical, and institutional considerations, requiring an integrated river basin management framework. For efficient operation, a monitoring system is essential, which provides the reservoir operator with the flows and water levels at various points in the river system including upstream extremities, tributaries and the major river channel as well as reservoir levels, and precipitation data throughout the basin.

Grigg (1996) emphasizes that there are many kinds of complexities and stresses that flood control should be seen as part of integrated strategies of river basin management and not just as a single-purpose water project task. The development of integrated operational strategies for flood control and multi-purpose projects is crucial during real-time flood events and emergency conditions. This involves: a) creation of real-time hydrometeorological database management systems, b) calibration and implementation a real-time river forecast system, and c) configuration of a real-time optimal computer control system or integrated reservoir system operation (Labadie, 1990).

A decision support system is an advisory system for management, usually computer based, that utilizes database, models and dialog system to provide decision makers with management information (Grigg, 1996). Computerization is an essential step in supporting the decision making process. Computing technologies not only organize and facilitate the processing of large amount of data, but they can also provide documentation of the process of selecting one alternative over all others. The general concepts and use of the decision support system as applied in water resources management was presented in the Proceedings of the American Society of Civil Engineers Workshop on Computerized Decision Support System for water resources managers. Computerized decision support system can enhance the process for maximizing the productivity, cost-effectiveness, and reliability of complex water resources systems (Labadie, 1988).

Geographic information systems (GIS) are also computer-based tools that generate, store, analyze, retrieve, manipulate and manage large amounts of spatial data. They are spatial database management techniques that were developed inherently to ease cartography but are being used these days for spatial analysis, estimation, planning, and modeling (Singh, 1995). Hydrologic or watershed modeling, for use in a flood forecasting system, requires accurate and representative data. However, the spatial nature of hydrologic data, the large volume of data, and the organization of data cause this task to be cumbersome in required data for this modeling. These data problems can be resolved through the application of GIS.

A spatial decision support system (SDSS) can be defined as the integrated application of a geographic information system (GIS) and a decision support system (DSS) to aid decision-makers with problems that have a spatial dimension. The spatial decision support system represents the state of art methodology to implement the real-time operation of multireservoir systems.

1.2 Study Objective

The objective of this study is the development of a methodology that improves current approaches of flood forecasting and control systems using the enhanced spatial decision support system in an integrated river basin management framework. The goal of this research is to enhance flood management by integrating several advanced technologies into a comprehensive river basin management system. This system includes a flood forecasting system, a monitoring system and real-time operation procedure for multireservoir systems. The proposed approach involves the development of relational database management system (RDBMS), and application of geographical information systems (GIS), an artificial neural network algorithm and a multidimensional dynamic programming algorithm.

The specific objectives of this study are follows:

1. Comprehensively review research on operation of surface water systems for flood management, system analysis, spatial analysis (geographic information systems), real-time flood forecasting systems (rainfall-runoff analysis, neural network algorithms), real-time operation of multireservoir systems, and spatial decision support systems.
2. Develop a database management system that is used as the core of a SDSS to manage the spatial and textual data. Various real-time hydrologic data will be

required for flood control in a river basin. To collect, store, retrieve and manage the data, the database management system is an essential component of a spatial decision support system. For generating the input data files for developed modules, several query systems were designed in a graphical user interface (GUI).

3. Link a spatial analysis module that integrates visualization of the basin topologies and the spatial analysis into a spatial decision support system. The visualization of the basin topologies consists of digital elevation, aspect and contour maps for the basin, river basin boundary maps, and location maps of rainfall and flow telemetry stations. Using those base maps, the spatial analysis was performed to generate the isohyetal map and its related data for the flood forecasting model.

4. Develop nonlinear time variant rainfall-runoff models as a flood forecasting module for the inflows and local inflow at the proposed points using artificial neural network algorithms. To develop these models, the backpropagation learning algorithm was used with Levenberg-Marquardt Technique. This technique uses gradient descent and the Gauss-Newton method to solve the problem of finding local minimum and to enhance the speed of convergence.

5. Develop a real-time operation module of multireservoir systems for flood control combining the Dynamic Programming with Successive Approximation (DPSA) algorithm in CSUDP and a hydrologic routing model. The developed system strives to maintain the maximum water resources without including flood damages throughout the river basin. The module was designed to fully integrate

operations considering all nodes and reaches of a basin. The module generates the optimal release polices to satisfy the various objectives.

6. All of the developed subsystems were integrated in a spatial decision support system with a user-friendly graphical user interface and a graphical display system for each module. The user-friendly graphical user interface can communicate with the user and generate the necessary data files for the models using queries from the database as well as generating the graphical views for the model results.
7. Demonstrate the implementation and use of the developed procedures for integrated river basin flood control using the Han River Basin in Korea as a case study.

1.3 Organization of the Dissertation

Chapter 1 presents an introduction with problem overview and the objectives of this research. Chapter 2 covers literature review of pertinent topics such as flood control in the river basin management, operation of surface water systems for flood control, rainfall-runoff modeling with neural network algorithms, real-time operation of multireservoir system and spatial decision support systems.

Chapter 3 presents an application of geographic information systems as the essential part of the Spatial Decision Support System. The overall procedures for generating isohyets map and dynamic database table were also described. Chapter 4 presents the development of a flood forecasting module using neural network algorithms.

The first part of this chapter describes the theory of neural network algorithm, including multi layer feed forward neural network algorithms and learning algorithms. The overall procedures for rainfall-runoff modeling are also described, including local inflow calculation process, input and output data setup, selection of model structure, training strategies and parameter estimation.

Chapter 5 presents the real-time multireservoir operation module for flood control. Following a brief overview of the generalized dynamic programming model CSUDP, the procedures are described for developing the real-time multireservoir operation module for flood control in the Han River Basin utilizing the Dynamic Programming with Successive Approximation (DPSA) algorithm.

Chapter 6 presents the development of a Spatial Decision Support System (SDSS). This includes the process for integrating the developed modules, their graphical user interface (GUI) and graphical display system (GDS), and the Relational Database Management System (RDBMS). In this chapter, the design and construction of the Han River Basin Database Management System is described. The GUI and GDS for the Hydrologic Data Monitoring System and the development of the Spatial and Temporal Analysis Tools for Rainfall are also described.

Chapter 7 is the application of the developed methodology using the 1995 flood event in the Han River Basin as a case study. A summary and conclusions are presented in Chapter 8. A list of references used in the research and appendices that contain tables, figures and computer programs related to various modeling works are presented at the end of the document.

CHAPTER 2

LITERATURE REVIEW

2.1 Flood Control in the River Basin Management

2.1.1 Flood and Flood Characteristics

A flood should be defined as an event when the waters from various surface water features in the hydrologic cycle exceed their regulated normal limits (ASCE, 1996). Flood control preventing damage of floods, which is a different type of mission than other objectives such as providing water supply or controlling water quality (Grigg, 1996). Floods often endanger lives and cause millions of dollars in damage. However, floods also have beneficial effects, which includes cleaning stream channels, replenishing soil moisture, depositing fertile fine sediments on agricultural lands, restricting upstream movement of salt fronts in estuaries and maintaining the storage capacity in water resources projects (ASCE, 1996).

The causes of floods and flooding vary from natural characteristics to man-made factors that affect floods (Chow, 1964). Watershed or river basin characteristics such as size, slope and surface topology affect floods. In general, a round river basin produces larger flood peaks than a long narrow one. A watershed with a steep slope also produces larger flood peaks than basins with small slopes. Larger floods occur on basins with rocky or other impervious surfaces than basins with deep and pervious soil cover.

Precipitation is primary source of flood events. Intense, short-duration rainfall often causes severe floods on small streams. In some mountain areas, melting of seasonal snowpack provides the primary source of floodwaters. Ice can have a significant effect on floods or flooding. During the winter, ice can form in the stream channel to reduce conveyance and cause flooding of overbanks. Erosion and sedimentation contribute a large portion of the annual damage due to floods. Floods carry sediments eroded from the watershed and scoured from the stream channel.

Landuse characteristics also affect floods. Forested and heavily vegetated drainage basins generally produce floods of smaller peaks and longer durations than comparable bare basins. Construction of reservoirs usually reduces flood peaks downstream: however, small uncontrolled reservoirs on tributaries can disrupt natural runoff timing and cause increases in flood peaks on the receiving stream depending on the relative location of these reservoirs. Urban and suburban developments can have profound effects on flooding. Creation of impervious surfaces reduces infiltration. Construction of storm sewers and improvement of drainage channels, including streets with curbs and gutters, causes rapid concentration of runoff. The result is usually a much larger flood peak with increased runoff volume during shortened flow durations. Though infrequently, reservoirs and other water-retaining structures have failed and produced major floods causing severe loss of lives and property damages.

2.1.2 History of Floods and Flood Control Works

In 1887 one of the worst floods in recorded history occurred when the Huang He River in China known as Yellow River broke through its levees, killing more than a million people (Encyclopedia, 1996). The basic methods of flood control have been practiced since ancient times. These methods include reforestation and the construction of levees, dams, reservoirs, and floodways (artificial channels that divert floodwater).

The ancient Chinese built levees to raise the banks of the Huang He on the supposition that the confined river would then deepen its channel to contain the maximum flow. The result, however, was a raising of the riverbed, because the sedimentary deposit of alluvial soil previously distributed over the entire flood plain during annual flooding was confined to the river bottom. Levees were constructed during the Middle Ages on the Po, Danube, Rhine, Rhône, and Volga rivers and have been supplemented in modern times by reforestation and by storage reservoirs (Encyclopedia, 1996).

Levees are still in extensive use, notably on the Mississippi, where the river has been confined to a narrow channel to provide the depth necessary for navigation. Maintaining that depth has required repeated dredging of the channel, adding to the already large cost of sustaining the levee system. Floods in the Mississippi Valley have demonstrated that levees alone do not provide sufficient protection against flooding on a large river, and other methods of flood control, including dams and floodways, are now in use on the Mississippi River. However, flood-control measures failed to contain the great flood of the summer of 1993, one of the worst in United States history (Water, 1993). Swelled by record spring rains, the Mississippi and Missouri rivers and many of their tributaries overflowed their banks, inundating an estimated 8 million acres by early August. The raging floodwaters also inflicted major damage on levees, dams, and floodways, ruined an additional 12 million acres of cropland, and caused about $12 billion in damage. At its height, the Missouri River crested almost 50 ft above its banks.

Although dams have been used for many centuries, their primary purposes were to build up water reserves for irrigation and other domestic uses and to create power. Only recently have they been constructed specifically for flood control. An effective method of controlling floodwaters is to construct coordinated groups of dams and reservoirs on the headwaters of the streams that lead into the main rivers, so that water can be stored during periods of heavy runoff and released gradually during dry seasons. The Hoover Dam on the Colorado River, the reservoirs in the Miami Conservancy District, and dams of the Tennessee Valley Authority (TVA) have demonstrated the value of this method. When the tributaries on which these dams are located are at their normal level, the dams operate solely to produce power and provide water for various purposes. During time of high water the dams operate to slow down the flow. The dams closest to the origins of the tributaries restrain the floodwaters while the dams farther down slowly release their normal demand and are drained. Then the floodwaters are released to each succeeding dam and finally emptied into the main river, the capacity of which has been increased by straightening and deepening.

In other countries, one remarkable flood-control project is the Delta Plan, a Netherlands effort begun in 1958 and completed in 1985. The project consists of a series of giant dams that link islands in the deltas of the Rhine, Maas, and Schelde (Escaut) rivers. A huge storm-surge barrier 9 km (5.6 mi.) long is lowered only when a sea flood is anticipated; at other times, tides move freely through the passage. Another such project, on a somewhat smaller scale, was completed across the Thames River a short distance below London in 1983.

Through the centuries people have created a flood problem by cutting down trees and digging up the vegetation cover of the soil, thus increasing soil erosion. Cultivation decreases the ability of the soil to retain water and increases runoff. Vast land areas along the headwaters of rivers throughout the world have been laid waste by intensive cultivation and subsequent erosion. Flood control in these areas has been directed to restoring vegetation and instituting efficient methods of soil management, such as crop rotation and contour plowing.

Another method of flood control is the construction of floodways on the lower reaches of rivers to divert floodwaters. The rivers are widened at certain points and allowed to overflow. Inundation of certain confined areas prevents the flooding of other areas. The Egyptians have used regulated flooding for thousands of years. Many areas in the Nile Valley depend for their continued fertility on periodic flooding because the soil deposited by sedimentation from floodwaters is very rich.

In the 20th century the problem of flood control in the United States has assumed national importance because of the increasing frequency and intensity of floods in all of the great river valleys as a result of deforestation. In addition, agricultural and industrial development in these valleys has necessitated a coordinated program of flood control. Federal legislation has been passed to aid the states in effecting adequate control measures.

Federal action in this field was long hampered by many constitutional limitations. As late as 1879, the problem of Mississippi River flood control was left to the 31 states in that river's drainage system. In that year, the federal government, under the guise of improving navigation (a power constitutionally granted to it), helped finance the construction of levees. The federal government has played an increasingly important role in the problem of flood control.

When scientific research into the causes of floods showed that the construction of levees was insufficient as a method of control, the first steps were made to provide for reforestation and soil conservation. The Clarke-McNary Act of 1924, the Mississippi Flood Control Act of 1928, and the McSweeney-McNary Act of 1928 were all directed toward that end. In 1935 the Soil Conservation Service was established by the Congress of the United States under an act declaring a policy of permanent provision for control and prevention of soil erosion, and for control of floods. In the same year the Fulmer Act was passed, authorizing the secretary of agriculture to enter into cooperative agreements with the states for better forestland management. In 1937 further authority was granted to the secretary of agriculture in the Bankhead-Jones Farm Tenant Act to control soil erosion and to mitigate floods. Another act of Congress provided for an investigation of the material resources in the California watersheds. Similar acts covered the watersheds of the Rio Grande and the Pecos River. The period of the 1930s is notable for the many national forests that were established to assist in the soil-conservation program. The most important single act directed at the problem of flood control was the establishment of the TVA in 1933.

By 1940 the Supreme Court of the United States had passed on the constitutionality of almost all federal activities in the field of flood control and had upheld actions that related to almost all waters of the United States, without limiting these actions to the navigable streams, as had been done earlier. In the Flood Control Act of 1946, Congress authorized construction of 123 projects to aid river regulation, flood control, and power development.

In 1972 Congress moved to reduce the hazards from the 28,000 nonfederal dams in the country by passing a bill providing for a dam-inspection program. The action was spurred by two disastrous dam failures during the year. At Buffalo Creek, West Virginia, a makeshift dam at a coal mine site collapsed with a loss of more than 100 lives; and at Rapid City, South Dakota, two earthen dams gave way, resulting in more than 200 deaths.

Many aspects of flood control can be handled by individual states or groups of states acting on a regional basis. One such project, completed in 1922, is the Miami Conservancy District, a system of reservoirs in the Miami River valley in Ohio that works to reduce flood hazards. Such organizations as the Los Angeles County Flood Control District, the TVA, and others relating to specific areas have made important studies of hydrologic and meteorological conditions to aid in the forecasting of flood dangers and to plan flood control.

2.1.3 Basic Strategies for Flood Management

The Natural Hazard Research Center (1992) listed four basic strategies and its related tools for flood management:

1. *Modify susceptibility to flood damage and disruption*

   The related tools are floodplain regulations, development and redevelopment policies, disaster preparedness, disaster assistance, floodproofing, flood forecasting systems, warning systems and emergency plans.

2. *Modify the flood*

   The related tools are dams, reservoirs, dikes, levees, floodwalls, channel alterations, high flow diversions, land treatment measures, and on-site detention.

3. *Modify the impacts of flooding on individuals and the community*

   The related tools are information, education, flood insurance, tax adjustments, flood emergency measures, and postflood recovery.

4. *Restore and preserve the natural and cultural resources or flood plains*

   The related tools are floodplain, wetland and coastal barrier resources regulations, development and redevelopment policies, information, education, tax adjustments, and administrative measures.

Grigg (1996) classified these measures into structural and nonstructural measures. The most important structural measures for controlling floods are reservoirs and levees, which use traditional engineering tools and are still being implemented in some countries. If a flood can be stored in the available storage capacity, downstream areas won't be impacted, and then the stored floodwater should be released smoothly after the flood events. However, sometimes a flood exceeds the available storage space of the reservoir, then it is necessary to carefully release waters during the flood event. In many places, levees and associated floodwalls are protective structures as an essential part of comprehensive flood protection systems.

Most developed countries, especially the U.S., have turned their attention to nonstructural measures to flood management (Grigg, 1996). The Inter-Agency Task Force listed three principles for flood management in 1976:

1. *The federal government has a fundamental interest in how the nation's floodplains are managed, but the basic responsibility for regulating floodplains lies with the state and local governments.*

2. *Floodplains must be considered in the context of total community, regional, and national planning and management.*

3. *Flood loss reduction should be viewed in the larger context of floodplain management, rather than as an objective in itself.*

For the best or optimum strategy for flood management, comprehensive, river basin wide, coordinated and sustainable projects should be provided considering financial limitations. Even if there are a lot of enhanced and emergent technologies in the world, the water resources manager must make a best decision within the available budget. However, the water resources manager may be faced with overcoming the financial limitation to provide the optimum strategy. In that case, international or interstate financial corporations should be involved.

Through the literature, we can conclude that the flood management involves many kinds of complexities. In this study, comprehensive integrated river basin wide flood control systems will be addressed using operational flood management strategies.

2.2 Operation of Surface Water Systems for Flood Control

2.2.1 Real-Time Flood Forecasting

In order to operate flood control systems, the forecasting of flood events is very important. The term "forecasting" refers to the determination of the discharges and water surface elevation at various points throughout the river basin as a result of observed or predicted inflow flood hydrographs (Mays, 1992). The three characteristics that classify hydrological forecasts are: 1) the forecast variable is water level for rivers, lakes, and reservoirs; 2) the purpose of the forecast is to determine the water levels resulting from a seasonal floods, flash floods, and dam breaks; and 3) the forecast period could range from short period to long period (Nemac, 1986). Flood forecast includes the steps of 1) obtaining real-time precipitation and stream flow data through various communication networks, 2) inserting the data into rainfall-runoff and stream flow routing programs, and 3) forecasting flood flow rate and water levels for periods of a few hours to a few days ahead (May, 1992). To collect and transmit the real-time hydrometeorological data, a real-time data collection system is required over the river basin. This system is used to provide information for a flood forecasting model. This information is of two types: 1) the water surface elevations at various locations throughout the river-reservoir system, and 2) rainfall for the catchment areas throughout the basin (Mays, 1992). Flood forecasts used to help the water manager operate the real-time flood control systems and to provide warnings for people to evacuate areas threatened by floods.

2.2.2 Real-Time Data Collection Systems for River Basin

The first phase of the forecasting and warning system requires the collection and transmission of real-time hydrologic data including precipitation, river stage, and other significant variables. The system may be simple, relying on manually read rain gages and stream flow gages with information called to a central point for evaluation by office personnel, possibly through simple look up tables. Or it might be fully automated with computer modeling of the entire river basin. Whether the data acquisition system is manual or automated, the information transfer is similar.

A real-time data collection system generally consists of 1) rainfall gages in the river basin, 2) stream flow gages on the tributaries and main channel, 3) repeater stations to transmit from the remote sensors to the base station, and 4) the base stations (ASCE, 1996). The overall system is often a compromise between forecast accuracy desired and first cost / annual operation and maintenance costs of the system.

2.2.3 Flood Forecasting Models

After transmission of the real-time rainfall and river stage data to the base station, the data are processed and input to a watershed hydrologic model to forecast flood levels and the time to reach these levels at flood control points. Flood forecasting models include a variety of flood routing procedures, which are based upon rainfall-runoff models. Although all have the same basic concept, they are developed to various levels of sophistication by using different mathematical functions to derive watershed responses. An appropriate model should be selected based on the density of data collection stations, desired accuracy of the forecast, the availability and capability of computers, and the ability of the user to operate the model. Flood forecasting models are grouped into the following categories based upon the tasks the model accomplishes (ASCE, 1996).

1. *Event-oriented rainfall-runoff models simulate rainfall over a basin and resulting flows through the watershed one storm at a time.*
2. *Continuous simulation rainfall-runoff models, on the other hand, can provide long-term simulations dealing with multiple storm events because they include routines that track soil moisture between periods of rain or snow.*
3. *Steady-flow flood routing models can calculate the flow depth and velocity at various locations along the channel as the flood moves downstream. The basic assumptions often used include flow being steady, uniform, and one-dimensional.*
4. *Unsteady-flow flood routing models should be used when steady flow conditions cannot be assumed, such as dam-breaks, or large tributary flows enter the main channel.*

The rainfall-runoff models and the flood routing models can also be referred to as hydrologic and hydraulic models respectively.

2.2.4 Flood Early Warning Systems

The final phase in the flood forecasting and warning system is the dissemination of pertinent information and warning to populated and propertied areas. A precise plan of information dissemination must be prepared for flood emergencies. Then the information announcement must be timely and as accurate as possible. The warning time must be determined for appropriate actions to occur. If warning time is very short, little action other than life saving may be possible. If several hours or more are available, additional damage reduction measures are possible.

The responsibility as to who issues flood warnings must be clearly established. Those personnel who are authorized to provide input into these decisions also must be clearly identified. The delivery of warning is critical. A general warning broadcast over the electronic media will often be ignored, unless the individuals receiving the warning have been recently flooded. To have the highest success of a positive response to a flood warning, an individual should receive specific information as to the height of the flood crest, when the crest will occur, the area that will be inundated, and information on the appropriate evacuation path. If possible, personnel issuing the warning should go door-to-door to insure that the warning is received and that proper action is taken.

If floods occur frequently, periodic rehearsals of activating the entire system should be conducted. These rehearsals should insure that all key personnel are familiar with the system and skilled at the roles they should play during an actual flood emergency. The Guidelines for flood warning and preparedness are available from local, state, or federal agencies (FIAC, 1985)

2.2.5 River-Reservoir Operation for Flood Control

The real-time reservoir operation problem involves the operation of a reservoir system by making decision on releases, as information becomes available, with relatively short time intervals such as one hour. Real-time operation of multireservoir systems involves various hydrologic, hydraulic, operational, technical, and institutional considerations requiring an integrated river basin management framework (Mays, 1992).

For efficient operation, a monitoring system is essential, which provides the reservoir operator with the flows and water levels at various points in the river system including upstream extremities, tributaries and major creeks as well as reservoir levels, and precipitation data throughout the basin. Reservoir inflow forecasting models or systems are required to provide the input data for operation of the reservoir system.

Optimization or simulation models can be used to determine the flood control operation of the reservoir systems. The objective of such a model is to find operating policy (release) that will minimize flood damage as well as maximize maintaining water storage for future time periods.

2.3 Rainfall-Runoff Modeling

2.3.1 Classification of Rainfall-Runoff Models and Modeling

Since the development of the Stanford Watershed Model in 1966 by Crawford and Linsley, there has been a proliferation of rainfall-runoff models (Renard, 1982; James, 1982; Singh, 1989). Rainfall-runoff models can be classified as lumped or distributed models according their process description.

A lumped model, in general, consists of ordinary differential equations they do not account for spatial variability of processes, input, boundary conditions and watershed geometric characteristics (Singh, 1995). Examples of lumped models are HEC-1 (Hydrologic Engineering Center, 1981), HYMO (Williams and Hann, 1972), RORB (Laurenson and Mein, 1983), SSARR (U.S. Army Engineer, 1972), and the TANK model

(Sugawara, 1984). However, distributed models take explicit account of spatial variability of processes, input, boundary conditions and/or system characteristics. Examples of distributed models are SHE (Abbott, 1986), IHM (Morris, 1980), SWMM (Metcalf, 1971), and NWSRFS (HRL, 1972).

Rainfall-runoff models are classified as deterministic, stochastic, or mixed. If all of the components of a model are governed by the law of certainty, then it is a deterministic model. Stochastic models deal with hydrologic time series and predict hydrologic events by simulating the statistical behavior of the time series. Sometimes, components of a rainfall-runoff model use a mix of deterministic and stochastic components. Then this model is termed a stochastic-deterministic, hybrid or mixed model.

Two major approaches for modeling the R-R process have been explored in the literature: "conceptual" (physical) modeling and "system theoretic" modeling (sometimes referred to as "black box"). Conceptual rainfall-runoff (CRR) models are designed to approximate within their structures (in some physically realistic manner) the general internal sub-processes and physical mechanisms which govern the hydrologic cycle. CRR models usually incorporate simplified forms of physical laws and are generally nonlinear, time-invariant, and deterministic, with parameters that are representative of watershed characteristics (Yun, 1986).

While conceptual models are of importance in the understanding of hydrologic processes, there are many practical situations such as stream flow forecasting where the main concern is making accurate predictions at specific watershed locations. In the system theoretic approach, difference equation or differential equation models are used to identify a direct mapping between the inputs and outputs without detailed consideration of the internal structure of physical process. The linear time series models such as ARMAX (auto-regressive moving average with exogenous inputs) models developed by Box and Jenkins have been most commonly used in such situations because they are relatively easy to develop and implement. However, such models do not attempt to represent the nonlinear dynamics inherent in the transformation of rainfall to runoff and therefore may not always perform well (Hsu, 1995).

2.3.2 Areal Estimates of Precipitation

All rainfall-runoff models require areal estimates of precipitation as a fundamental input. Traditionally, there are three methods used to calculate the basin wide rainfall volume on the areal estimate of precipitation. These are the Arithmetic Average Rainfall Method, the Thiessen Polygon Method, and Isohyetal (rainfall contouring) Method. In any method, there are errors and related with density of the rain-gauge network and basin characteristics.

2.3.2.1 Arithmetic Mean Method

The arithmetic mean method is the simplest way of determining area average rainfall volume. It involves averaging the rainfall depths recorded at a number of gages. This method is satisfactory if the gages are uniformly distributed over the area and individual gage measurements do not vary greatly about the mean. Equation (2-1) shows the calculation of the areal estimates of precipitation.

$$\overline{P} = \overline{p} \times A \qquad (2\text{-}1)$$

where $\overline{P}$ = Areal Estimates of Precipitation

$\overline{p}$ = Arithmetic Mean Precipitation of Gages

A = Area of Basin

Orthographic effects on rainfall and its distribution and density of gauging stations are not considered in this method. This method can be used in plan area for relatively homogeneous rainfall distribution.

2.3.2.2 Thiessen (Polygon) Method

If the distribution of gauging stations is not even, the Thiessen method can be used. The relationship between a rainfall depth from each gauging station and its representative area are considered in this method. The Thiessen method assumes that at any point in the watershed the rainfall is the same as that at the nearest gage so the depth recorded at a given gage is applied out to a distance halfway to the next station in any direction. The relative weights for each gage are determined from the corresponding areas being formed by the perpendicular bisectors of the lines joining adjacent gages (Chow, 1988). If there are J gages, and the area within the watershed assigned to each is a_j, and p_j is the rainfall recorded at the j^{th} gage, the areal estimates of precipitation for the watershed is

$$\overline{P} = \frac{1}{A}\sum_{j=1}^{J} a_j p_j \tag{2-2}$$

where $\overline{P}$ = Areal Estimates of Precipitation

A = Area of the Basin

a_j = Supervising area of the each gage

p_j = Precipitation of the each gage

The Thiessen method is generally more accurate than the arithmetic mean method, but it is inflexible, because a new Thiessen network must be constructed each time there is a change in the gage network, such as when data is missing from one of the gages. Also, the Thiessen method does not directly account for orthographic influences on rainfall.

2.3.2.3 The Isohyetal Method

The isohyetal method overcomes some of these difficulties of the previous methods by constructing isohyets, using observed depths at rain gages and interpolation between adjacent gages. The arithmetic means of rainfall depth between isohyets are used to estimate areal rainfall depth. Equation (2-3) shows the calculation of this method.

$$\overline{P} = \frac{1}{A}\sum_{j=1}^{J} \overline{a}_j \overline{p}_j \qquad (2\text{-}3)$$

where $\overline{P}$ = Areal Estimates of Precipitation

A = Area of the Basin

$\overline{a}_j$ = Area between the isohyets

$\overline{p}_j$ = Average precipitation between the isohyets

Topographic effects and the spatial relationship of a rainfall can be considered in this method. However, to consider these effects, the gages should be distributed over various elevations in a basin. This method is well adapted to get an areal estimate of precipitation for the huge area, but it is very complicated and time-consuming without the use of Geographic Information system (GIS) technology.

2.3.2.4 Discussion and Other Methods

There are advantages and disadvantages of each method. The arithmetic mean method is very simple and results are satisfactory, if the gauging stations are uniformly distributed and basin topography is flat. However, influences of orthography cannot be taken into consideration. For non-uniformly distributed and widespread gauging stations, this method gives unreliable results. However, using the Thiessen method, a non-uniform gaging distribution in the basin can be taken into account by the sub-area size. Disadvantages of use this method is that there is discontinuous between the each subarea; nevertheless, the nature of rainfall is a continuous process. The isohyetal method is the most accurate approach among the three methods. The distance between isohyets can be arbitrarily narrow, so that no marked steps occur in the relief of the rainfall distribution. However, this method requires extensive calculation that requires careful attention for designing each isohyet.

There are several other methods, such as the distance weighting/gridded method, the MAPX method, and Index Stations method, which were proposed by the National Weather Service. The Distance Weighting/Gridded method is another station weighting technique. A grid of point estimates is made based on a distance weighting scheme. Each observed point value is given unique weighting for each grid point based on the distance from the grid point in question. The grid point precipitation value is calculated based on the sum of the individual station weight multiplied by observed station value. And divided by number of grid points to obtain the areal average precipitation divides the sum. The MAPX method is an NWS-specific gridded technique. Areal runoff zone precipitation estimates are made using the 4 x 4 Km WSR-88D 1 hourly gridded precipitation estimates. The arithmetic mean calculation method is used to average the grid point estimates. The Index Stations method is used in some area of the country (primarily mountainous areas), where pre-determined station weights based on climatology are used to compute basin average precipitation.

2.3.3 Rainfall-Runoff Modeling with Neural Network Algorithms

2.3.3.1 Rainfall-Runoff Modeling

The rainfall-runoff (R-R) process is defined to be highly nonlinear, time-varying, spatially distributed, and not easily described by simple models (Singh, 1964; Kulandaiswamy and Subramanian, 1967; Chiu and Huang, 1970; Pilgrim, 1976). Until recently, for practical reasons (data availability, calibration problems, etc.) most conceptual watershed models used lumped representations of the parameters. Among the more widely used and reported lumped parameter watershed models are the Sacramento Soil Moisture Accounting (SAC-SMA) model of the U.S. National Weather Service, HEC-1 [U.S. Army Corps of Engineers], and the Stanford Watershed Model (SWM).

While such models ignore the spatially distributed, time-varying, and stochastic properties of the R-R process, they attempt to incorporate realistic representations of the major non-linearity inherent in the R-R relationships. However, the implementation and calibration of such a model can typically present various difficulties, requiring sophisticated mathematical tools, significant amounts of calibration data, and some degree of expertise and experience with these model.

2.3.3.2 Rainfall-Runoff Modeling with Artificial Neural Networks

A neural network is an implementation of an algorithm inspired by research into the brain, therefore neural networks are made out of neuron-like nodes that are arranged in layers and pass data through weighted connections. In Fig 2.1, the basic neuron structure and its activation are represented. This schematic diagram was first proposed by McCulloc-Pitts (1943). This neuron computes a weighted sum of its inputs from other units, and the neuron passes this sum to the output process through an activation function. For example, digital values for the step function and analog value for the sigmoid function are common activation functions.

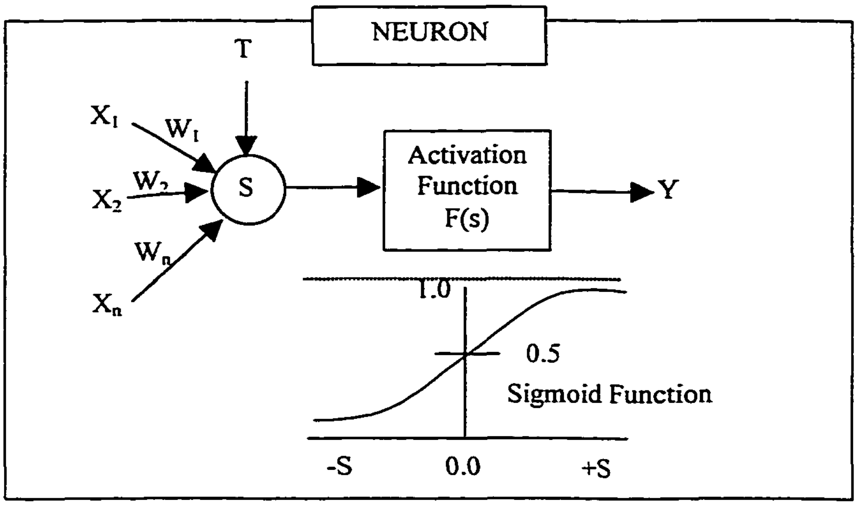


Fig. 2.1 The Neuron Dynamics and sigmoid function

If nonlinear activation functions are used for the neurons, the neural network system becomes a nonlinear system by the influence of nonlinear outputs. Moreover, the neuron is characterized by the threshold value, that is, the value that the weighted sum of inputs must reach or exceed for the neuron to fire. The net topology, neuron characteristics, and training or learning rules specifies neural network models. Until now, neural networks were used and implemented in applications in several fields; specially, pattern recognition, classification, function estimation, forecasting and time series analysis, and optimization etc.

Thirumalaiah and Deo (1998) stressed the advantages of neural networks for application in rainfall-runoff models as follows;

- *Neural networks are useful when the underlying problem is either poorly defined or not clearly understood.*
- *Their application does not require knowledge of the underlying process beforehand.*
- *They are advantageous when specific solutions do not exist to the problem posed.*
- *Neural networks are most suitable for dynamic forecasting problems because the weights involved can be updated when fresh observations are made available.*
- *They save on data storage requirements because it is not necessary to keep all past data in memory.*
- *They do not require any exogenous input other than a set of input-output vectors for training purpose.*

Lachtermacher and Fuller (1994) developed and tested the Hybrid methodology for use of neural networks in stationary time series forecasting. The methodology consists of two phase, exploratory and modeling. In the exploratory phase, "lag components" of time series was identified using Box-Jenkins methods. Based on these results, a small structure is suggested and then a backpropagation neural network was trained.

An artificial neural network (ANN) is a nonlinear mathematical structure, which is capable of representing arbitrarily complex nonlinear processes that relate the input and outputs of the system. A recent series of papers have discussed the capability of three-layer feed forward ANN to approximate any continuous input-output mapping and its derivatives to arbitrary accuracy (Funahashi, 1989; White, 1990; Hornik et al., 1990; Blum and Li, 1991; Ito, 1992; Gallant and White, 1992; Cardaliaguet and Euvrard, 1992; Takahashi, 1993). ANN models have been used successfully to model complex nonlinear input-output time series relationships in a wide variety of fields (Vemuri and Rogers, 1994).

ANN approach may prove to be an effective and efficient way to model the R-R process in situations where explicit knowledge of the internal hydrologic sub-process is not required. Some studies in which ANN models have been applied to problems involving runoff forecasting and weather prediction have been reported in the literature.

2.4 Real-Time Operation of Multireservoir System

2.4.1 Real Time Reservoir Operation Systems

There have been many reservoir operation models provided in the literature but only few have been presented reservoir operation under flood control concerns (Mays, 1992). The U.S. Army Corps of Engineers (1973, 1979) developed HEC-5 and HEC-5C for reservoir operation for flood control. In these systems, the releases are selected by applying a pre-determined fixed set of heuristic rules and priorities that are patterned after typical operation studies. These models are based upon hydrologic routing techniques. One application of these models was to the Kanawha River Basin (U.S. Army Corps of Engineers, 1983) which contributes flow to the Ohio River at Ft. Pleasant, West Virginia.

Windsor (1973) used a recursive linear programming (LP) procedure for operation of flood control systems employing the Muskingum method for hydrologic routing and the mass balance equation for reservoir computations. Yazicigil (1980) developed an LP optimization model for the daily real-time operations of the Green River basin in Indiana, a system of four multipurpose reservoirs. The model inputs are deterministic. The objective of operation is to follow a set of target states, deviations from which are penalized. The channel routing is performed using a linear routing procedure similar to the Muskingum method, called multi-input linear routing. The reservoir calculations are based on mass-balance equations that take into account precipitation input.

Jamieson and Wilkinson (1972) developed a dynamic programming (DP) model with employing forecasted inflows that were inputs to the model. The Tennessee Valley Authority (1974) developed an incremental dynamic programming and successive approximations technique for real-time operations with flood control and hydropower generation being the objectives.

Can and Houck (1984) developed a goal-programming model for the hourly operations of a multireservoir system and applied it to the Green River basin in Indiana. A hierarchy of goals defines the model objective, with the best policy being a predetermined rule curve. Wasimi and Kitanidis (1983) developed an optimization model for the daily operations of a multireservoir system during floods, which combines linear quadratic gaussian optimization and a state-space mathematical model for flow forecasting.

2.4.2 Multidimensional Dynamic Programming

Dynamic programming (DP) was proposed by Bellman in 1957. DP is particularly suitable for multistage sequential decision problems. Its principal is based on "Bellman's Principal of Optimality" such that "*The Optimal policy for the remaining stages is independent of the policy adapted in previous stages*." DP has been flexibly applied for a variety of objective functions and constraints where finding optimal solutions of nonlinear, nonconvex and separable problems. The primary advantage of DP that is in its ability to decompose complex optimization problems involving large numbers of variables into an equivalent sequence of smaller problems that must be solved one stage at a time recursively (Labadie, 1996). This approach results in a linear increase in the computational burden with the number of the stages in the DP problem.

Standard DP can be formulated either in the continuous or discrete form and the latter is more popularly used for reservoir system operation due to its simplicity. However, the computational burden of the discrete DP increases exponentially with the number of state variables, which is called "Curse of Dimensionality of DP" by Bellman. This computational burden at each stage of analysis can be expressed as m^n combinations for a system with n state variables and m levels of discretization of each state variable (Labadie, 1996).

Various modified solution procedures have been proposed to reduce or circumvent the dimensionality problem. Incremental Dynamic Programming (IDP) was developed by Larson (1968) reducing the number of discretizations while keeping the accuracy of the solution. This IDP procedure begins with an initially guessed set of trajectories. The discrete DP procedure is applied to examine the corridor of the state variable defined by one discretization above and below the initial trajectory. Then, if the neighboring trajectory gives better objective function values, the initial trajectory is replaced by the improved new trajectory and the procedure is repeated until the specified convergence criteria are satisfied.

The IDP algorithm is assumed to yield a local optimum and has been applied by Hall et al. (1969), Troff and Yeh (1971), and Heidari et al. (1971). Although it has a reduced computational load of the 3n, where n is the number of state variables, Fontane et al. (1986) showed that the IDP method has difficulty in handling problems with more than 6 reservoirs.

The other method to solve the computational burden of DP is using A Dynamic Programming Successive Approximations (DPSA) approach, which was suggested by

Bellman and Dreyfus (1962) and generalized by Larson (1968). In DPSA, only one component is varied at a time, instead of evaluating the optimal value function for all possible combinations of the state vector. The problem is solved as a one-dimensional DP problem to obtain an optimum solution. Then, another variable is chosen to vary and the entire procedure is repeated until convergence.

Trott and Yeh (1971), Yeh and Trott (1972), and Giles et al. (1981) have applied DPSA algorithm for multi-reservoir system operation. Recently, Yi (1996) successfully applied this method to the Lower Colorado River Basin scheduling of hydropower problem that has 27 state variables.

2.4.3 Developing Operation Polices for Flood Control using Optimization Techniques

Optimization models should be involved in determining the flood control operation policies of the reservoir systems as represented in Fig. 2.2. The objective of such a model is to determine the operating policies (releases) that minimize the flood damages for reaches 1, 2 and 3. Inputs to the model consist of the damage functions and weekly average historical flows representing the largest flood recorded at the gaging station. The minimum storage in reservoir 1 and 2 is the conservation pool storage and the maximum storage is the full flood pool storage.

In this situation, we simply developed a DP model where decision variables are releases from reservoir 1 and 2 and state variables are the storage in reservoir 1 and 2 respectively.

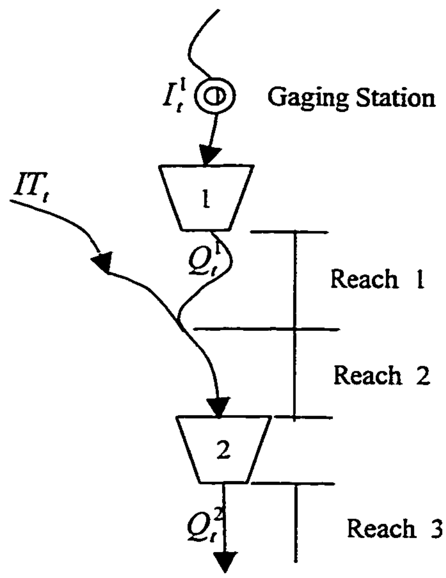


Fig. 2.2 Simple Reservoir Systems.

The objective function may be stated as

$$\text{Min } Z = \sum_{t=1}^{N} r_t(Q_t^1, Q_t^2) \tag{2-4}$$

Then, DP stage return function (damage for time period t) is

$$r_t(Q_t^1, Q_t^2) = D_1(Q_t^1) + D_2(Q_t^1 + IT_t) + D_3(Q_t^2) \tag{2-5}$$

where, Q_t^1 ; The release from reservoir 1 at time period t

Q_t^2 ; The release from reservoir 2 at time period t

IT_t ; The local inflow from tributary at time period t

D_1 ; The damage function at reach 1

D_2 ; The damage function at reach 2

D_3 ; The damage function at reach 3

N; Number of time periods

The constraints on continuity (state equation) are

$$S_{t+1}^1 = S_t^1 + I_t^1 - Q_t^1 \qquad \text{for reservoir 1} \qquad (2\text{-}6)$$

$$S_{t+1}^2 = S_t^2 + Q_t^1 + IT_t - Q_t^2 \qquad \text{for reservoir 2} \qquad (2\text{-}7)$$

where, S_t^1; The Storage for reservoir 1 at time period t

S_{t+1}^1; The Storage for reservoir 1 at time period t+1

S_t^2; The Storage for reservoir 2 at time period t

S_{t+1}^2; The Storage for reservoir 2 at time period t+1

Boundary conditions on storage for each reservoir are

$$S_{\min}^1 \le S_t^1 \le S_{\max}^1 \qquad \text{for reservoir 1} \qquad (2\text{-}8)$$

$$S_{\min}^2 \le S_t^2 \le S_{\max}^2 \qquad \text{for reservoir 2} \qquad (2\text{-}9)$$

Boundary conditions on release for each reservoir are

$$Q_{t,\min}^1 \le Q_t^1 \le Q_{t,\max}^1 \qquad \text{for reservoir 1} \qquad (2\text{-}10)$$

$$Q_{t,\min}^2 \le Q_t^2 \le Q_{t,\max}^2 \qquad \text{for reservoir 2} \qquad (2\text{-}11)$$

The DP recursion equation for forward (canonical order) algorithms would be

$$f_t(\overline{S_t}) = \underset{Q_t}{Min}\left[r_t(\overline{Q_t}) + f_{t-1}(\overline{S_{t-1}})\right] \tag{2-12}$$

This example model, proposed by Mays (May, 1992), which can be extended to various real-time multireservoir operation problems.

2.5 Spatial Decision Support System

2.5.1 Spatial Analysis with GIS/RS in Rainfall Runoff Modeling

2.5.1.1 Geographic Information System (GIS) and Remote Sensing (RS)

From the earliest civilizations to modern times, spatial data have been collected by navigators, geographers, and surveyors and rendered into pictorial form by the mapmakers or cartographers to aid navigation and military strategies (Hodgkiss, 1981). During the 1960s and 1970s, new trends arose in the way mapped data were being used for resource assessment such as land evaluation and planning. By the late 1970s there had been considerable investment in development and application of computer aided cartography, particularly in North America by government and private agencies (Tomlinson and et. al, 1981).

The history of using computers for mapping and spatial analysis shows that there have been parallel developments in automated data capture, data analysis, and presentation in several broadly related fields such as cadastral and topographical mapping, civil engineering, mathematical studies of spatial variation, and remote sensing and image analysis. Essentially, all these disciplines are attempting the same sort of operation-namely to develop a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes (Burrough, 1993).

This set of tools constitutes a "Geographic Information System (GIS)". GIS is a general-purpose technology for handling geographic data in digital form, with the ability to pre-process data into a form suitable for analysis, to support analysis and modeling, and post-processing of results (Goodchild, 1993). GIS has important three components, computer hardware peripherals, a set of application software modules, and a proper organizational context, which all need to be in balance if the system is to function satisfactorily (Burrough, 1993).

Remote Sensing (RS) is defined as the science and technology by which the characteristics of objects of interest can be identified, measured or analyzed the characteristics without direct contact (JARS, 1993). The technical term "Remote Sensing" was first used in U.S. in 1960s, and encompassed photogrammetry, photo-interpretation, photo-geology etc. Since Landsat-1, the first earth observation satellite launched in 1972, remote sensing has become widely used.

The characteristics of an object can be determined, using reflected or emitted electro-magnetic radiation, from the object. That is, each object has unique and different characteristics of reflection or emission if the type of object or the environmental condition is different. A sensor in a limited number of bands with respect to their electro-magnetic characteristics generally measures different objects after various factors have affected the signal. Then the observed RS data is processed automatically by computer and/or manually interpreted by humans. Finally this information is utilized in various fields, such as military, agriculture, land use, forestry, geology, hydrology, meteorology, environmental, etc.

2.5.1.2 Applications of GIS/RS in Rainfall-Runoff Modeling

To alleviate the lack of adequate data to quantitatively describe a hydrologic process accurately, which is major problem in hydrology, remote sensing technology aids as follows (Schultz, 1988):

1. *It provides areal measurements in place of point measurements.*
2. *All information is collected and stored at one place.*
3. *It offers high resolution in space and/or time.*
4. *Data are available in digital form.*
5. *Data acquisition does not interfere with data observation.*
6. *Data can be gathered for remote areas that are otherwise inaccessible.*
7. *Once remote sensing networks are installed, data measurement is relatively inexpensive.*

RS data can be used for rainfall-runoff modeling and are useful, especially where data collection sites and cost-effectiveness of data collection are important on one hand, and these are increasing requirements for data on the other (Singh, 1995). Remote sensing data from satellites can be used to better define soils and land covers over a watershed, which are needed to determine infiltration, evapotranspiration, and runoff. In addition, RS measures data over space rather than a point, and can, therefore, be used to correct errors in input data based on point measurements of rainfall, evaporation, and the like.

With the vastly improved capability to observe hydrometeorologic data, RS technology is finding its niche in a range of hydrologic applications. These applications are becoming operational at an accelerated pace. Some of these applications are exemplified in real-time flood forecasting by a distributed model with radar rainfall measurements as input.

However, there are some difficulties in storing and manipulating the collected hydrologic data, which can be cumbersome for three reasons; the spatial nature of hydrometeorologic data, the large volume of data and the organization of data. Through the use of GIS and associated software, such data can be compiled and processed with relative ease (Singh, 1995). The physical characteristics of the watershed such as soils, land use and topology vary spatially. In distributed rainfall-runoff models, these characteristics can be used directly. However, the watershed will have to be spatially characterized into homogeneous sub areas. To that end, the traditional data file structure is less than troublefree. Clearly, a general-purpose spatial data analysis and manipulation tool will be desirable (Singh, 1995).

The use of a GIS permits subdividing a watershed spatially into hydrologically homogeneous sub-areas. Depending on the type of application requiring categorization of hydrologic properties, many combinations of spatial overlay can be performed. With this technique, it is possible to delineate areas of varying soil loss rates (Ventura, 1988), identify potential areas of non-points sources water quality pollution (Shim, 1995), map groundwater contamination susceptibility (Whittemore, 1982), and so on.

2.5.2 Decision Support System (DSS)

Decision support systems (DSS) provides information in a given domain of application by means of analytical decision models and access to databases, in order to support a decision maker in making decisions effectively in complex and ill-structured tasks. Smith and et al.(1985) defined a DSS as an interactive, easy to use, computer system that uses model building and analysis tools to help in solving problems that range from ill-structured ideas to fully structured relationships. DSS may be defined alternatively, as an advisory system for management, usually computer-based, that utilizes databases, models, and communication/dialog systems to provide decision-makers with management information (Grigg, 1996).

Labadie (1988) proposed the general concepts and use of the decision support system as applied in water resources management. These presented in the Proceedings of the ASCE Workshop on Computerized Decision Support Systems for water resources managers. In addition, he also stressed that computerized decision support system can provide the function for maximizing the productivity, cost-effectiveness, and reliability of complex water resources systems (Labadie, 1988).

The essential components of DSS are the data subsystem, the modelbase subsystem, and the dialog subsystem (Labadie, 1989). The database subsystem should able to combine a variety of data sources through a data capture and extraction process. It also should have the ability to add and delete data sources quickly and easily. The modelbase subsystem provides analysis and interpretation for the decision-makers through various algorithms and procedures. It should be capable of creating new models rapidly and easily. It should be also capable of exploring the decision alternatives through use of the database and modelbase subsystems. The dialog subsystem represents the user-computer interface and should be able to provide a range of dialog styles and accommodate user actions in a variety of media. Also, it should have a capability of presenting outputs of both database and modelbase subsystems.

This DSS concepts and methodologies have been successfully applied to many kinds of problems in water resources management. With a microcomputer as a computational tool, a DSS was developed for use by local water managers, where the appropriate water rights doctrine applied and irrigation was the primary water use (Koch, 1986). Stansbury (1991) developed a DSS to help decision-makers analyze the economic, social, and ecological ramifications of water transfers. Davis and et al. (1991) developed a prototype DSS to estimate the effects of potential land-use and land-management policies on water quality and the costs of implementing the policies. A DSS with an embedded simulation model for ranking feasible management practices had been developed to evaluate environmental and economic consequences of alternatives on ground and surface water quality (Yakowitz, 1992). A DSS was developed to provide designers and irrigators with a rapid method to analyze many design alternatives (Wilmes, 1994). A DSS for evaluating pump-and-treat (P&T) remediation alternatives to environmental scientists and engineers was developed at Rice University (Rifai and et al., 1994). A personal computer based DSS can provide real-time information for improved flood prevention and control in the Trinity River Basin in Texas (Ford, 1995). A generic DSS which was originally designed for the planning stage of decision making associated with complex river basins was extended to incorporate modules relating to the operational stage of decision making (Andreu, 1996). Shim and Fontane (1996) developed a decision support system as a prototype for the ChungJu multipurpose reservoir for an operational planning problem in water conservation use.

2.5.3 Spatial Decision Support System

Both decision support systems and geographic information systems have been widely used in water resources system and contributed to our understanding of water resources in recent years. The spatial decision support system (SDSS) may be defined as the conjunctive application of a geographic information system (GIS) and a decision support system (DSS) to aid decision-makers with problems that have a spatial dimension. The spatial analysis and display capability of GIS can improve each component of a DSS and have enabled the evolution of DSS to SDSS, including water resources models that are part of water resources DSS (Walsh, 1993).

Labadie (1996) proposed three kinds of SDSS development schema in his lecture, which are the simplest level of integration through flat files, deeper level of integration through a common database and interface, and full integration through embedding models in GIS. Walsh (1993) stress that the success of SDSS in water resources will require the collaboration of GIS developers, water resources modelers, DSS designers, and water resources decision makers to accept the challenges arising from the integration of these technologies.

Fredericks and Labadie et al. (1993) developed a SDSS through integration of the finite difference groundwater model (MODRSP) with a capacitated river basin network management model (MODSIM) using GIS and database technology. The developed SDSS allows analysis of conjunctive use plans that are capable of considering decreed flow and storage rights, river calls, exchanges, trades, and plans for augmentation. Alexander (1996) extended the existing DSS that managed the water quality of sewered urban area in large river basin to a SDSS that can provide the capability of mapping sewer boundaries as well.

There are many kinds of interesting applications for water resources management with GIS that were represented at the ESRI Users Conferences in 1997. PSOMAS Inc. developed a PC-Based desktop-mapping tool for a floodplain determination project in Los Angeles using the ArcView and MapObjects with an objected-oriented programming technique (Rick, 1997). The developed system used the 100-year and 500-year floodplain maps from the FEMA's National Flood Insurance Program (NFIP) to determine which area will be in the floodplains and report to the householders. One of the most interesting applications is GIS-based DSS which integrates a river basin visual presentation and logical representations of a river basin into an operational framework (McKinney, 1997).

CHAPTER III

GIS MODULE IN THE SPATIAL DECISION SUPPORT SYSTEM

3.1 Overview

One of the essential components of a spatial decision support system is the geographic information system that can perform the acquisition, management and processing of the spatial data and information. A geographic information system is a general-purpose technology for handling geographic data in digital form, with the ability to pre-process data in to a form suitable for analysis, to support analysis and modeling directly and to post-process results (Goodchild, 1993).

For reliable flood control and reasonable reservoir management, the areal estimates of precipitation for the basin are very important. Traditionally, this is fundamental component for the flood forecasting system. In this study, a geographic information system represents the physical aspects of basin's spatial data such as rainfall and flow gauging stations, main river channels, tributaries, reservoirs and basin boundaries. The Korean government has been using the Thiessen method for calculating the areal estimates of rainfall during floods. The Administration of Construction and Transportation set up 82 rainfall gages with 30 subbasins in the Han River Basin. The flood control office of the Han River Basin pre-determined the weights of the each gage in a subbasin. The National Weather Service of the U.S is using radar data. However, ash a developing country, Korea doesn't yet have a sufficient budget for constructing the radar to provide estimates of areal rainfalls. In addition, an application of the isohyetal method is important as an alternative to present use of the Thiessen method since the upstream portion of the Han River Basin is most mountainous area. In the past, isohyetal method was not used because of its extensive calculation requirement. However, since a geographic information system can easily handle spatial calculations, it is no longer a time consuming process for the isohyetal method.

Using the spatial analysis tools, ArcView 3.0a with Spatial Analysts Extension, the isohyetal map of each time period can be easily calculated and generated to develop a rainfall-runoff module. In addition, this software can generate images with its attributes for isohyetal map. These generated images and data will be stored in the database management system to be used for the various models in the spatial decision support system. Fig.3.1 represents the relationship between each module in the spatial decision support system.

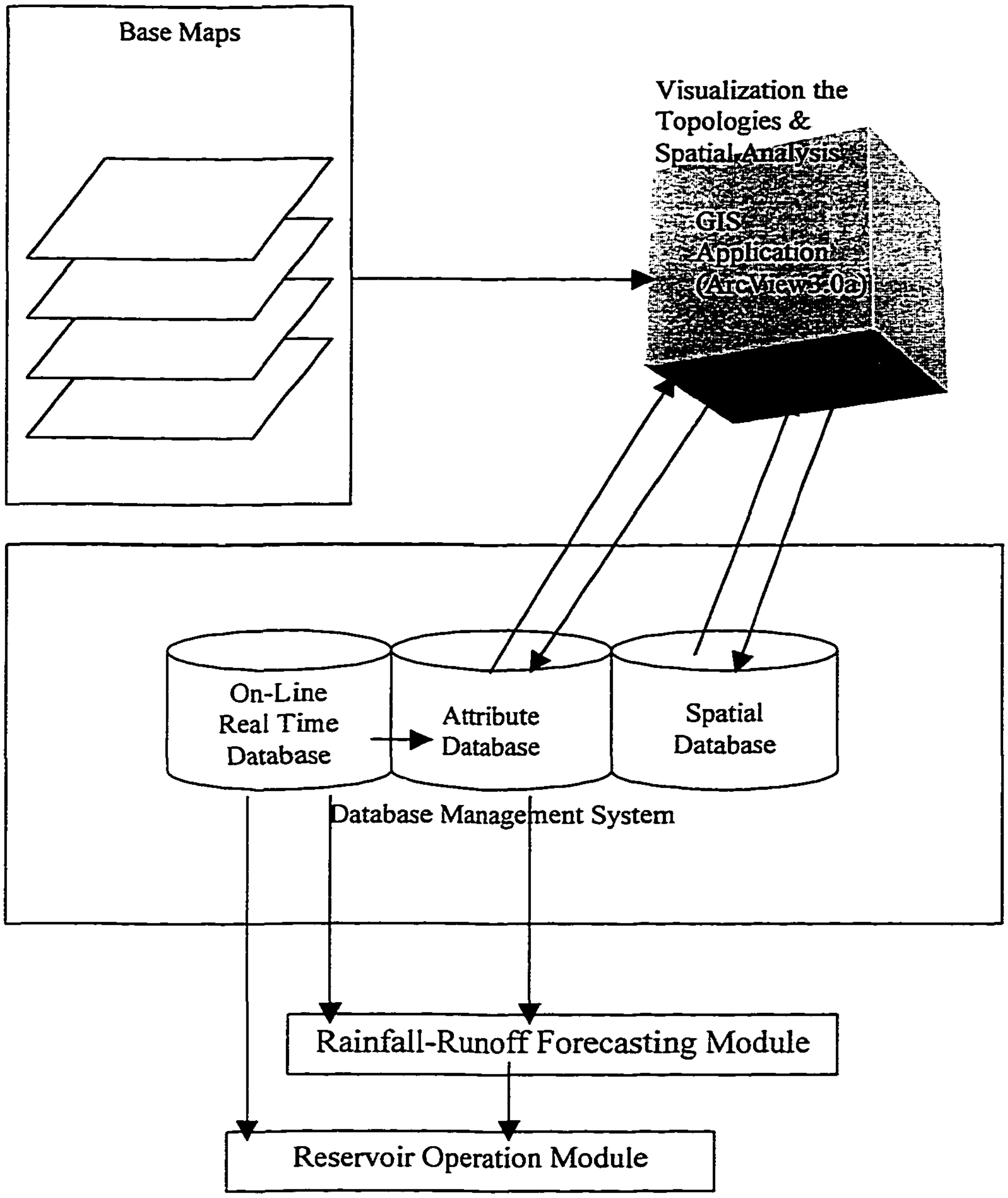


Fig. 3.1 The relationship between the each module in the spatial decision support system

3.2 Collecting and Generating the Base Maps

3.2.1 Digital Elevation Maps

Digital elevation models (DEMs) are sampled arrays of surface elevation in raster form. A DEM provides elevation values in rows and columns corresponding to a regular grid of points on the Earth's surface. Using the DEMs, the various thematic maps can be generated such as slope, aspect, and contour maps. The base DEM for this study was extracted from the Global 30-Arc-Second Elevation Data Set (GTOPO_30). The GTOPO_30 data set is so named because the spacing between adjacent elevation points is 30 arc-seconds (approximately 1 kilometer) of the latitude and longitude. Completed ln 1997, the GTOPO_30 was developed over a 3-year period through a cooperative effort led by the United States Geological Survey's EROS Data Center (USGS_EDC, 1997).

To extract the base DEM for this study, the boundary of the Han River Basin was digitized as a mask. The base DEM for the Han River Basin is represented in Fig. 3.2.

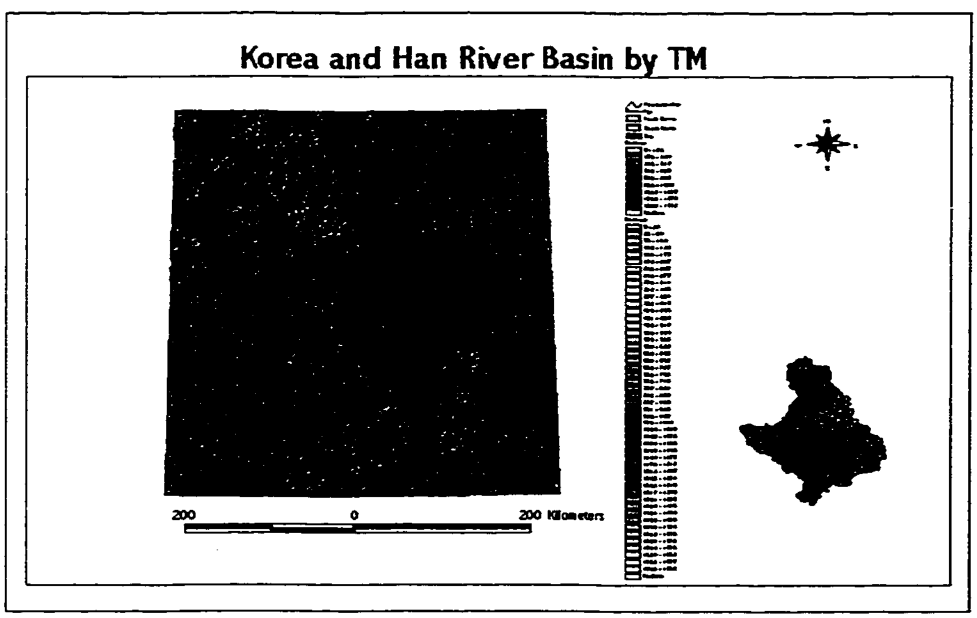


Fig. 3.2 DEM for the Han River Basin

3.2.2 Thematic Maps

From the earliest civilizations to modern times, spatial data have been collected by navigators, geographers, and surveyors and rendered into pictorial form by the mapmakers or cartographers. Originally, maps were used to describe far-off places, as an aid for navigation and for military strategists (Hodgkiss 1981).

The developments in the assessment and understanding of natural resources that began in nineteenth century and have continued to this day provided new material to be mapped. Whereas topographical maps can be regarded as general purpose because they do not set out to fulfil any specific aim, maps of the distribution of rock types, soil series or land use are made for more limited purposes. These specific-purpose maps are often referred to as 'thematic' maps because they contain information about a single subject or theme (Burrough, 1993).

In this study, thematic maps were collected and generated to perform spatial analysis of a water resources system. The Korea boundary, streams, water bodies, and railroad maps were extracted from the Digital Chart of the World. The Digital Chart of the World is one of most popular and comprehensive 1:1,000,000-scale vector basemap of the world, which is made by the Environmental System Research Institute, Inc. It consists of geographic, attribute, and textual data that can be accessed, queried, displayed and modified with ARC/INFO software. In addition, thematic maps of the boundary, reservoirs, rainfall gauging stations, flow gauging stations of the Han River Basin were generated based on the map from Korea National Geographic. The coordinate reference system (Map units) of the thematic maps is decimal degree, which will be projected in to the Traverse Mercator. The thematic maps for this study are represented in Fig. 3.3.

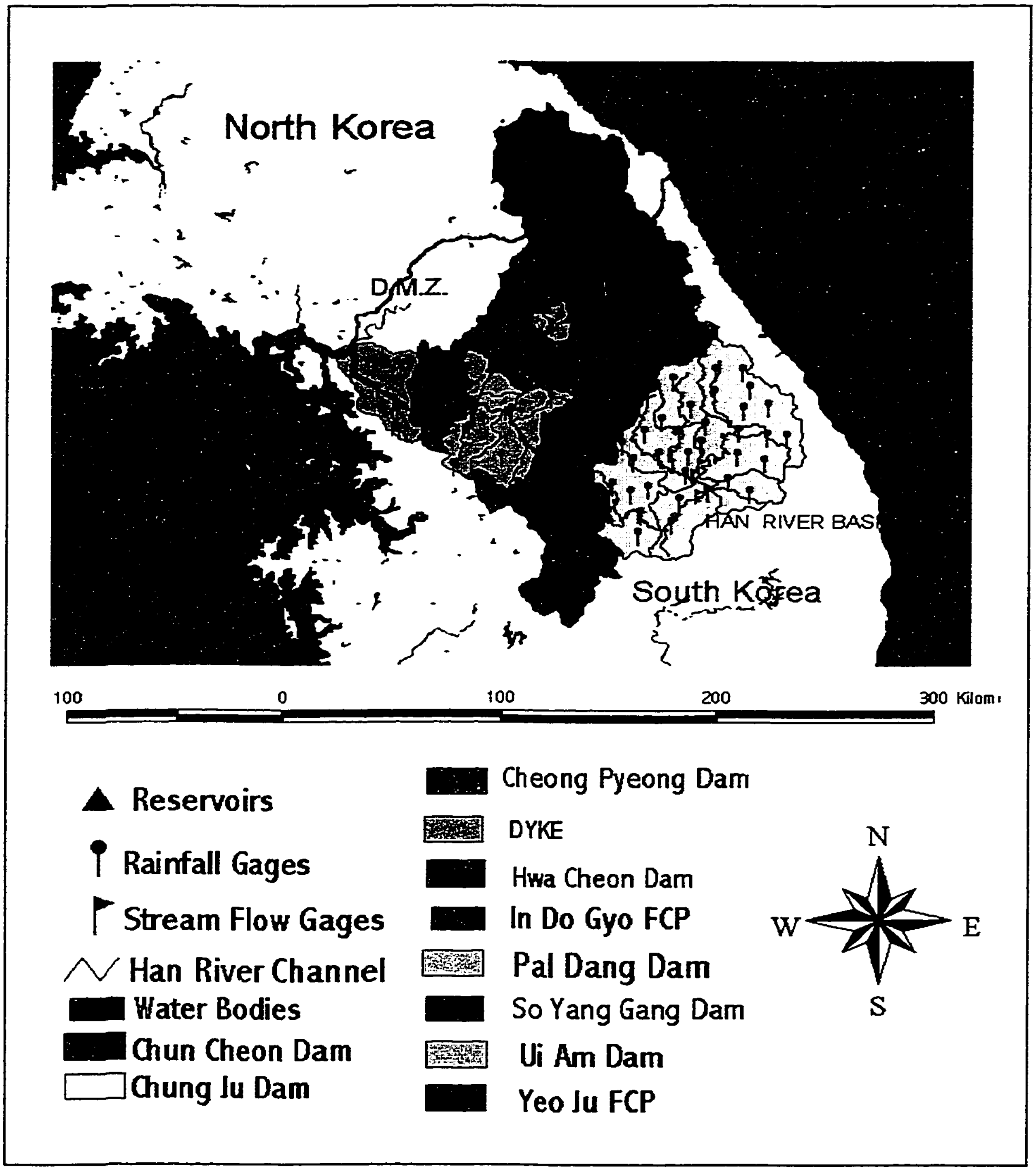


Fig. 3.3 The thematic maps for the Han River Basin

3.3 Spatial Analysis

In this study, a geographic information system was used to generate the isohyets of the Han River Basin for every one-hour period. Then, the one-hour isohyet was used to calculate the areal estimates of rainfall of each subbasin using spatial analysis tools. The schema of the spatial analysis is represented in Fig. 3.4.

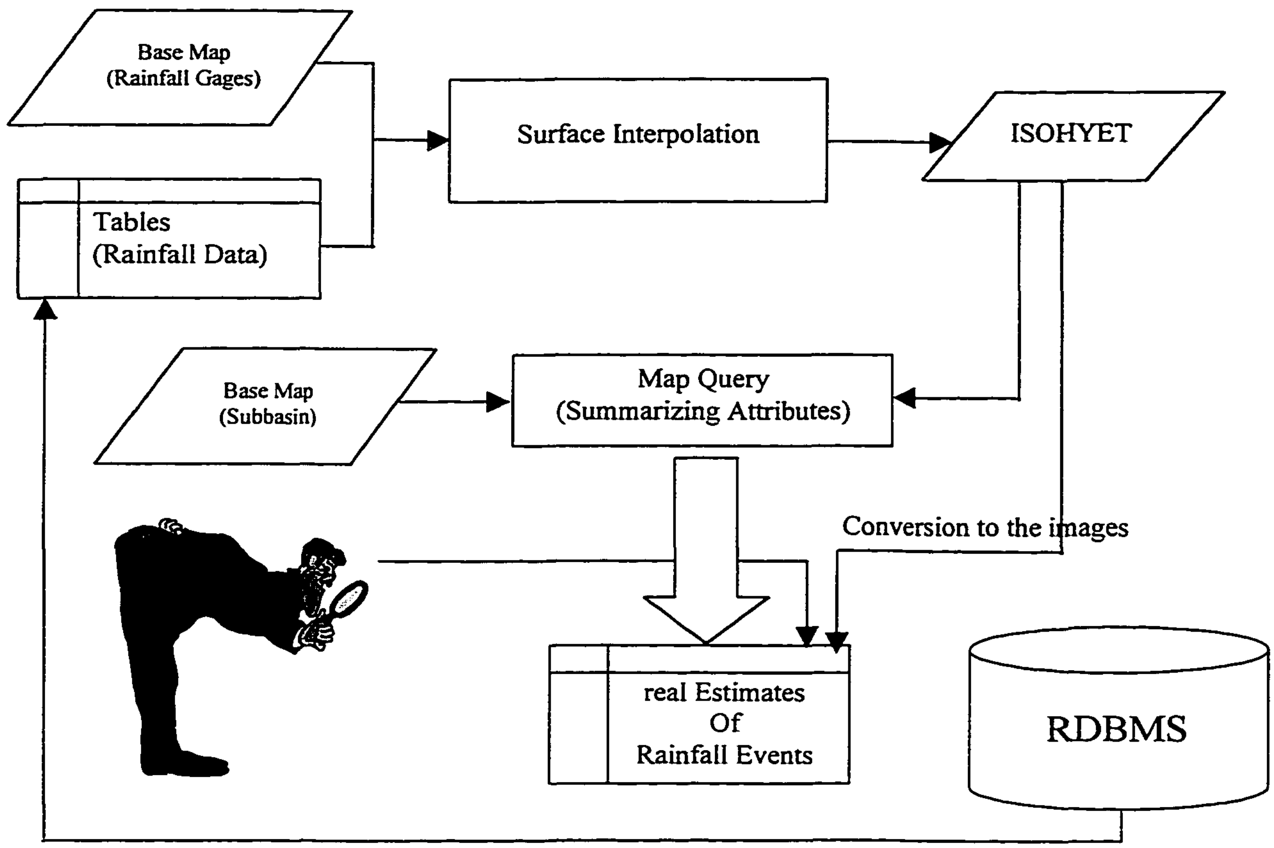


Fig. 3.4 The schema of the spatial analysis

To generate the isohyets, extension of each isohyets was fixed with left at 261248.518161 m, top at 609147.564196 m, bottom at 330733.386249, right at

481958.633503 m. Each isohyet has 110 columns and 139 rows with 2 x 2 Km resolution of each grid. Fig. 3.5 represents an example of isohyet at 3 o'clock A.m. on August 25, 1995. The database file of areal estimates of rainfall for the each subbasin will be generated using two maps, the isohyets map and the subbasin map for each hour. Table 3.1 is an example of the database file for 3 o'clock A.m. on August 25, 1995. In this table, the grid1_mean field refers to the areal estimates of rainfall for the each subbasin.

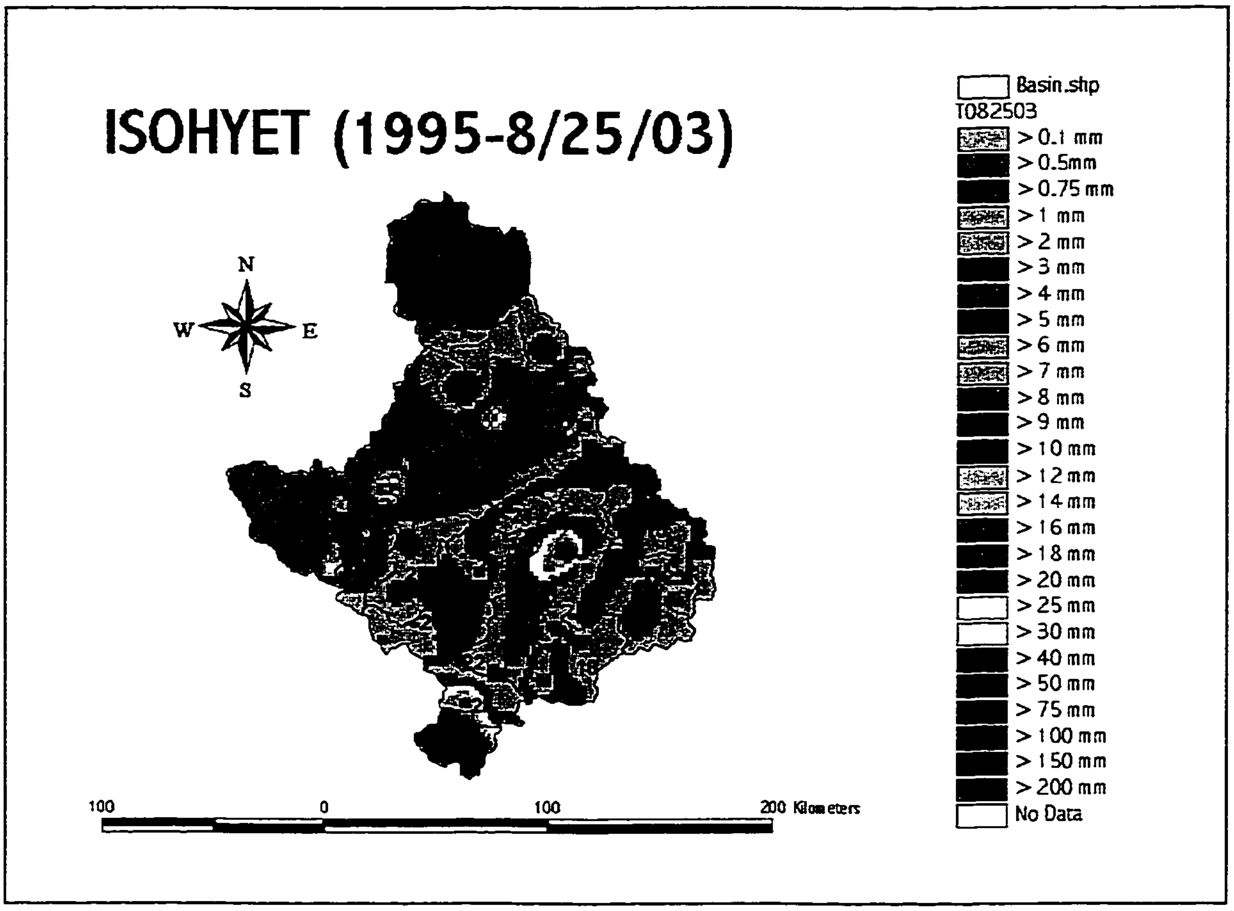


Fig 3.5 The Subbasin and its isohyets.

Table 3.1 Example of the Database File by Resulting Spatial Analysis (at 1995/08/25/10)

Hanb3_id	Count	Area (Km^2)	Grid1_ min	Grid1_ Max	Grid1_ range	Grid1_ mean	Grid1_ std	Grid1_ sum
1	419	1676	9.5988	11.6496	2.0508	10.9433	0.5481	4585.2422
2	398	1592	8.1803	12.3561	4.1758	10.7543	1.1368	4280.2134
3	240	960	5.044	14.7894	9.7453	10.227	2.5094	2454.4819
4	202	808	5.2432	8.7741	3.5309	6.5797	0.7551	1329.0966
5	273	1092	2.1869	18.9083	16.7214	13.0307	2.6743	3557.3916
6	255	1020	8.0335	21.6849	13.6515	13.6637	2.6371	3484.239
7	164	656	0.2815	18.8287	18.5473	10.321	5.315	1692.6385
9	223	892	7.0185	21.6535	14.6351	12.964	2.748	2890.9785
10	163	652	3.0439	16.1121	13.0682	6.948	2.7797	1132.5276
11	342	1368	2.1186	8.9514	6.8328	5.0497	1.8214	1727.0095
12	96	384	2.0193	4.3873	2.368	2.7977	0.4329	268.5817
13	166	664	4.0218	17.4629	13.4411	10.4908	3.9436	1741.4722
14	282	1128	2.0046	24.1195	22.1149	5.3284	4.2064	1502.6224
15	391	1564	2.0022	17.9015	15.8994	5.8529	4.1103	2288.4778
16	265	1060	1.049	4.678	3.629	2.5674	0.5533	680.3668
17	121	484	2.4119	3.9807	1.5688	2.9171	0.3138	352.9714
19	511	2044	2.0041	14.4079	12.4038	4.0547	1.9362	2071.9407
20	175	700	4.0377	16.5673	12.5296	8.4906	2.7143	1485.8549
21	193	772	7.1013	38.3307	31.2295	15.5716	7.6767	3005.3242
22	109	436	3.7223	13.9078	10.1855	7.8027	1.8588	850.4955
23	127	508	7.6167	16.0011	8.3844	10.9284	1.9629	1387.9032
24	116	464	15.3091	38.9187	23.6096	25.4704	5.3645	2954.5667
25	242	968	7.1184	42.2578	35.1395	18.3363	7.3473	4437.3809
26	214	856	7.0781	16.8403	9.7621	11.2738	2.043	2412.5999
27	283	1132	4.1264	12.1177	7.9913	6.8286	1.635	1932.4862
28	196	784	2.0065	7.5173	5.5108	4.3297	1.2806	848.6205
29	292	1168	2.0099	5.9042	3.8942	3.4157	0.9554	997.3702
30	307	1228	2.2272	4.9716	2.7444	3.7851	0.6021	1162.0371

CHAPTER IV

DEVELOPMENT OF FLOOD FORECASTING MODULE USING A NEURAL NETWORK ALGORITHM

4.1 Theory of Artificial Neural Networks

4.1.1 Introduction

A new and effective procedure for identification of an ANN model is presented in this study. As in the identification of other nonlinear types of models (systems theoretic or conceptual), there are two steps involved: 1) a model structure must be identified and 2) the model parameters must be calibrated through an iterative procedure that explores an objective function surface in search of an optimum. In the case of ANN modeling, the model parameters are called "weights" and the calibration procedure is called "network training." As in the calibration of parameters of other nonlinear types of models, the calibration (training) procedure is not without its problems. The success of the calibration procedure depends largely on the power of the optimization method used to search for the best parameter estimates.

4.1.2 A Multi Layer Feed Forward Neural Network

Figure 4.1 represents the basic neuron structure and its activation as a schematic diagram, as proposed by McCulloc-Pitts (1943). This neuron computes a weighted sum

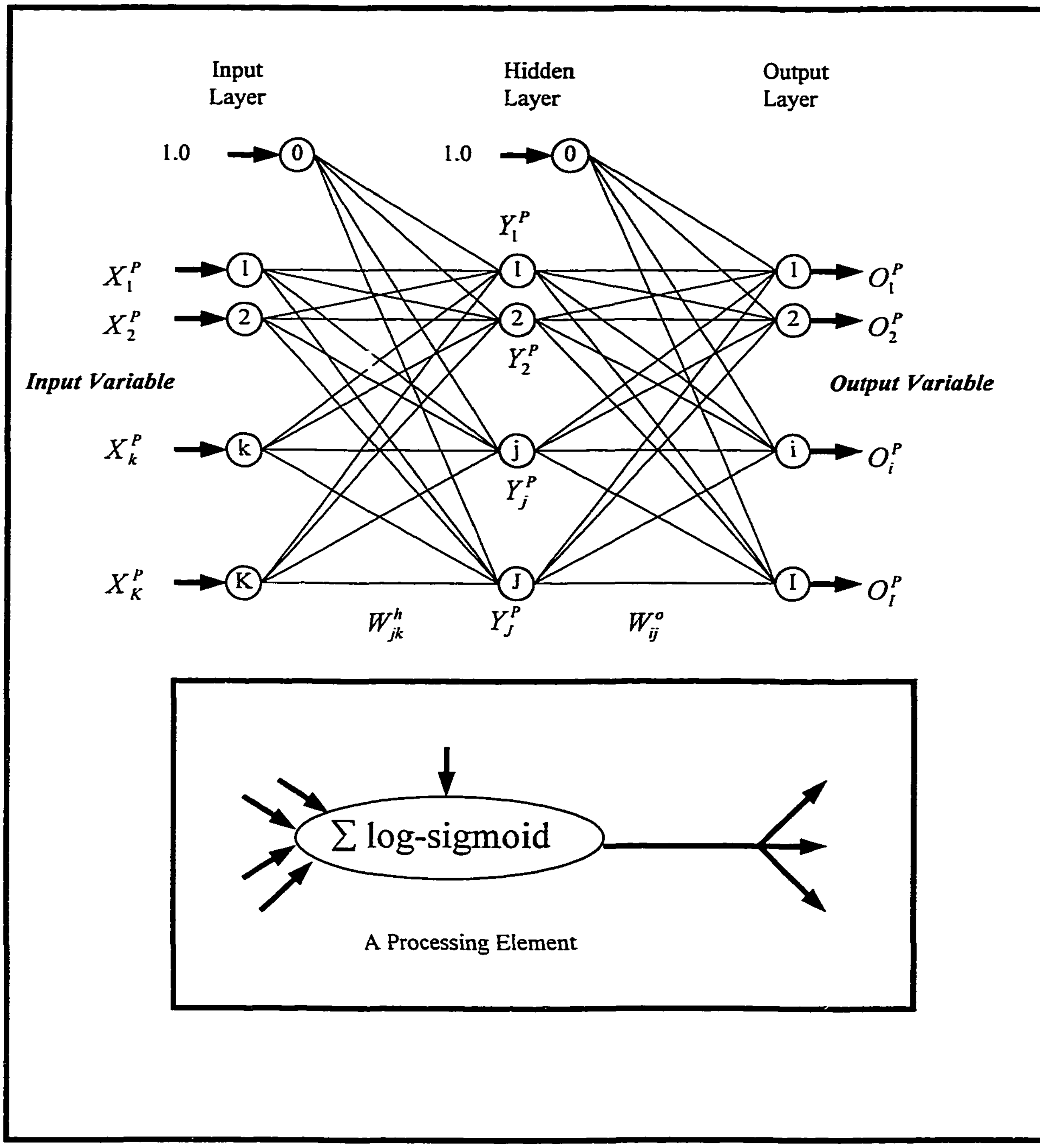


Fig. 4.1 The typical three-layer feed forward neural network.

of its inputs from other units, and the neuron passes this sum to output. The output can be a digital value or an analog value, according to the threshold functions, through an activation function. If a nonlinear activation function exists in the neurons, the neural network system becomes a nonlinear system by the influence of nonlinear outputs. Moreover, the neuron is characterized by the threshold value; that is, the value that the weighted sum of inputs must reach or exceed for the neuron to fire.

A Multi-layer Feed Forward Neuron Network (MFFNN) consists of a set of neurons logically arranged into two or more layers. Input neurons receiving the external stimuli do not perform processing themselves, while the output neurons active in several ways, corresponding to their threshold function; linear output, sigmoid output, etc. There are usually one or more hidden layers between the input and output layers. The hidden layers link the input layer to the output layer using weights. These weights are adjustable values associated with a connection between layers and can be considered as measures of correlation between each layer of neurons. The input-output relation, that means the output of each neuron in the network, is a function of the neuron input. This process is called "mapping" and the MFFNN is regarded as the representation of the mapping process.

In the Fig. 4.1, the structure of MFFNN is depicted for three layers. The dynamics of the neuron of layers are;

For input nodes

The input to the j^{th} hidden neurons are X_k^p, where k = indicates of input neurons (1...K), and p = indices of training patterns (1...P).

For hidden nodes

The outputs from the hidden neurons are represented in EQ. (4-1).

$$Y_j^P = g(h_j^P) = g(\sum_{k=1}^{K} W_{jk} X_k^P + \theta_j) \tag{4-1}$$

where, j ; indices of hidden neurons (1...J)

θ_j ; a threshold for j^{th} hidden neuron.

For output nodes

The output from the i^{th} output neurons is represented in EQ. (4-2).

$$O_i^P = g(h_i^P) = g(\sum_{j=1}^{J} W_{ij} Y_j^P + \theta_i) \tag{4-2}$$

where, i ; indices of output neurons (1...I)

θ_i ; The threshold for i^{th} output neuron.

In above notation, W_{jk} are the weights for connections from k^{th} input neurons to j^{th} hidden neurons, K is the number of input neurons and J is the number of hidden neurons. And W_{ij} are weights for connections from j^{th} hidden neuron to i^{th} output neuron, I is the number of output neurons.

The activation functions transform the input to the output. Usually, the sigmoid or logistic function has been used for the hidden layer and the output neurons are defined as

$$g(x) = \frac{1}{1+\exp(-x)} \tag{4-3}$$

with associated derivative

$$g'(x) = g(x)(1-g(x)) \tag{4-4}$$

4.1.3 The Learning Algorithm (Backpropagation)

MFFNN requires a learning algorithm for setting the weights of all connections between each neuron and the threshold values for all neurons in each layer. In this study, a general Backpropagation (BP) algorithm using an approximation of Newton's method, called the Levenberg-Marquardt method, was applied for minimizing the sum square error of output values. This optimization technique is more powerful than the gradient descent method, but it requires more memory.

After one training set pass through the MFFNN, at the first, the weights between hidden layer and output layer, W_{ij} , and the thresholds of output neurons, θ_i, are updated by adding ΔW_{ij} for the weights and $\Delta\theta_i$ for the thresholds. Then in a backward direction, the weights between hidden layer and input layer, W_{jk}, and the thresholds of hidden neurons, θ_j, are updated by adding ΔW_{jk} for the weights and $\Delta\theta_j$ for the thresholds.

The Levenberg-Marquardt update rule in matrix form is

$$\Delta W = (J^T J + \mu I)^{-1} J^T e \tag{4-5}$$

where, J ; the Jacobian matrix of derivatives of error to each weight

μ ; a scalar

e ; an error vector

If the scalar μ is very large, the above expression approximates gradient descent, while if μ is small the above expression becomes the Gauss-Newton method (Math Works, 1994). Because this second method is faster, but tends to be less accurate when near the point of minimum error, the scalar μ is adjusted, just like the adaptive learning rate. As long as the error gets smaller, μ is made bigger. But if the error increases, μ is made smaller.

4.2 Forecasting Models in the Han River Basin

4.2.1 Overview

Inflow forecasting models for the upstream reservoirs (HwaCheon, SoYangGang, ChungJu reservoir) and local inflow forecasting models for downstream reservoirs (ChunCheon, UiAm, CheongPyeong and PalDang reservoir), and flood control points (YeoJu, InDoGyo Station) in the Han River Basin were developed using a Multi-layer Feed Forward Neuron Network (MFFNN) Algorithm. Each catchment area and the related subbasins ID at the outlet of each catchment are defined in Table 4.1.

The general nonlinear rainfall-runoff relationship can be defined as:

$$Q(t+i) = f[R_1(t-k), R_2(t-k), ..., R_s(t-k), Q(t-j)] \quad (4\text{-}6)$$

For $i = 1...24$, $k = \text{LT-5}...\text{LT}$, $j = 0...6$

where, $Q(t+i)$; Predicted stream flow series

$Q(t-j)$; Observed stream flow series

$R_s(t-k)$; Given rainfall data series of each subbasin s.

LT ; Lag-Time

The RHS of the EQ(4-6), the 6 interval ((Lag-Time – 5) to Lag-Time) sliding window of rainfall: $[R_1(LT-5), R_1(LT-4), ..., R(LT)]$ and 7 hours sliding window of

Table 4.1 The related subbasins ID with each outlet of catchment

Catchment Name	Subbasin ID	Subbasin Area (Km^2)	Total Sum Area (Km^2)
HwaCheon Reservoir	1	1676.0	4228.0
	2	1592.0	
	3	960.0	
SoYangGang Reservoir	5	1092.0	2768.0
	6	1020.0	
	7	656.0	
ChungJu Reservoir	13	664.0	6944.0
	14	1128.0	
	15	1564.0	
	16	1060.0	
	17	484.0	
	18	828.0	
	19	1216.0	
ChunCheon Reservoir	4	808.0	808.0
UiAm Reservoir	8	304.0	304.0
CheongPyeong Reservoir	9	892.0	2608.0
	10	652.0	
	11	1064.0	
PalDang Reservoir	12	384.0	2300.0
	27	1132.0	
	28	784.0	
YeoJu Station	20	700.0	4704.0
	21	772.0	
	22	436.0	
	23	508.0	
	24	464.0	
	25	968.0	
	26	856.0	
InDoGyo Station	29	1168.0	1168.0

stream flow: $[Q(t), Q(t-1), ..., Q(t-6)]$ can be used for the consideration of time variability.

The EQ. (4-6) was approximated by the following equation using a MFFNN model as

$$X(t+i) = f(\sum_{j=1}^{J} W_{ij} g(\sum W_{jk} Y(t-k) + \theta_j) + \theta_k) \qquad (4\text{-}7)$$

where, $X(t+i)$; Time series to be predicted

(E.g. hourly inflow or local inflow series)

Y(t-k) ; Trained time series (E.g. hourly rainfall and stream flow)

W_{ij} ; The weights from hidden layer (j) to output layer(i)

W_{jk} ; The weights from input layer(k) to hidden layer(k)

θ_j ; Threshold value for hidden layer neurons

θ_k ; Threshold value for input layer neurons.

Functions g() and f() are non-linear Sigmoid activation functions, and are used in all networks in this study. Because the range of the sigmoid threshold function is from 0 to 1, the input rainfall data and the output stream flow data were normalized within those ranges. In this study all data were normalized between 0 to 0.9 to ensure the ability of forecasting the peak.

4.2.2 Rainfall-Runoff Modeling

The steps involved in the identification of a dynamic model of a system are 1) selection of input-output data, 2) selection of lag-time between the center of isohyets and the peak flow at outlet for each subbasin, 3) selection of a model structure and estimation of its parameters, and 4) validation of the identified model.

4.2.2.1 Local Inflow Calculation Process and I/O Data Setup

It is easy to set up the data for both training and forecasting purposes for the inflow forecasting models at upstream reservoirs, since all of the required data were collected through an automated data transmission system. However, there is no measuring facility for local inflow to the downstream reservoirs and flood control points. Therefore, the local inflows have to be calculated using a flood routing model for both training and forecasting purposes. Fig. 4.2 represents the process of local inflow forecasting.

First, release from the upstream reservoir 1 and inflow to the downstream reservoir 2 are known data through the automated data transmission system. The release from the upstream reservoir 1 is input data to a routing model. In this study, the Muskingum Method was used. The inflow to reservoir 2 consists of the results of routing, the upstream releases and local inflow to the downstream reservoir 2. Therefore, the local inflow can be easily calculated by subtraction of routed upstream flows from the measured inflow to reservoir 2. After calculating the local inflow, it is possible to use this information to train an ANN model with areal estimates of rainfall data resulting from the spatial analysis represented in Ch.3.

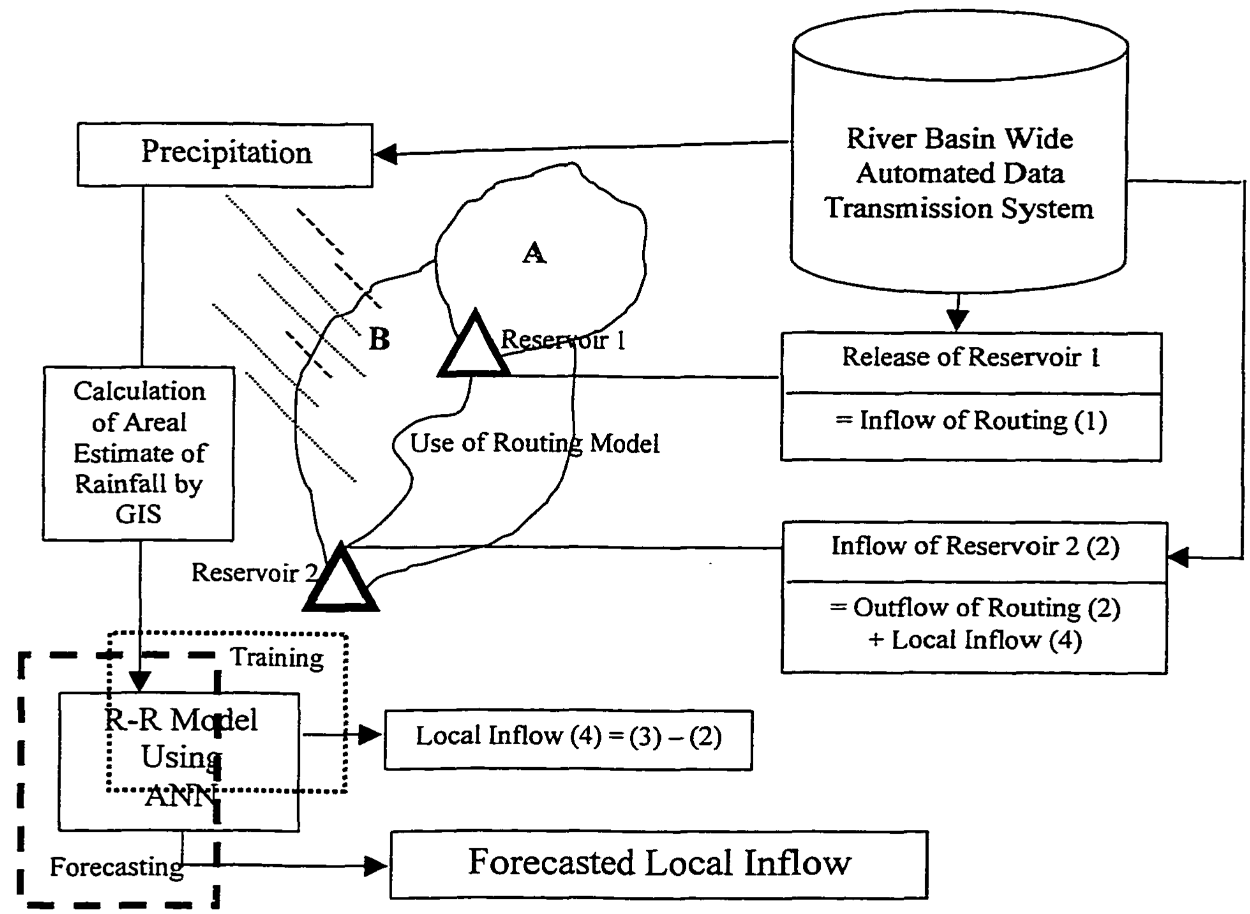


Fig. 4.2 The Local Inflow Forecasting Process

4.2.2.2 Selection of the Lag-Time

Classical hydrology defines stream flow in terms of three components: 1) surface runoff, 2) interflow, and 3) ground water flow. Notwithstanding classical hydrology, recent theories of stream flow generation have emphasized the timing, rather than the path, of the components of stream flow. The lag-time was defined as the time variation between the center of effective rainfall and the peak flow of the outlet. It is an important characteristic of the temporal relationship between the rainfall and runoff. In this study, the lag-time was used to make the relationship between the rainfall and runoff.

4.2.2.3 Selection of Model Structure

- HwaCheon Reservoir Inflow Forecasting Model

$$HCI(t+i) = f[R_s(\cdot), HCI(t-j)] \tag{4-8}$$

$R(\cdot) = R(t-k)$ For $i = 1 \ldots 24, j = 0 \ldots 6$

where, $HCI(t+i)$; Forecasted HwaCheon Reservoir Inflow series

$HCI(t-j)$; Given Hwa Cheon Reservoir Inflow series

$R_s(t-k)$; Given rainfall data series of subbasin s,

$s = 1,2,3$ and k=LT-5...LT.

- SoYangGang Reservoir Inflow Forecasting Model

$$SOI(t+i) = f[R_s(\cdot), SOI(t-j)] \tag{4-9}$$

$R(\cdot) = R(t-k)$ For $i = 1 \ldots 24, j = 0 \ldots 6$

where, $SOI(t+i)$; Forecasted SoYangGang Reservoir Inflow series

$SOI(t-j)$; Given SoYangGang Reservoir Inflow series

$R_s(t-k)$; Given rainfall data series of subbasin s,

s=5,6,7 and k=LT-5...LT.

- ChungJu Reservoir Inflow Forecasting Model

$$CJI(t+i) = f[R_s(\cdot), CJI(t-j)] \tag{4-10}$$

$$R(\cdot) = R(t-k) \text{ For } i = 1 \ldots 24, j = 0 \ldots 6$$

where, $CJI(t+i)$; Forecasted ChungJu Reservoir Inflow series

$CJI(t-j)$; Given ChungJu Reservoir Inflow series

$R_s(t-k)$; Given rainfall data series of subbasin s,

s=13...19 and k=LT-5...LT.

- Chun Cheon Reservoir Local Inflow Forecasting Model

$$CCLI(t+i) = f[R_4(\cdot), CCLI(t-j)] \tag{4-11}$$

$$R(\cdot) = R(t-k) \text{ For } i = 1 \ldots 24, j = 0 \ldots 6$$

where, $CCLI(t+i)$; Forecasted Chun Cheon Reservoir Local Inflow series

$CCLI(t-j)$; Given Chun Cheon Reservoir Local Inflow series

$R_4(t-k)$; Given rainfall data series of subbasin 4, k=LT-5...LT.

- Ui Am Reservoir Local Inflow Forecasting Model

$$UALI(t+i) = f[R_8(\cdot), UALI(t-j)] \tag{4-12}$$

$R(\cdot) = R(t-k)$ For $i = 1 \ldots 24, j = 0 \ldots 6$

where, $UALI(t+i)$; Forecasted Ui Am Reservoir Local Inflow series

$UALI(t-j)$; Given Ui Am Reservoir Local Inflow series

$R_8(t-k)$; Given rainfall data series of subbasin 8, k=LT-5...LT.

- CheongPyeong Reservoir Local Inflow Forecasting Model

$$CPLI(t+i) = f[R_s(\cdot), CPLI(t-j)] \tag{4-13}$$

$R(\cdot) = R(t-k)$ For $i = 1 \ldots 24, j = 0 \ldots 6$

where, $CPLI(t+i)$;Forecasted CheongPyeong Reservoir Local Inflow series

$CPLI(t-j)$; Given CheongPyeong Reservoir Local Inflow series

$R_s(t-k)$; The given rainfall data series of subbasin s,

s=9,10,11 and k=LT-5...LT.

- YeoJu Local Inflow Forecasting Model

$$YJLI(t+i) = f[R_s(\cdot), YJLI(t-j)] \tag{4-14}$$

$R(\cdot) = R(t-k)$ For $i = 1 \ldots 24, j = 0 \ldots 6$

where, $YJLI(t+i)$; Forecasted Local Inflow Series of YeoJu Station

$YJLI(t+i)$; Given Local Inflow Series of YeoJu Station

$R_s(t-k)$; Given rainfall data series of subbasin s,

s=20...26 and k=LT-5...LT.

- PalDang Reservoir Local Inflow Forecasting Model

$$PDLI(t+i) = f[R_s(\cdot), PDLI(t-j)] \tag{4-15}$$

$R(\cdot) = R(t-k)$ For $i = 1\ldots24, j = 0\ldots6$

where, $PDLI(t+i)$; Forecasted Pal Dang Reservoir Local Inflow series

$PDLI(t-j)$; Given PalDang Reservoir Local Inflow series

$R_s(t-k)$; Given rainfall data series of subbasin s,

s=12,27,28 and k=LT-5...LT.

- InDoGyo stream flow Forecasting Model

$$IDGLI(t+i) = f[R_{29}(\cdot), IDGLI(t-j)] \tag{4-16}$$

$R(\cdot) = R(t-k)$ For $\mathrm{i} = 1\ldots24, \mathrm{j} = 0\ldots6$

where, $IDGLI(t+i)$; Forecasted Local Inflow series of In Do Gyo Station.

$IDGLI(t-j)$; Given Local Inflow series of InDoGyo Station

$R_{29}(t-k)$; Given rainfall data series of subbasin 29, k=LT-5...LT.

4.2.2.4 Training Strategies and Parameter Estimation

Generally, it took a very long time to train the weights to the data set, since each model had 24 forecast periods. Based on experiments, a model with 24 output nodes required several days for training to the desired convergence criteria using a PC computer (Pentium Pro 200 MHz). It is very important to minimize the training time since the forecast models will need to retrain their weights after fresh observations of the input data become available. To attempt to minimize the training time, the 24 output node model was divided into 24 different segment models each with a single output node. In addition, initial weights for the next segment model, were provided by the optimal weights from the current segment model. Table 4.2 shows the comparison of correlation coefficients between predicted and observed streamflows for the 24 output node model (called Case 1) and for the single output node models (called Case 2) at Hwa Cheon Reservoir as an example.

Table 4.2 The Comparison of Model Accuracy for Hwa Cheon Reservoir Inflow Forecasting Models

Seg.-Model	Case 1	Case 2	Seg.-Model	Case 1	Case 2
SER01	0.9930	0.9983	SER13	0.9859	0.9684
SER02	0.9953	0.9919	SER14	0.9802	0.9781
SER03	0.9932	0.9944	SER15	0.9756	0.9691
SER04	0.9926	0.9862	SER16	0.9692	0.9700
SER05	0.9916	0.9908	SER17	0.9695	0.9616
SER06	0.9879	0.9909	SER18	0.9667	0.9530
SER07	0.9893	0.9804	SER19	0.9695	0.9438
SER08	0.9882	0.9937	SER20	0.9669	0.9360
SER09	0.9893	0.9806	SER21	0.9510	0.9273
SER10	0.9891	0.9931	SER22	0.9275	0.9089
SER11	0.9912	0.9772	SER23	0.9047	0.8890
SER12	0.9886	0.9894	SER24	0.8830	0.8933

In Case 1, there are 24 different series of outputs. Those are comparable to the individual outputs of each segment model in Case 1. Evaluation of Table 4.2 shows that the correlation coefficients for Case 2, the sequence of simple output node models, are sometimes better and sometimes worse than case 1, however, overall they are very close. Since Case 2 required less than 1 hour of training time, the process based on Case 2 provides a significant timesaving for training the models without sacrificing prediction accuracy.

Before training for each model, two experimental were performed to find out the best range of parameters: 1) the Number of Hidden Nodes, 2) the Desired Sum Square Error Goal Test. The intention was to compare model training speed time and performance under the different situations. The tested model has 79 (3 x 24 + 7) input node and 1 single output node. The results of experiment 1) and 2) were represented in Table 4.3 and Table 4.4 respectively.

In Table 4.3, NHN refers to the number of hidden nodes. The Training time (TT) statistic measures the entire segment module (24 time step) training time in second. The Correlation (COR) statistic measures the linear correlation between observed and simulated flows, where the best value is 1.0. The Peak flow difference (PD) statistic measures the error in matching the peak flow of the data record, where 0.0 is the best value. The Volume difference (VD) statistic measures the error in volume under the observed and simulated hydrographs, summed over the entire period. Training time exponentially increased depending upon the NHN increment. However, other statistics were not effected by NHN. The shaded area was selected as a reasonable range for selecting the number of hidden nodes.

Table 4.3 The Results of Experimental 1)

NHN	TT(Sec)	COR	PD(CMS)	VD(CMS)
2	10.9	0.9941	-461.30	49.17
3	33.2	0.9941	-593.27	-700.34
4	35.2	0.9967	-296.53	-499.06
5	81.3	0.9948	-489.83	-630.26
6	80.6	0.9969	-223.89	1869.81
7	145.7	0.9957	-395.00	-632.52
8	146.5	0.9969	-322.38	-509.96
10	260.7	0.9976	-239.14	-210.76
11	443.6	0.9961	-323.37	-1463.16
13	728.8	0.9970	-300.73	497.35
14	1161.5	0.9968	-213.99	406.83
15	1631.6	0.9968	-257.92	318.87

Table 4.4 The results of experimental 2)

DEG	TT(Sec)	COR	PD(CMS)	VD(CMS)
0.0001	545.36	1.0000	-1.63	67.47
0.001	338.99	1.0000	0.20	429.52
0.01	147.09	0.9998	-37.99	1579.54
0.02	143.84	0.9997	-53.00	1662.24
0.03	105.06	0.9986	-150.12	1390.15
0.04	82.77	0.9974	-187.49	1795.83

In Table 4.4, DEG refers to the desired sum squared errors goal. Training time was linearly increased by DEG accuracy. Other statistics (COR, PD, VD) also highly related with DEG accuracy. The shaded area was selected as a reasonable range for selecting the desired sum squared errors goal. Each forecast model was trained under considering the results of 2 experimental above.

CHAPTER V

REAL-TIME MULTI-RESERVOIR OPERATION MODULE FOR FLOOD CONTROL

5.1 Overview

One of the most important aspects of minimizing the impacts of floods is the operation of flood control systems. The forecasting of flood events is important in order to operate these systems. The real-time reservoir operation problem involves the operation of a reservoir system by making decisions about reservoir releases, as information becomes available, with relatively short time intervals that may vary between several minutes to several hours. Real-time operation of multireservoir systems involves various hydrologic, hydraulic, operational, technical, and institutional considerations (Mays, 1992).

In this study, the objectives of the module are to minimize the impacts of floods along the downstream reaches, while maintaining the target storages in the reservoirs for the next hydrologic period. The overall methodology employed in real-time operation of multireservoir systems is represented in Fig. 5.1. The current status of the systems is measured,. including inflows, stages of reservoirs, and downstream river stages, and telemetered to the control center. The flood forecasting models, which were described in Chapter 4, are initialized for the forecasted river conditions and an optimization model of the multireservoir systems computes the optimal release policies for each reservoir for the current and future time steps over the operational forecast window. Only optimal release policies for the current time step are adopted for the reservoirs. The current status of systems is again measured, telemetered and checked against computed values. A hydrologic flood routing model is reinitialized based on current system measurements. An optimization model of multireservoir systems is executed to correct the predictive release policies until no significant improvement of policies, and process continues throughout the operational horizon.

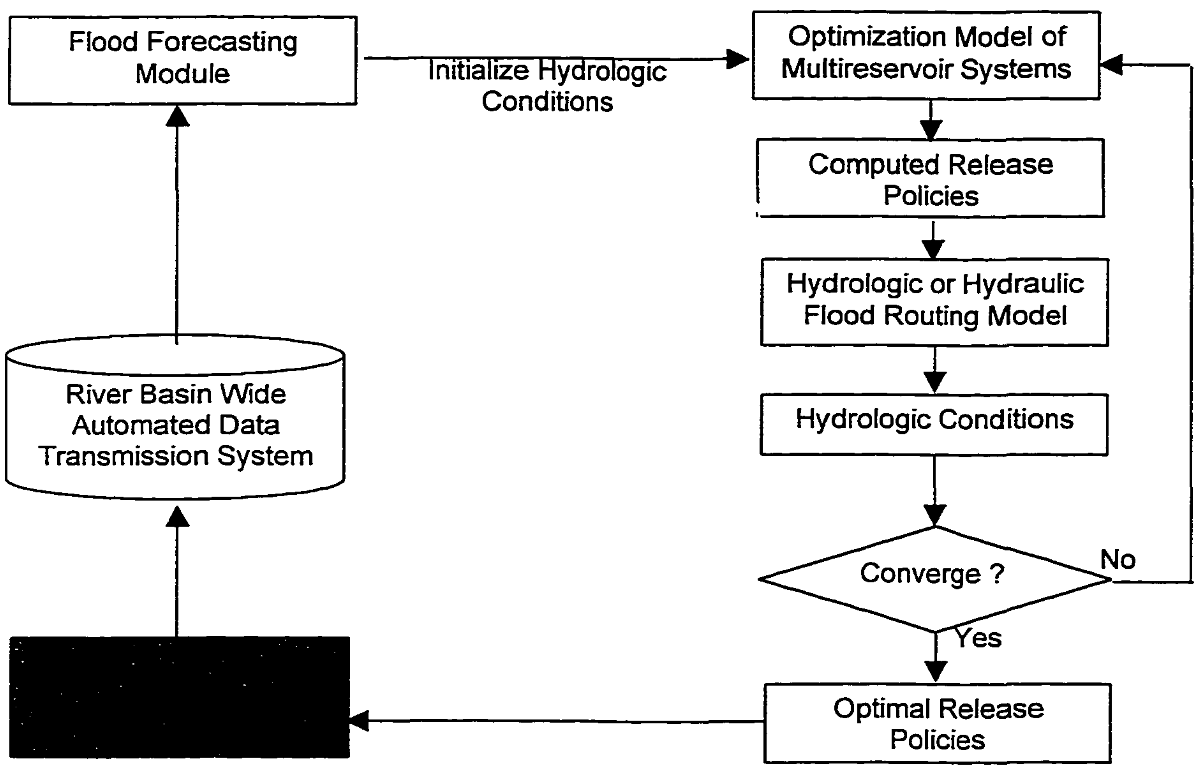


Fig. 5.1. Real-Time Multi-Reservoir Operation Module for Flood Control

5.2 CSUDP

5.2.1 Introduction

Dynamic programming (DP) is an optimization technique particularly well applied to sequential decision problems such as reservoir system operation. Using this method, large-scale problems can be decomposed into the series of small decision problems. DP has the advantage of being able to handle problems with special characteristics such as nonlinearity, stochasticity, nonconvexity, and nondifferentiability. The Incremental dynamic programming (IDP) and Dynamic Programming with Successive Approximation (DPSA) method are specially designed to solve multidimensional optimization problem in CSUDP (Labadie, 1990). In this study, considering the capabilities of DPSA and IDP, a discrete dynamic programming approach was selected to solve the joint operation of the multi reservoir system in the Han River Basin.

CSUDP program is a generalized dynamic programming code, designed to solve stage-wise, sequential decision problem such as planning, design and operation problem in engineering. CSUDP has been used in many kinds of fields, such as Civil Engineering, Mechanical Engineering, and Agricultural and Chemical Engineering at Colorado State University (Labadie, 1990). The user to must describe the problem they wish to solve through user-supplied subroutines, which are linked to the main CSUDP code.

5.2.2 Multidimensional Dynamic Programming Algorithms in CSUDP

Generally, in the application of a reservoirs system for dynamic programming, a dimensionality can be serious problem in computational speed and time (Labadie, 1996). For a real-time flood control using a short time period like 1 hour, the computational speed and time are very important factors, which effect the overall decision making process. A typical stage in a multidimensional sequential decision problem is represented in Fig. 5.2.

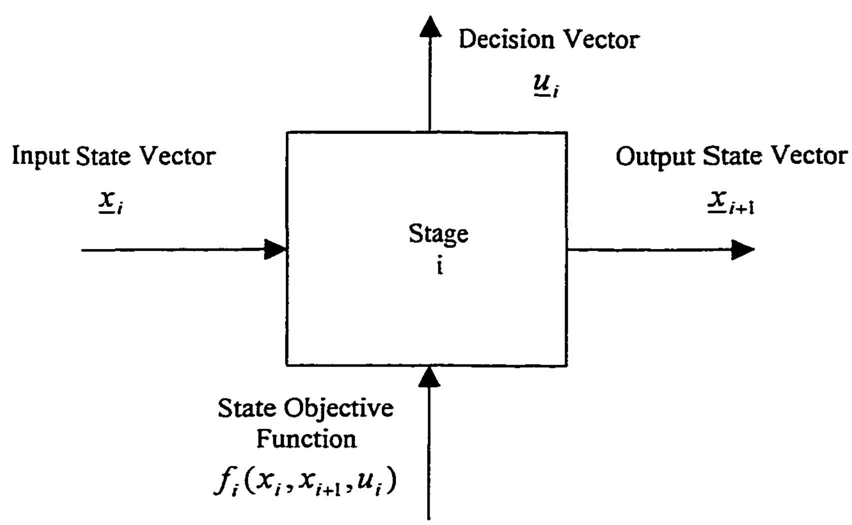


Fig. 5.2 A typical stage in a multidimensional sequential decision.

Assuming there are n components of the state vector and m discrete values, then the total numbers of combinations will be n^m for each stage i respectively. The computational burden of DP therefore increases geometrically as the number of state variable increase. This is termed the "curse of dimensionality".

5.2.2.1 Incremental Dynamic Programming

Incremental dynamic programming (IDP) was first proposed by Larson in 1968. After that time, it has been proposed in various problems. IDP reduces combinations for each stage by reducing the component of the state vector to 3. Hall, et al (1969) initially applied IDP to water resources system.

The steps of IDP algorithm procedure are illustrated in Fig. 5.3 and Fig. 5.4. The first step of IDP procedure is setting up the initial trajectory based upon engineering judgement to produce an initial optimal solution for each state variable as shown in Fig. 5.3.(a).

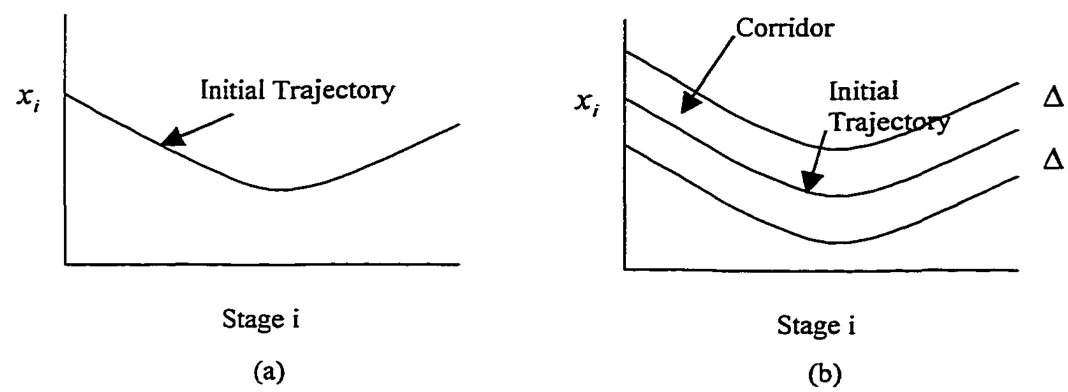


Fig. 5.3 The Initial Trajectory and its corresponding Corridor.

After guessing the initial trajectory, the corresponding corridor will be defined as $x_{ij} + \Delta x, x_{ij} - \Delta x$ around the initial trajectory, which is represented in Fig. 5.3.(b). With this restricted state space, the solution procedure of the multidimensional DP problem will be started. The IDP is solved and if the optimal trajectory is same as the initial trajectory, which means the solutions are all interior to the corridor, then the solution procedure will be terminated. Otherwise, a new trajectory will be defined. The corresponding new corridor will be defined as $x_{ij} + \Delta x, x_{ij} - \Delta x$ again around the new obtained trajectory, which is represented in Fig. 5.4.(b). When convergence does occur, the splicing factor should be applied to come up with refined solution. The splicing factor is a procedure for reducing the size Δx. The final solution will be produced when the discretization interval has been reduced (spliced) to the desired level of accuracy.

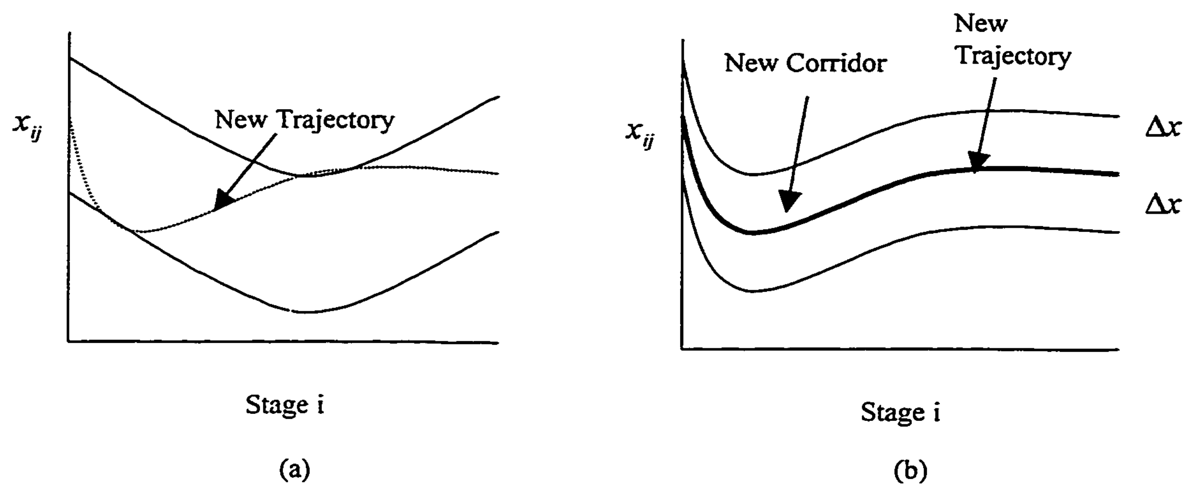


Fig. 5.4 The New Trajecory and its corresponding Corridor.

5.2.2.2 Dynamic Programming with Successive Approximations

Another way of alleviating the curse of dimensionality is to use Bellman's concept of successive approximations. Instead of evaluating the optimal value function for all possible combinations of the state vector, only one component is changed at a time. The process of Dynamic Programming with Successive Approximations (DPSA) is as follows. Each component of the state vector is optimized one at a time with initial trajectory assumed as a starting point:

$$F_i(x_{i1}^0, x_{i2}^0, \ldots, x_{im}^0) \quad (5\text{-}1)$$

where F_i is the dynamic programming optimal value function for stage i, and x_{im} is a m state variable for stage i. A superscript 0 is used to indicate the initial trajectory.

All the components are fixed to their initial values except the first.

$$F_i(x_{i1}, x_{i2}^0, \ldots, x_{im}^0) \quad (5\text{-}2)$$

A one-dimensional dynamic programming problem is now solved over the first component only. That is, $x_{i2}^0, \ldots, x_{im}^0$ are held constant in the objective function and all constraints and only x_{i1} is allowed to vary. When an optimal solution is obtained over all stages i, it is indicated with a superscript 1:

$$F_i(x_{i1}^1, x_{i2}^0, \ldots, x_{im}^0) \quad (5\text{-}3)$$

Next, the second state component is varied, while maintaining all other components are present values, and a new solution is found

$$F_i(x_{i1}^1, x_{i2}, \ldots, x_{im}^0) \quad (5\text{-}4)$$

which is designated with a superscript one.

$$F_i(x_{i1}^1, x_{i2}^1, \ldots, x_{im}^0) \quad (5\text{-}5)$$

This process is continued until the final component is reached. At this point, the entire process is repeated starting with the new values found as the new trajectory. This process is terminated when no significant improvement is possible.

$$F_1(\underline{x}_1^{(k)}) \cong F_1(\underline{x}_1^{(k-1)}) \tag{5-6}$$

5.2.2.3 Comparison of the Methods

In comparing these methods, each has advantages and disadvantages. IDP offers the greatest assurance of convergence to local minimum, but is limited as to the number of state variables that can be considered. A good estimate of the global optimum solution might be obtained by selecting multiple feasible initial trajectories together with a reasonable selection of discretization and splicing factors (Ko, 1997). However, the procedure may or may not converge if the initial state of trajectory is infeasible (Labadie, 1996). Fontane et al.(1986) showed that the IDP method has difficulty in handling problems with more than 6 state variables.

The advantage of DPSA method is that the solution of the multi-dimensional DP problem is obtained by solving a series of one-dimensional DP problems which provides considerable reduction in computational burden, since as the number of state variables increases linearly instead of exponentially. The drawbacks to DPSA for breaking the bounds of dimensionality are twofold (Yi, 1996). In the first place, there is the possibility of converging to a local optimum solution. Inequality constraints on the state and decision variable can cause considerable difficulty. Secondly, since the solution is closely related to initial state trajectory values, inappropriate initial trajectory values may result in a local or infeasible solution.

5.3 Real-Time Multi-Reservoir Operation Module for Flood Control in the Han River Basin

5.3.1 Introduction

There are 9 reservoirs with hydropower plants and one proposed reservoir in the Han River Basin. Fig.5.5 represents the location map of the Han River Basin reservoir system. Three multipurpose storage reservoirs, SoYangGang, ChungJu, HongCheon reservoir are managed or planned by the Korean Water Resources Corporation (KOWACO). The other storage reservoirs, HwaCheon and five other small-scale flow-through reservoirs are managed by Korea Electric Power Corporation (KEPCO) for the single purpose of hydropower generation.

Flood control is one of the major purposes of multipurpose reservoirs in Korea. Two reservoirs, SoYangGang and ChungJu reservoirs were built and operation policies were established for these purposes in the Han River Basin. In addition, the HwaCheon reservoir can control the flood in some degree. SoYangGang and ChungJu reservoirs, whose flood control capacities are 500 MCM and 616 MCM respectively, are the major reservoirs for flood control in the Han River Basin. HwaCheon reservoir is primarily designed to generate the hydropower however, it does provide storage flood at the upstream end of the North Han River. The reservoir has a flood control capacity of 213 MCM.

These three reservoirs are operated to meet the municipal and industrial water supply of the Seoul metropolitan area. Releases from the three reservoirs also have a direct impact on flooding in the downstream portion of the basin. However, there is not enough room for flood control storage in the other reservoirs. Therefore, other reservoirs just have been fully opening their gates during the flood events.

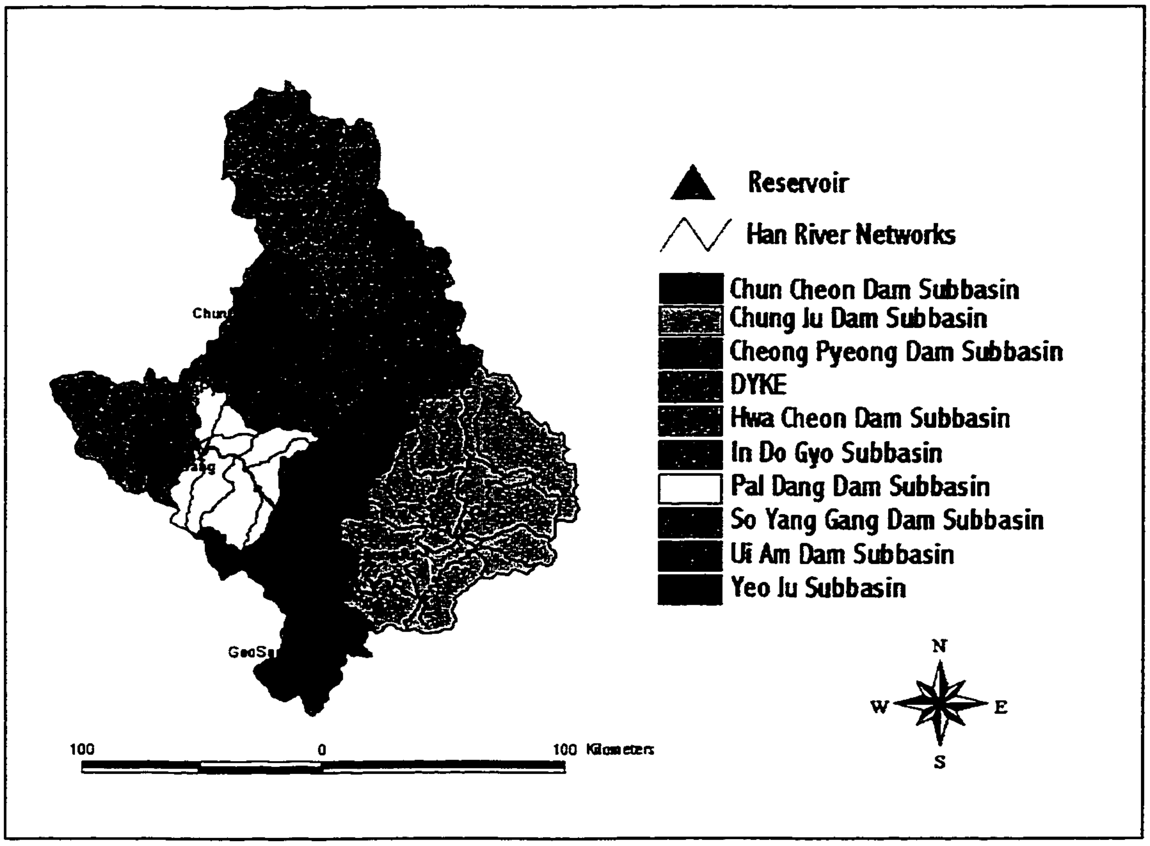


Fig. 5. 5 Location Map of the Han River Reservoir System

The schematic representation of the Han River Reservoir System is illustrated in Fig. 5.6. Moreover, these three reservoirs are not operated in a complementary fashion.

One of the major reasons for the lack of coordinated operation is that KEPCO operates the HwaCheon reservoir while KOWACO operates the other two.

Currently, KOWACO uses simulation models for flood control, such as the Technical Reservoir Operation Method (ROM), Spillway Rule Curve ROM, Rigid ROM, Auto ROM and Scheduled Release Discharge ROM. The Technical ROM is the most efficient model in the above simulation models. This model decides the release schedule within the available flood capacity, from the current water level to the predetermined flood control water level or target water level based on predicted reservoir inflows. The rest of the simulation models just use the predetermined release after calculating the flood control capacity.

However, in all these simulation models, the downstream conditions are not considered downstream effects of the reservoir release are computed by trial and error methods after a release has been decided. In addition, complementary flood control that might be available through the joint operation of reservoirs in the basin is not considered in the decision process.

In this section, the development of a joint operation module for real-time flood control using multiple reservoirs in the Han River Basin is described. The developed module can not only minimize the flood damage for the downstream portion of the river, but also maximizes the benefits of the water storage for potential use for the next hydrological period. The Dynamic Programming with Successive Approximations Algorithm in CSUDP will be used since number of state variable over 5.

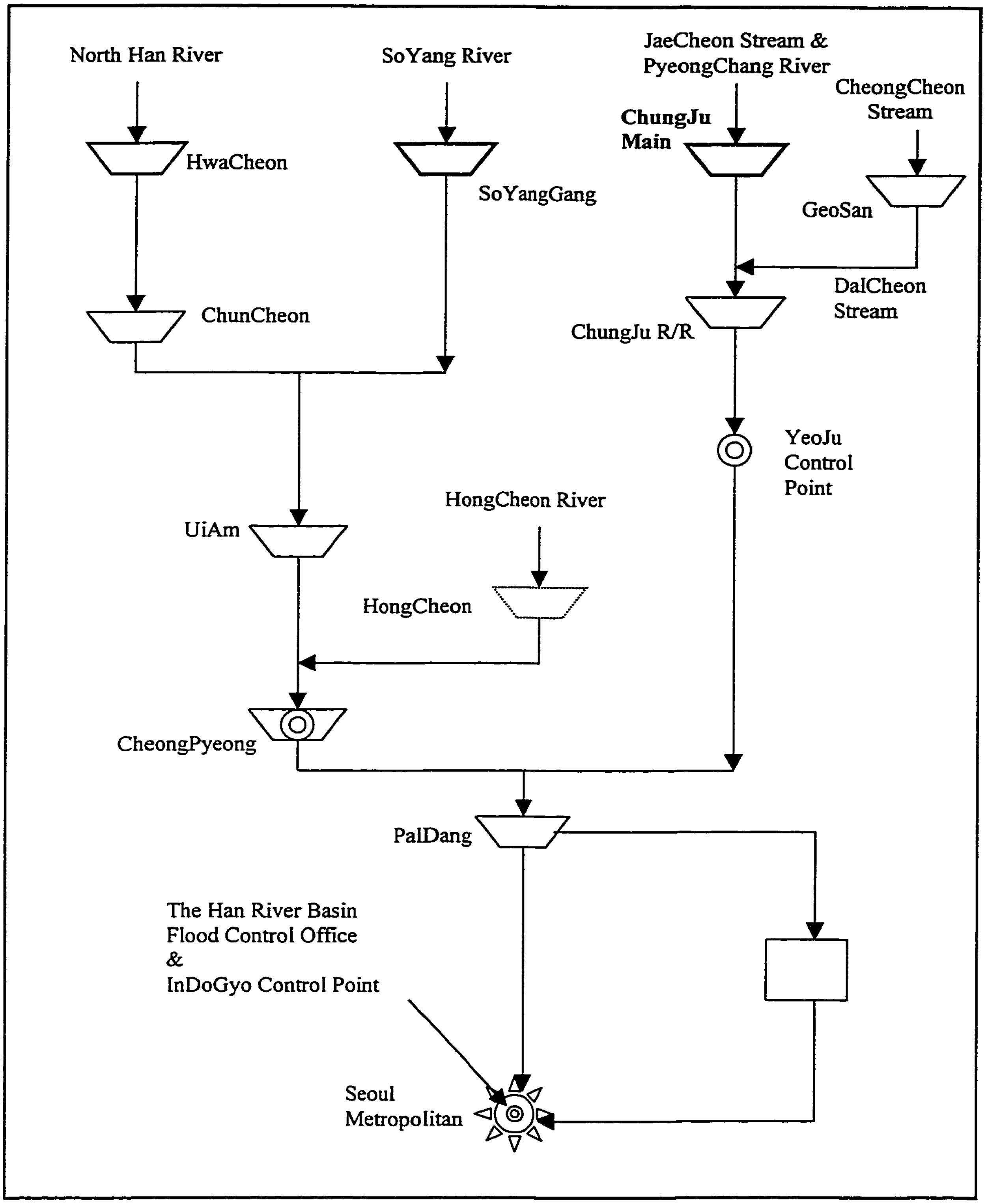


Fig. 5.6 The Schematic Representation of the Han River Reservoir System.

5.3.2 Problem Formulation

In this study, the three flood control storage reservoirs, HwaCheon, SoYangGang and ChungJu Main, four non-storage reservoirs and two flood control points of downstream are considered as the state variables to develop the real-time operation model for flood control in the Han River Basin. These are represented in Fig. 5.7.

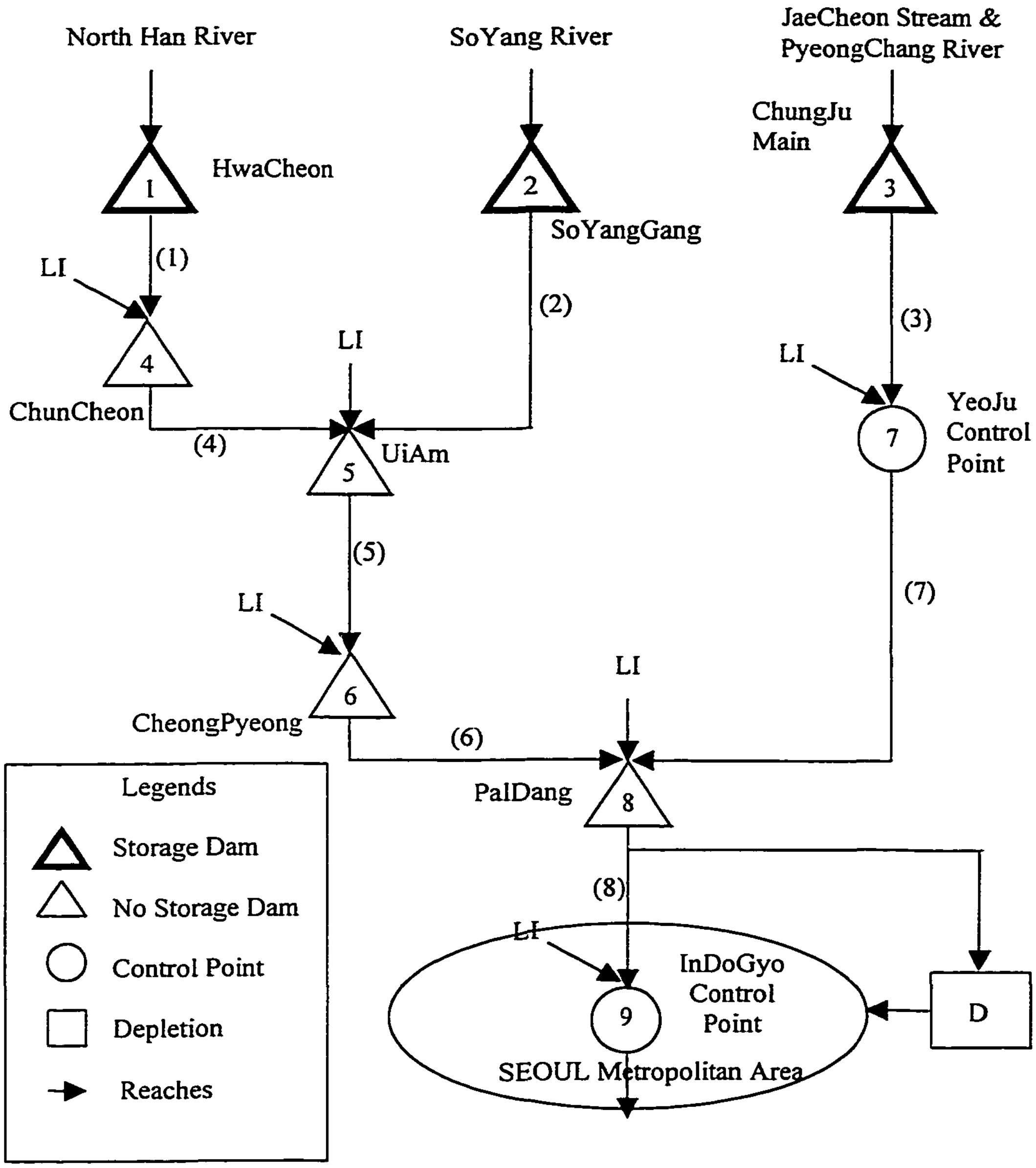


Fig. 5.7. Schematic Layout of Han River Flood Control Project.

The objective function for the real-time operation of multireservoir system for flood control problem incorporates seven objectives: 1) minimizing the downstream flooding effects through the basin; 2) maintenance of ideal target storage for water use for the next hydrologic period; 3) avoiding potential exceeding the maximum storage for the flood control resulting in endanger reservoir safety and creating a backwater effect; 4) satisfaction of required demands for monthly water use; 5) assuring optimal policies within the actual available release; 6) avoidance of rapid variation in releases resulting in unacceptable gate control; and 7) stability of final storage in the storage reservoirs at the end of the forecasted period, assuring recovery of control capacity in the next operational cycle.

The objective function is stated as follows:

$$\underset{x,u,Q}{Minimize} \quad \sum_{t=1}^{T}\sum_{i=1}^{N} w_1^i (Q_t^i - DFlood^i)^2 + \sum_{t=1}^{T}\sum_{i=1}^{N} w_2^i (x_t^i - TSTO^i)^2 + \sum_{t=1}^{T}\sum_{i=1}^{N} w_3^i (x_t^i - x_{\max}^i)^2$$

$$+ \sum_{t=1}^{T}\sum_{i=1}^{N} w_4^i (Q_t^i - QPlan^i)^2 + \sum_{t=1}^{T}\sum_{i=1}^{N} w_5^i (u_t^i - u_{t,\max}^i)^2 + \sum_{t=1}^{T}\sum_{i=1}^{N} w_6^i (u_t^i)^2$$

$$+ \sum_{i=1}^{N} w_7^i (x_{T+1}^i - SLSTO^i)^2 \qquad (5\text{-}7)$$

subject to:

$$x_{t+1}^i = x_t^i + I_t^i - u_t^i \qquad (i = 1,\ldots,3; t = 1,\ldots,T) \qquad (5\text{-}8.a)$$

$$x_{t+1}^4 = x_t^4 + I_t^4 + \alpha_{1,t} \cdot u_t^1 - u_t^4 \qquad (t = 1,\ldots,T) \qquad (5\text{-}8.b)$$

$$x_{t+1}^5 = x_t^5 + I_t^5 + \alpha_{2,t} \cdot u_t^2 + \alpha_{4,t} \cdot u_t^4 - u_t^5 \qquad (t = 1,\ldots,T) \qquad (5\text{-}8.c)$$

$$x_{t+1}^6 = x_t^6 + I_t^6 + \alpha_{5,t} \cdot u_t^5 - u_t^6 \qquad (t = 1,...,T) \qquad (5\text{-}8.d)$$

$$x_{t+1}^7 = x_t^7 + I_t^7 + \alpha_{3,t} \cdot u_t^3 - u_t^7 \qquad (t = 1,...,T) \qquad (5\text{-}8.e)$$

$$x_{t+1}^8 = x_t^8 + I_t^8 + \alpha_{6,t} \cdot u_t^6 + \alpha_{7,t} \cdot u_t^7 - u_t^8 - D_t \qquad (t = 1,...,T) \qquad (5\text{-}8.f)$$

$$x_{t+1}^9 = x_t^9 + I_t^9 + \alpha_{8,t} \cdot u_t^8 - u_t^9 \qquad (t = 1,...,T) \qquad (5\text{-}8.g)$$

$$x_{\min}^i \le x_t^i \le x_{\max}^i \qquad (i = 1,...,3; t = 1,...,T) \qquad (5\text{-}9.a)$$

$$x_{\min}^i = x_t^i = x_{\max}^i \qquad (i = 4,5,6,8; t = 1,...,T) \qquad (5\text{-}9.b)$$

$$x_t^i = 0 \qquad (i = 7,9; t = 1,...,T) \qquad (5\text{-}9.c)$$

$$u_{\min}^i \le u_t^i \le u_{\max}^i \qquad (i = 1,..., N; t = 1,...,T) \qquad (5\text{-}10)$$

$$Q_t^i \le DFlood^i \qquad (i = 7,9; t = 1,...,T) \qquad (5\text{-}11.a)$$

$$QPlan^8 \le Q_t^8 \qquad (t = 1,...,T) \qquad (5\text{-}11.b)$$

where, $i = 1,\ldots,N$ node locations in the system, with a node representing any point of storage, control or flow confluence.

$l = 1,\ldots,L$ reach locations in the system, with a reach representing any two point of node connection.

$t = 1,\ldots,$T time interval as a stage in DP formulation.

x_t^i = i^{th} node storage at the beginning of time interval t (system state variables).

x_{t+1}^i = i^{th} node storage at the end of time interval t (system state variables).

u_t^i = i^{th} node release rate at the end of time interval t (decision variable).

$x_{\min}^i, x_{\max}^i$ = lower and upper bounds on i^{th} node storage.

$u^i_{\min}, u^i_{\max}$ = lower and upper bounds on i^{th} node release

$u^i_{t,\max}$ = upper bounds on i^{th} node release at the end of time interval t (Note; only 1,2 and 3th node will be estimated by storage-maximum available release relationship).

I^i_t = i^{th} node forecasted inflows during period t (Note; for only 1,2 and 3th node will be referred as a natural inflow while 4,5,6,7 and 8th node will be referred as a local inflow).

Q^i_t = i^{th} node calculated discharges at the end of time interval t (Note; only 7 and 9th node will be calculated for evaluate the flooding effects of downstream).

$DFlood^i$ = i^{th} node designed top flood discharges (Note; only 7 and 9th node will be given by user for evaluate the flooding effects of downstream).

$QPlan^i$ = i^{th} node planned discharges for water supply (Note; only 8th node will be given by user for evaluate the satisfaction of water supply).

$TSTO^i$ = i^{th} node target storage (Note; only 1,2 and 3th node will be given by user for evaluate the demand storage for the next hydrologic period).

$SLSTO^i$ = i^{th} node limited storage for rainy season (Note; only 1,2 and 3th node will be given by user for evaluate the assurance of the flood control capacity).

$\alpha_{l,t}$ = routing coefficients of $(l)^{th}$ reach during period t (Note; accounting for attenuation and lagging of upstream releases to downstream nodes and system spills).

D^i = i^{th} node diversion or depletion for water supply (Note; only 8^{th} node will be given by user for evaluate the satisfaction of water supply).

w_j^i = i^{th} node weighting factor for the j^{th} objective term

(Note; $j = 1,...,7$; $0 \leq w_j^i \leq 10^9$).

In the objective function (EQ. (5-7)), the various settings of the weighting factor reflect decision-maker preferences with respect to the relative importance of the objectives. Specifically, setting weighting factor value to zero means that there will be no consideration of that objective for the specified node. For instance, consider the 1^{st} objective in EQ. (5-7). This objective should have a 0 weighting factor values for nodes 1, 2, 3, 4, 5, 6 and 8^{th}, since this term should not be considered at these nodes. However, the weighting factor for the 7^{th} and 9^{th} node should be defined within the range of $0 \prec w_1^i \leq 10^9$ depending on the decision maker's preference.

The target storage of each reservoir can be referred to as the demand storage for the next hydrologic period. The user defines the target storages with the associated weighting factors as input parameters, based on consideration of the hydrologic conditions throughout the basin. If the variation between the target storage and current storage is relatively large, then overall objective function value can be large. Hence, the overall decision process can ignore the decision, because it is minimizing the objective values.

The third objective is used to present the current storage from exceeding the maximum flood control storage of the reservoirs. This flood control storage was established for various purposes, such as reservoir safety and backwater effects upstream.

The 4th term of the objective function is used to find the optimal release policies to meet the water demands at the 7th node. The 7th node is very important for water supply since it has depletion point to water treatment facilities which serve more than 1.5 million people in the Seoul Metropolitan Area. This objective is incorporated with restriction, which is defined in EQ. (5-11.b).

The 5th term of the objective function is intended to restrict the derived optimal policies to the actual possible release. The $u^{i}_{t,\max}$ value can be estimated from the current storage using the curves derived by regression analysis.

The 6th term of the objective function is designed to avoid rapid variation in releases, which could result in unacceptable gate control operations.

The 7th term of the objective function is designed to insure that the final storage in the storage reservoirs, at the end of the forecasted period, is such that recovery of the flood control capacity in the next operational cycle is assured. The summation of the objective function values for the objective function terms 1, 3, 4 and 7 should be zero to obtain optimal release polices without violation of any penalty functions.

The state dynamics or transformation relationships were defined in EQ. (5-8.a)-(5-8.g). The order of these calculations is important for the water balance. The key to these formulations is the iterative calculation of the routing coefficient based on solution of the hydrologic flood routing model.

EQ. (5-9.a) defines the boundary conditions for the state variables. Since the 4, 5, 6 and 8th nodes are non-storage reservoirs during the flood season, their maximum storage is equal to the minimum storage required for opening the control gates, which is defined in EQ. (5-9.b). However, since, the 7th and 9th nodes are downstream flood gaging station, there state space is defined as a no capacity node (EQ. (5-9.c)). EQ. (5-10) defines the boundary conditions for the decision variables.

5.3.3 Flood Routing Method

In state dynamics, the routing coefficients are successively calculated at current iteration k as

$$\alpha_{l,t}(\underline{u}^{(k-1)}, \underline{QO}^{(k-1)}) = u_t^{i,(k)} / QO_{l,t}^{(k)} \qquad \text{(for } i = 1,\dots,N; t = 1,\dots,T; l = 1,\dots,L) \quad (5\text{-}12)$$

where flow rates at the upstream and downstream of reach l ($u_t^{i,(k)}, QO_{l,t}^{(k)}$, respectively) are obtained directly from the hydrologic flood routing model (Fig. 5.8) that simulates water levels and discharges based on a given status of the system, $\underline{u}^{(k-1)}, \underline{QO}^{(k-1)}$ which are calculated from the optimization model in the previous iteration, $k-1$. Labadie (1989) proposed this method in real-time urban storm water control using the optimal control theory then Flavio and Labadie (1997) successfully applied in optimal real-time control of irrigation canals with incorporation of current and forecasted demands. Since the number 1, 2 and 3 nodes are very upstream in the basin, the routing coefficient doesn't have to be incorporate (EQ. (5-8.a)). However, the routing coefficient has to incorporated for the other nodes (EQ. (5-8.b)-(5-8.g)).

The Muskingum method is a commonly used hydrologic flood routing method for handling a variable discharge-storage relationship. First, McCarthy modeled the storage volume of flooding in a river channel by a combination of wedge and prism storages that are represented in Fig. 5.9.(a).

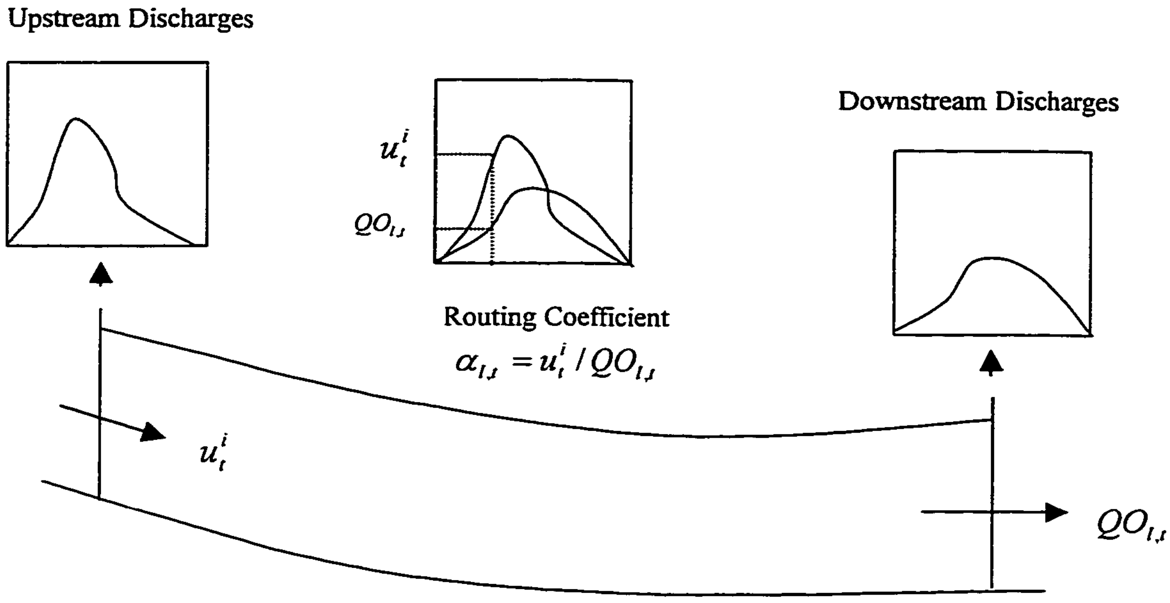


Fig. 5.8 Typical reach illustrating calculation of routing coefficients.

This method assumes that the cross-sectional area of the flood flow is directly proportional to the discharge at the section. During the advance of a flood wave, inflow exceeds outflow, producing a wedge of storage while during recession, outflow exceeds inflow, resulting in a negative wedge, which was represented in Fig. 5.9.(b). The volume of prism storage is equal to KO where K is a proportionality coefficient, and the volume of wedge storage is equal to $KX(I-O)$, where X is a weighting factor having the range $0 \leq X \leq 0.5$.

Therefore, the total storage is the sum of components,

$$S = KO + KX(I-O) \qquad (5\text{-}13)$$

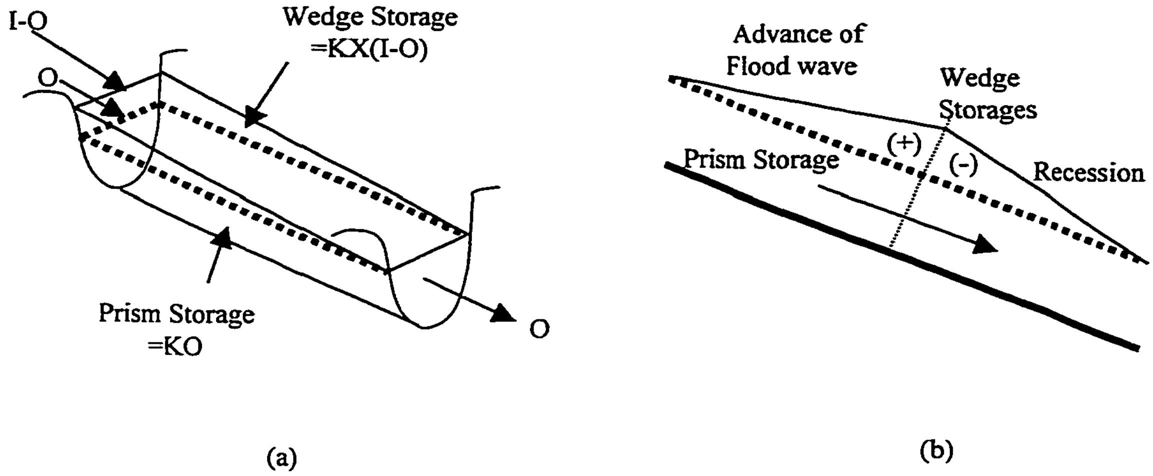


Fig. 5.9 Prism and Wedge Storages in a Channel Reach

which can be rearranged to give the storage function for the Muskingum method

$$S = K[XI + (1 - X)O] \tag{5-14}$$

The value of storage at time j and $j+1$ can be written

$$S_{j+1} - S_j = K[X(I_{j+1} - I_j) + (1 - X)(O_{j+1} - O_j)] \tag{5-15}$$

The change in storage can also be expressed suing the differential form of Storage Equation, as

$$\frac{(I_{j+1} + I_j)}{2}\Delta t - \frac{(O_{j+1} + O_j)}{2}\Delta t = K[X(I_{j+1} - I_j) + (1 - X)(O_{j+1} - O_j)] \tag{5-16}$$

Simplifying on O_{j+1} then,

$$O_{j+1} = C_0 I_{j+1} + C_1 I_j + C_2 O_j \tag{5-17}$$

which is the routing equation for the Muskingum method where

$$C_0 = \frac{-(KX - 0.5\Delta t)}{K - KX + 0.5\Delta t}, \quad C_1 = \frac{KX + 0.5\Delta t}{K - KX + 0.5\Delta t}, \quad C_2 = \frac{K - KX - 0.5\Delta t}{K - KX + 0.5\Delta t} \tag{5-18}$$

Note that $C_0 + C_1 + C_2 = 1$.

The value of X depends on the shape of the modeled wedge storage; $X = 0$ and $X = 0.5$ for reservoir type storage and a full wedge respectively. In a natural stream, X is between 0 and 0.3 with mean value near 0.2. Great accuracy in determining X may not necessary because the results of the method are relatively insensitive to the value of this parameter (Chow, 1988). The values of X at the main channel reaches in the Han River Basin were be selected by 0.2 (Yun, 1986). The parameter K is the time of travel of the flood wave through the channel reach. The time of travel of the flood wave was provided by KOWACO, and is shown in Table 5.1 and Table 5.2 for So Yang Gang and Chung Ju Reservoir respectively. Based on these tables, the parameters K of channel reaches were determined.

Table 5.1 Distance and Travel Time for So Yang Gang Reservoir Release

SOR (CMS)	Unit	Ui Am	Cheong Pyeong	Pal Dang	In Do Gyo
1000	Hr	2.00	8.17	12.84	20.59
2000	Hr	1.67	7.17	11.00	18.17
3000	Hr	1.42	6.50	9.83	16.50
5000	Hr	1.25	5.75	8.58	14.50
7500	Hr	1.25	5.42	8.17	13.50
10000	Hr	1.17	5.00	7.67	12.59
15000	Hr	1.17	4.84	7.34	11.51
20000	Hr	1.08	4.58	6.91	10.58
Cu. Distance	Km	21.50	65.30	91.80	130.50

Table 5.2 Distance and Travel Time for Chung Ju Reservoir Release

CHR (CMS)	Unit	Yeo Ju	Pal Dang	In Do Gyo
1000	Hr	8.33	17.58	25.33
2000	Hr	7.50	15.75	22.92
3000	Hr	7.50	15.17	21.84
5000	Hr	6.00	12.67	18.67
7500	Hr	5.25	10.58	15.91
10000	Hr	4.75	9.42	13.34
15000	Hr	4.17	8.34	12.51
20000	Hr	3.58	7.33	11.00
Cu. Distance	Km	53.05	107.05	145.75

5.3.4 Simple Curve-Fitting for Maximum Available Release vs. Storage Volume

The 5th term of the objective function restricts derived release to the actual possible release. The KOWACO provided water level-storage volume relationship and water level-maximum spill relationship. Based on those data, the simple curve-fitting analyze were performed. The summary of results is shown in Table 5.3 and graphical representations are in Fig. 5.10 to Fig. 5.12.

Table 5.3 Equations for Maximum Available Release for Upstream Reservoir

Name	Equation
Hwa Cheon Reservoir	$u^1_{t,\max} = (173.6272 - (84187274 / \ln(\frac{x^1_t + x^1_{t+1}}{2})^2)^2 + 185.0$
So Yang Gang Reservoir	$u^2_{t,\max} = (299.5865 - 80222.0233 * \ln(\frac{x^2_t + x^2_{t+1}}{2}) / (\frac{x^2_t + x^2_{t+1}}{2}))^2 + 251.0$
Chung Ju Reservoir	$u^3_{t,\max} = 0.002842373 * \ln(\frac{x^3_t + x^3_{t+1}}{2})^2 - 5393.3646 + 828.0$

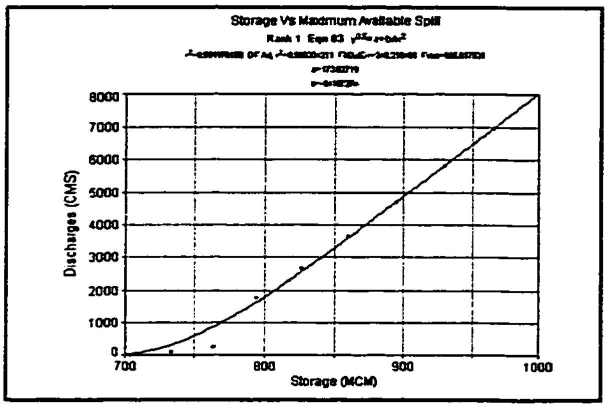


Fig. 5.10 Maximum Available Release-Storage Relationship for Hwa Cheon Reservoir

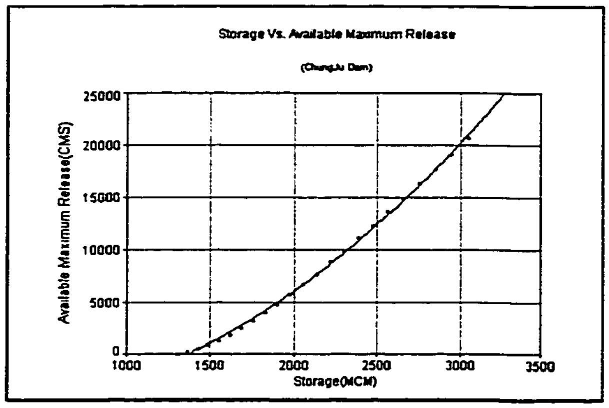


Fig. 5.11 Maximum Available Release-Storage Relationship for SoYang Gang Reservoir

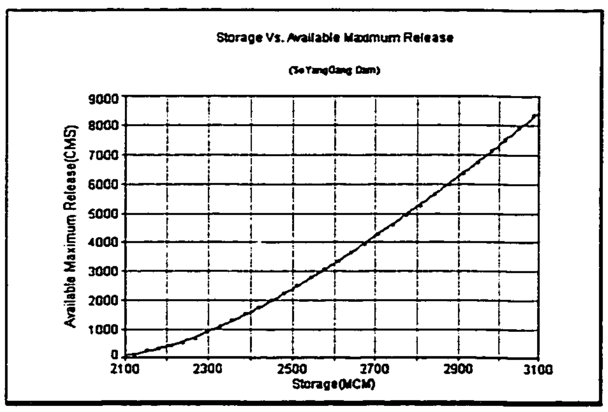


Fig. 5.12 Maximum Available Release-Storage Relationship for Chung Ju Reservoir

5.3.5 Model Structure and I/O Data

In order to analyze the real-time operation of the multireservoir system in the Han River Basin using CSUDP software, the HRBSDP model was developed. The Han River Basin System Dynamic Programming (HRBSDP) consists of user-supplied subroutines, READIN, STATE, OBJECT and RESULTS, Program ROUT (source code was represented in Appendix D) and the main CSUDP program were externally incorporated to calculate routing coefficients. Program ROUT was developed using Visual Basic Software. The CSUDP main program, DPSA, computes the optimal value of the recursion relationship using the user-supplied subroutines. Subroutine READIN, the source code is given in Appendix D3, reads problem specific input data from file, HRBS.ADD and routing coefficient data file, ALPHA.ADD. Subroutine STATE, the source code is shown in Appendix D1, calculates the mass balance for each node using the state transition equations. Subroutine OBJECT, the source code is shown in Appendix D2, computes the value of the objective function for individual stage. Subroutine RESULTS writes user-customized results to files XOUT.TXT for node storage at the beginning of the time interval, X1OUT.TXT for node storage at the end of the time interval, UOUT.TXT for node release during the time interval, and QOUT.TXT as an input file for program ROUT. The obtained node storages at the current iteration were used input for the initial trajectory at the next iteration. This was done by external utility program in the SDSS. The components and linkages of the HRBSDP model are represented in Fig. 5.13.

The HRBS.ADD, user-defined input file, contains inflow or local inflow, weighting factors, design flood, target storage, planned water supply discharges, enforced storage for the summer season and current reservoir releases. The GUI for the multireservoir operation module can help the user to create the file. The ALPHA.ADD file only contains one set of routing coefficients at a time. This file is initialized by setting all values to 1.0 for first execution. The ROUT program then reinitialize those values by calculating routing coefficients at each execution, as described in Section 5.3.3.

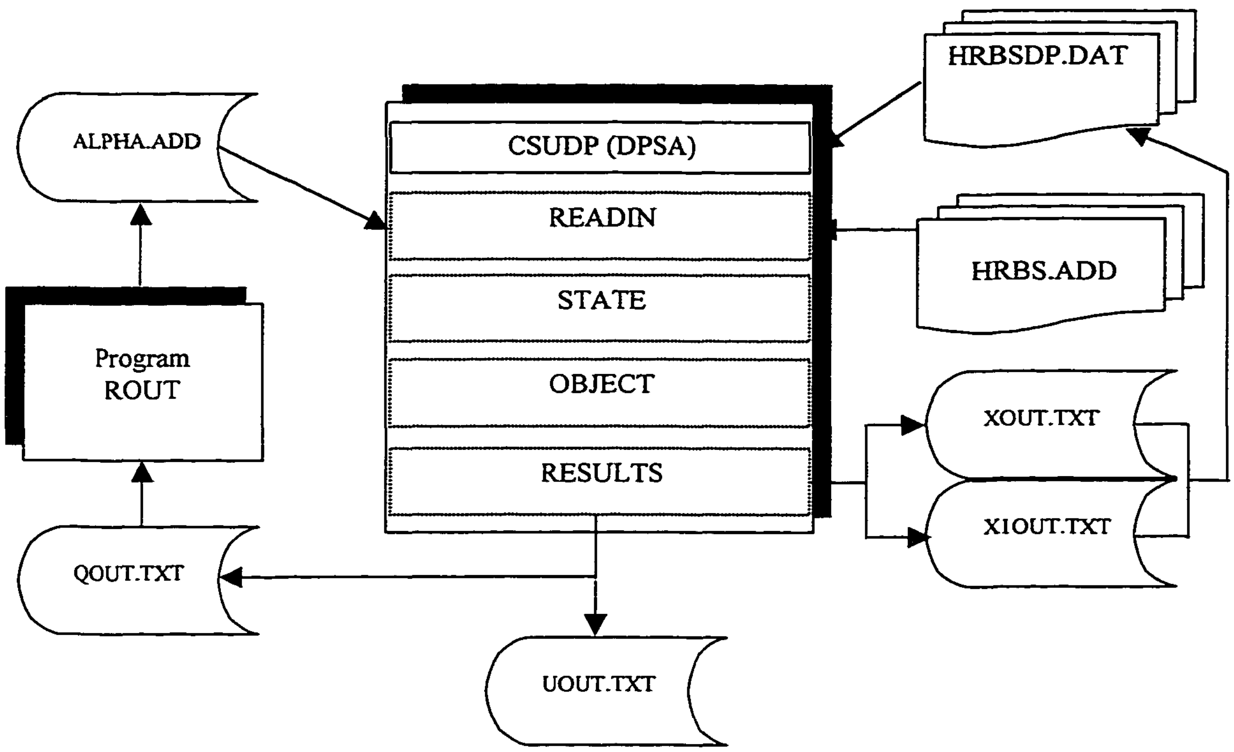


Fig. 5.13 The Components and Linkages of the HRBSDP model.

CHAPTER VI

THE DEVELOPMENT OF A SPATIAL DECISION SUPPORT SYSTEM

6.1 Development Overview

A spatial decision support system is the integration of enhanced computer technologies, consisting of database management, a model base, a user dialog system and spatial analysis module subsystem. The functions of the each component are as follows:

1) Database Management Subsystem

   Collecting, updating, processing, and managing the textual and geo-spatial data

2) Model Base Subsystem

   Solving the specific problems

   Generating useful information or alternatives for the overall decision making

3) Dialog Subsystem

   Guiding and helping the user to solve specific problems

   Querying, generating and providing the input/output data files for modules

4) Spatial Analysis Module Subsystem

   Processing, calculating, querying and generating the spatial relationship for geo-spatial data

The schematic relationships between each component are represented in Fig. 6.1. Each component is highly connected with others, centering on the database subsystem. Each subsystem was developed as an object using object-oriented programming techniques. The language, Visual Basic 5.0 for Window95, was used for the SDSS development. For the model base, various programming languages and software were used such as Fortran, Matlab, QuattroPro, Access. ArcView with Avenue was used as the development tool for spatial analysis module.

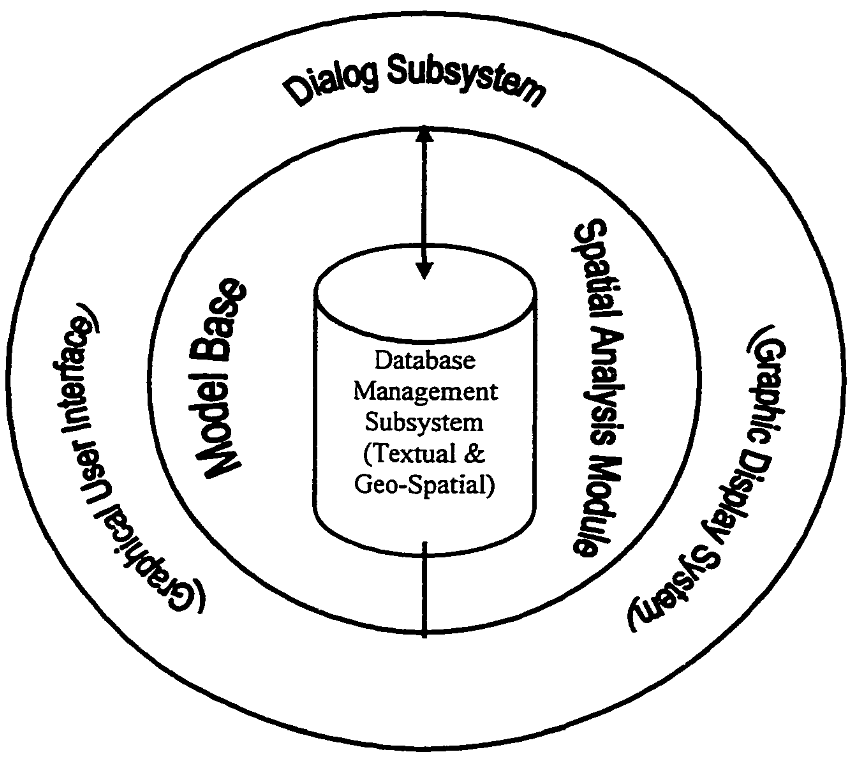


Fig. 6.1 The schematic relationships between the each component of a spatial decision support system.

6.2 Operational Strategy of a SDSS with Adaptive Control Process

It is practically impossible to perform the multireservoir operation with large time step or over many stages in a short time period due to the computational time and memory requirements. Most mathematical and simulation techniques use the adaptive control process to overcome these limitations. The adaptive control process is one of the discretization techniques, which divides a time period into a series of small regions to enable the computation using a short time step. In this study, the developed software is executed for 24-hour time-steps then the time horizon is shifted by one hours and process repeated. The process is shown in Fig. 6.2.

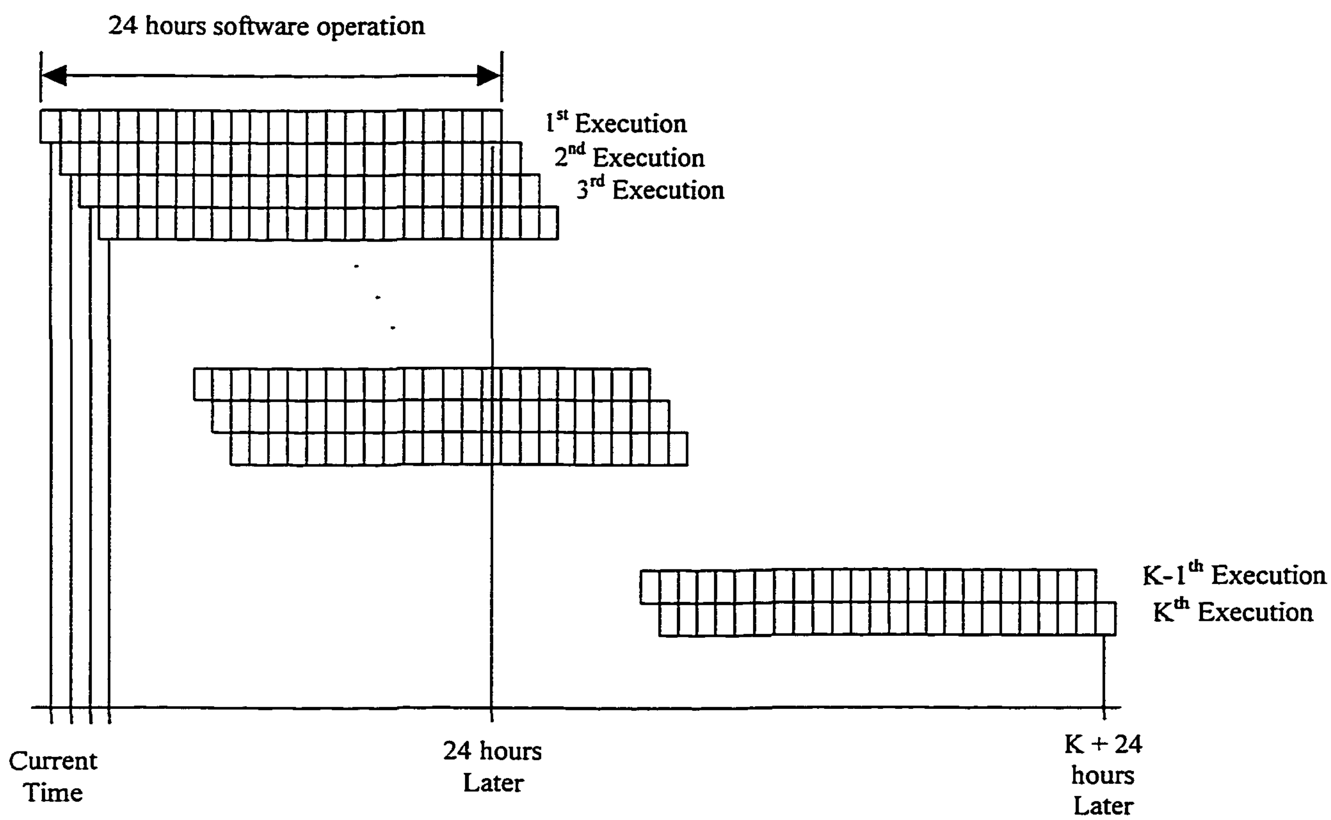


Fig. 6.2 The Adaptive Control Process for real-time operation of the SDSS.

6.3 Development of the Database Management System

6.3.1 The Overall Design

Database technology over the past 30 years can be classified into four generations. The earliest generation is the index sequential access method (ISAM) and virtual storage accessing method (VSAM), which are simple file systems. The next generation was the hierarchical database system, such as information management systems (IMS), System 2000. The third generation provided the environment where multiple users could access an integrated database. However, this environment didn't provide for independency of each data set and convenience to access the database system. Hence, the fourth generation, relational database management system (RDBMS) was introduced to overcome these disadvantages (Kim, 1994).

The real-time hydrologic data and attributes throughout the basin required for flood control are relatively large to implement in one database system. However, recently, there is enhanced and sophisticated database management software with built in tools of GUI, models and query systems. One of the more popular software for PC-based computer system is ACCESS for Windows95 from Microsoft Inc, which is a RDBMS. In this study, the rainfall data from 82 telemetry gages, water level data from 28 telemetry gages, and operational data of 7 reservoirs for 10 years (1987 – 1996) were collected, reformulated and then constructed as tables in a Han River Basin database system using ACCESS software. Original textural files from the Flood Control Office of the Han River Basin were extracted as raw data. The original formats of each data file for rainfall, water level of gages and operational data of reservoirs are represented in the Table. 6.1 – 3.

Table 6.1 Format of the original rainfall data for T/M gages

Field name	Date	ID of Gage	Value of T/M	Value of Modified	Rainfall	Accumulated Rainfall
Format	10	4	8	6	6	8
Example	1994091714	45	520	520	0	5

Table 6.2 Format of the original water level data for T/M gages

Field name	Date	ID of Gage	Value of T/M	Value of Modified	Water level
Format	10	4	7	5	7
Example	1990091717	18	00174	174	356

Table 6.3 Format of the operational data for reservoirs

Field name	Date	ID of Dam	Value of T/M	Value of Modified	Storage	Inf.	Rel.	No. of OG	Spill Rate
Format	10	4	7	7	7	7	7	5	5
Example	1987090415	6	09261	19261	2515	157	1050	3	1000

To reformulate these original data files into suitable tables for the hanbasin database system programs were developed using Fortran programming and the QuattroPro for Windows spreadsheet. The structure of the rainfall, stream flow, and operational databases are indexed by each year of 10 years of data, as illustrated in Fig. 6.3. The prefix of the table names represents the year of the database. The etymon of the table names represents the related reservoirs, rainfall and stream flow database as follows; FLD means rainfall, HH means stream flow, HWDM means HwaCheon Reservoir, SODM means SoYangGang Reservoir, CHDM means ChungJu Reservoir, and PADM means PalDang Reservoir.

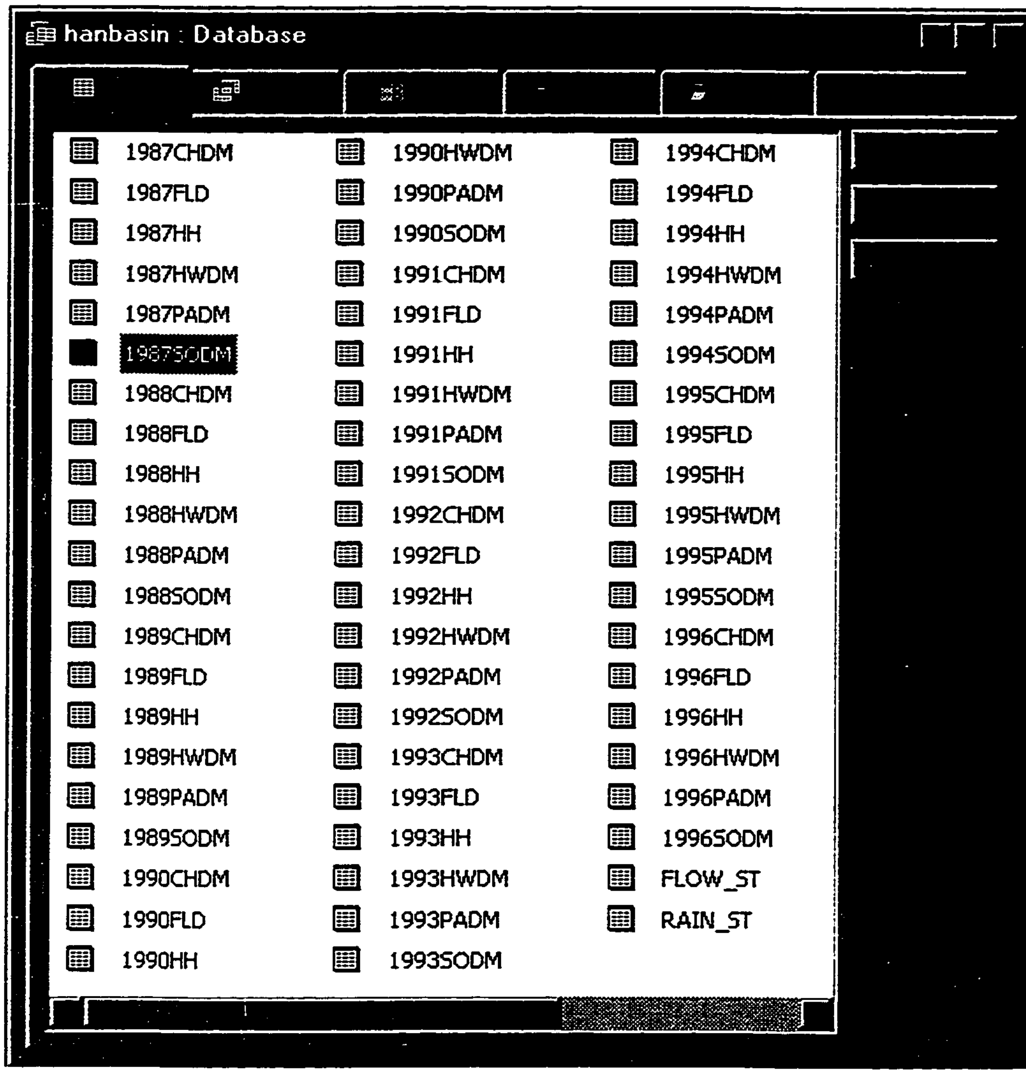


Fig. 6.3 The tables of the hanbasin database system.

For attributes of the location maps of rainfall and stream flow gages, RAIN_ST and FLOW_ST tables were produced from information in various reports about the Han River Basin. These tables will be used in spatial analysis module directly.

6.3.2 Design of each table

The original data files for rainfall, stream flow and operational data files were indexed by two fields, date and gage number (ID) in a single file for all 10 years. Therefore, seeking time for searching the 1-hour record of each gage or reservoir requires significant time. In the newly constructed database, the seeking time for searching the related record is reduced by segmenting the data files into individual tables as described in section 6.2.1 and indexing a single field (i.e. date) for each table.

Each table has a simple and meaningful structure as compared with the original data files. For the rainfall tables (xxxxFLD), the index field is DATE filed with ST1 to ST82 fields for gages, as illustrated in Fig. 6.4.

Index Field

Date	ST1	ST2	ST3	...	ST81	ST82
Time	record	record	Record	record	Record	record

Fig. 6.4 The design of rainfall database tables.

Therefore, one can seek the rainfall records of all 82 gages or the rainfall record of just one gage depending on the user's query structure.

Keeping the same logic, the tables (xxxxHH) for stream flow were constructed as shown in Fig. 6.5.

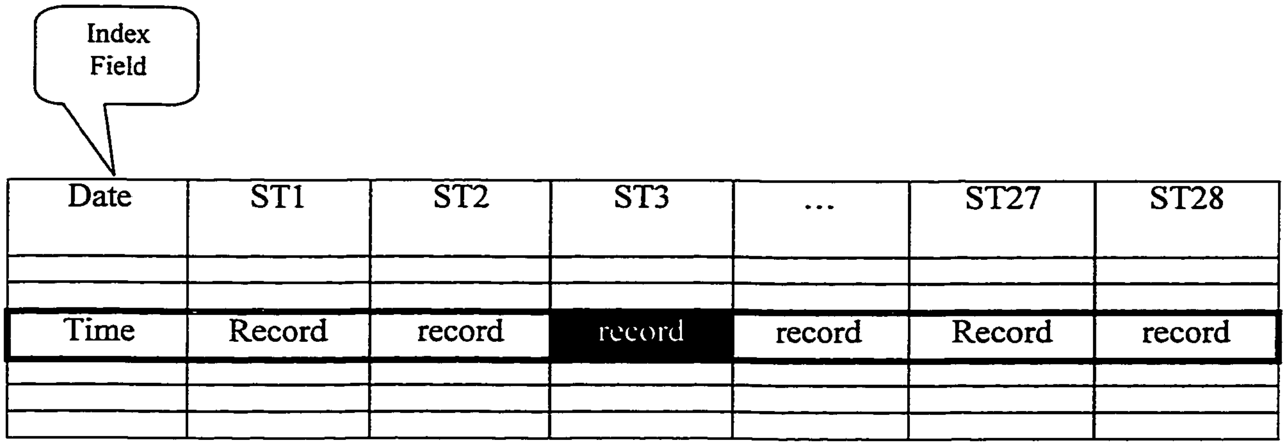


Fig. 6.5 The design of stream flow database tables.

However, the operational database tables for reservoirs have different fields compared with the two database tables described above. Since each reservoir has more fields, as shown in Fig. 6.6, than the T/M gages, more segmenting works were involved.

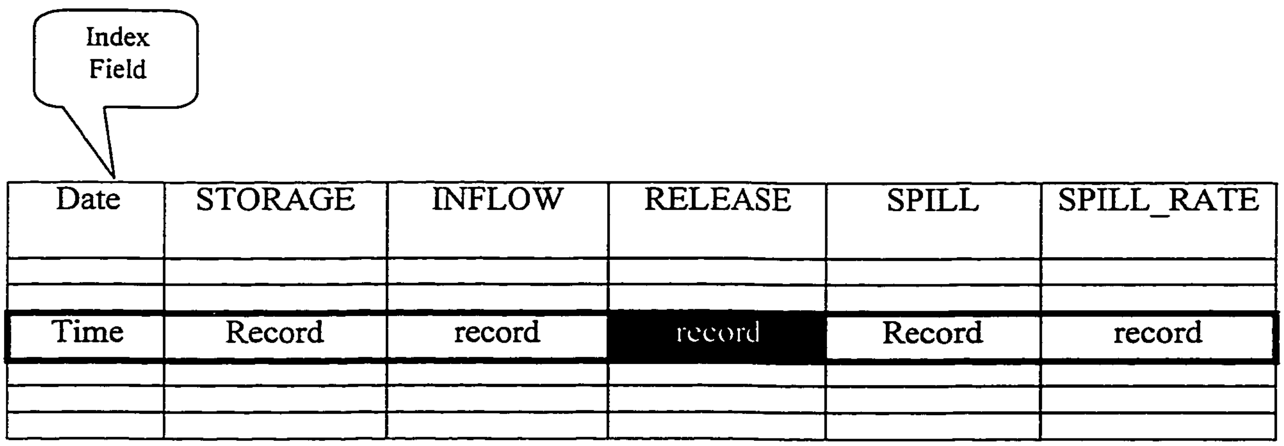


Fig. 6.6 The design of operational database tables for reservoirs.

The database tables of attributes for location maps use station_ID as the index field and other fields for various information. The structure of database table for the location maps is given in the Fig. 6.7.

Index Field

ID	HAN_ID	ST_NAME	BST_NAME	LAT(DMS)	LOG(DMS)
ID	Record	record	record	Record	record

Fig. 6.7 The design of database tables for Attributes of gages.

In the Fig. 6.7, each field name has the following meanings: HAN_ID field is the record set, which is related to the field name in Fig. 6.5 and Fig. 6.6; ST_NAME is the gage name; BST_NAME is the Broadcasting Station name for each gage for the purpose of the flood warning system; LAT (DMS) is the latitude of each gage and LOG (DMS) is longitude of each gage. If more information is needed then it can be easily imported in to the database file. In addition, the spatial analysis module has also a lot of attribute tables with related themes. Spatial analysis tools in the spatial analysis module will generate the dynamic database tables for estimates of average rainfall and isohyets, which is shown in the Table 6.4. Finally, after forecasting the reservoir inflows and local inflows to the basin, the dynamic database tables will be updated as the results database table, shown in

Table 6.5. Using this database table, the data files for the multireservoir operation model will be extracted.

Table 6.4 The dynamic database table for results of the spatial analysis.

Fields	DATE	SB_1	SB_2	...	SB_30	NOTICE	ISOHYET
Format	Value (Int)	Value (Real)	Value (Real)	...	Value (Real)	Text String (500 Letter)	Image Name (File Path)
Example	9582123	2.5	3.0	...	10.0	Beginning Rainfall event	D:\Hanprojt\Products\t082123.bmp

Table 6.5 The dynamic database table for results of the flood forecasting model

Fields	DATE	HWI	SOI	CHI	CCLI	UALI	CPLI	YJLI	PDLI	IDGLI
Format	Value (Int)	Value (CMS)	Value (CMS)	Value (CMS)	Value (CMS)	Value (CMS)	Value (CMS)	Value (CMS)	Value (CMS)	Value (CMS)

Table 6.6 The database table for results of the multireservoir operation model

Fields	DATE	HWSTO	HWREL	SOSTO	SOREL	CHSTO	CHREL
Format	Value (Int)	Value (MCM)	Value (CMS)	Value (MCM)	Value (CMS)	Value (MCM)	Value (CMS)

6.4 Development of the Graphical User Interface/Graphical Display System

6.4.1 The Overall Design

There are several philosophies for designing effective graphical user interfaces as discussed in the literature. One of the cornerstones of good user interface design is consistency. The definition of consistency is the ability of the user to predict what the software is going to do in a given situation, based on past experience with the product. The programmer should provide clear and obvious paths for the user to accomplish desired tasks.

Considering these concepts, the graphical user interfaces were designed for the flood forecasting and multireservoir operation modules and hydrologic data monitoring system as well as the customized spatial analysis module. The overall design of the graphical user interface and graphic display system is shown in Fig. 6.8. To customize the spatial analysis module the object-oriented language built in to ArcView, Avenue was used. For other modules, Visual Basic 5.0 software was used to develop the user interfaces. Then all of the GUIs for modules were integrated in a Windows95 environment, illustrated in Fig. 6.9.

The GUI was consists of Menus and Toolbar Controls as shown in Fig. 6.9. The user can invoke the each module by clicking either the related menu or the button on the toolbar. This will invoke the GUI for each module.

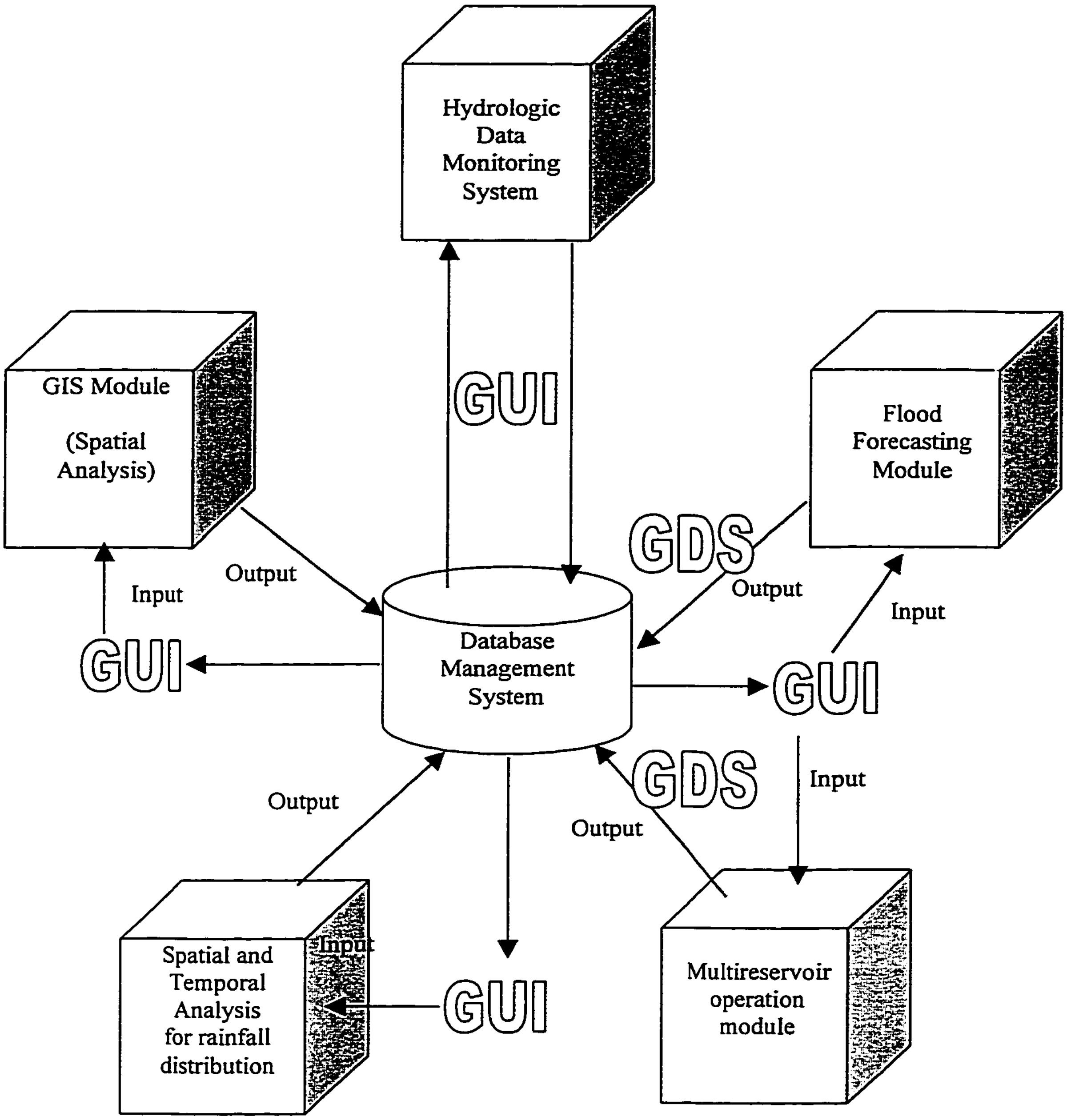


Fig. 6.8 The overall design of the GUI/GDS for subsystems

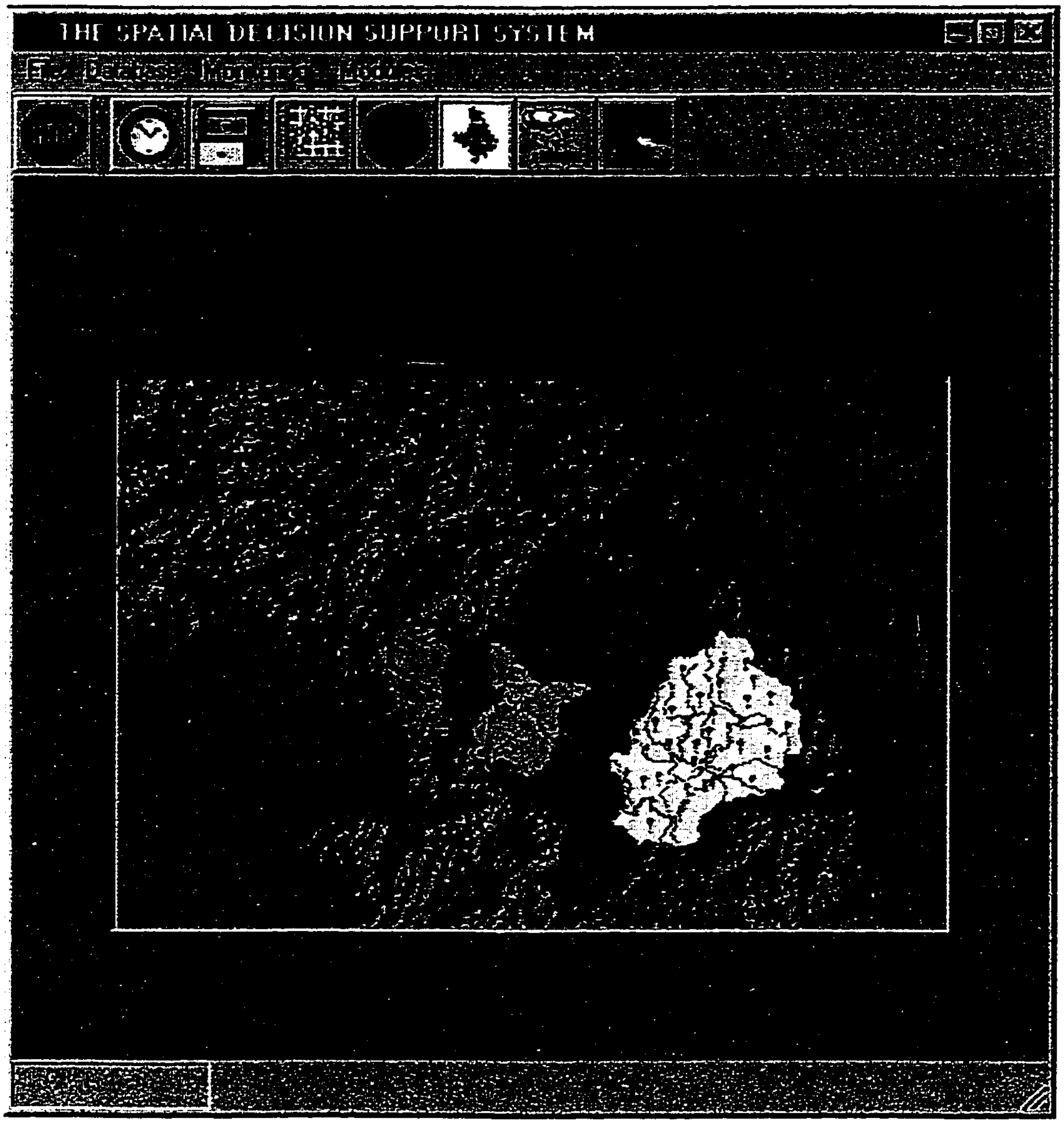


Fig. 6.9 The GUI for a Spatial Decision Support System

for Flood Control in the Han River Basin

6.4.2 The GUI/GDS for Hydrologic Data Monitoring System

For providing the hydrologic information of the preceding 24 hours to the decision-maker, a Hydrologic Data Monitoring System was developed. The main GUI of the system consists of the Picture Control for showing entire Han River Basin, the List Box Controls of rainfall and water level gages, Text Box Controls for longitude and latitude and the Text Frame Control for map extension (Fig. 6.10).

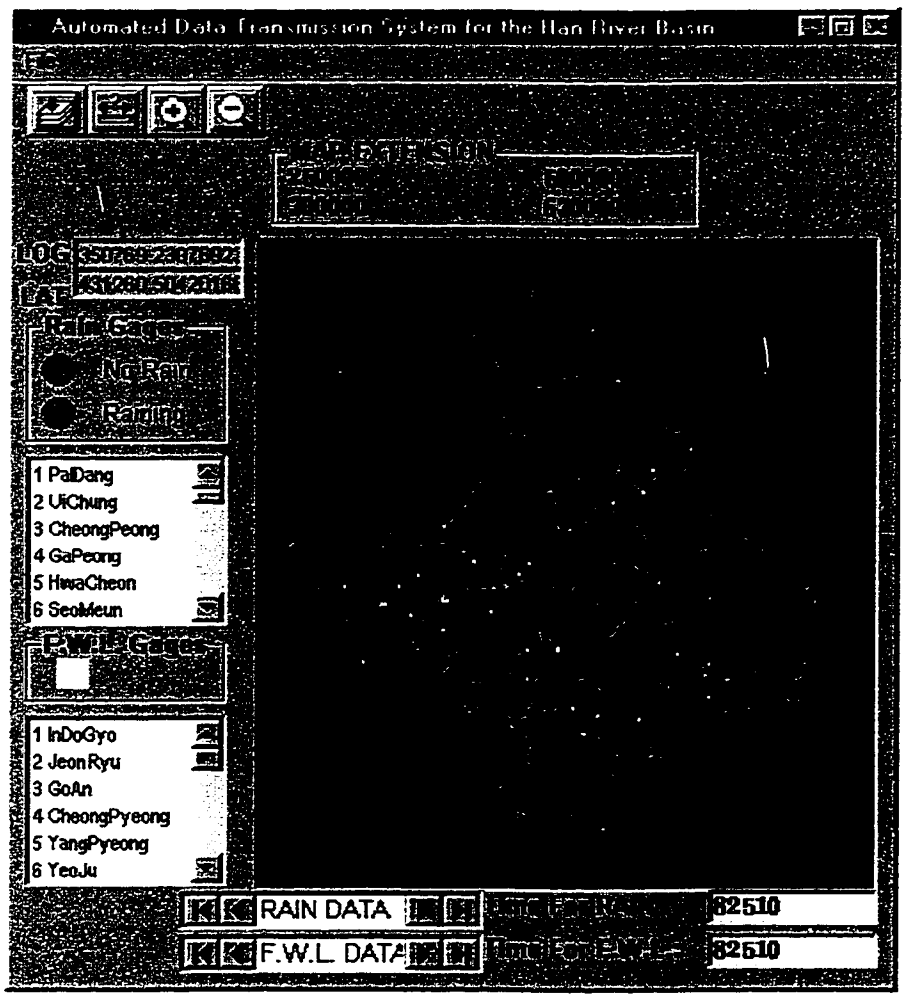


Fig. 6.10 The Main GUI for Hydrologic Data Monitoring System.

The major function for the Hydrologic Data Monitoring System is to query the information from the developed database system described in Section 6.3. To query the information, first, the user has to click a circle or rectangular shape on the Picture Control. This causes highlighting of the related name of gages in the List Box Control. Then the GUI displays the hyetograph or hydrograph by double clicking the highlighted name of gages.

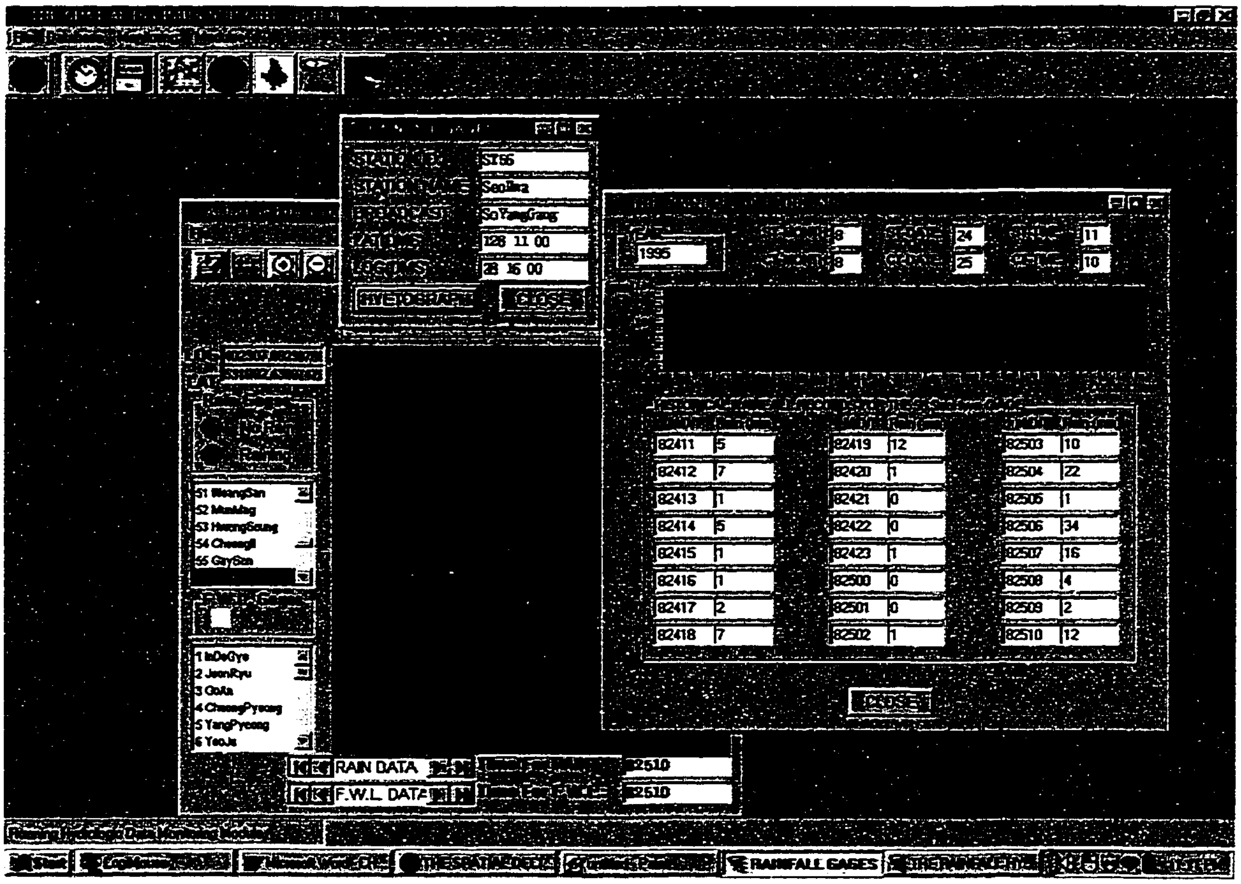


Fig. 6.11 The GDS for Rainfall Gages and its Hyetograph

The Fig. 6.11 shows the information for a rainfall gage, its related hyetograph and distribution of rainfall intensity for the preceding 24 hours. Fig. 6.12 displays the information for a water level gage and its related hydrograph. Using the Hydrologic Data Monitoring System, the user can immediately grasp the hydrologic conditions throughout the basin. In addition, the user can extract a table for current rainfall data for 82 gages, which can be used in the spatial analysis module to create isohyets.

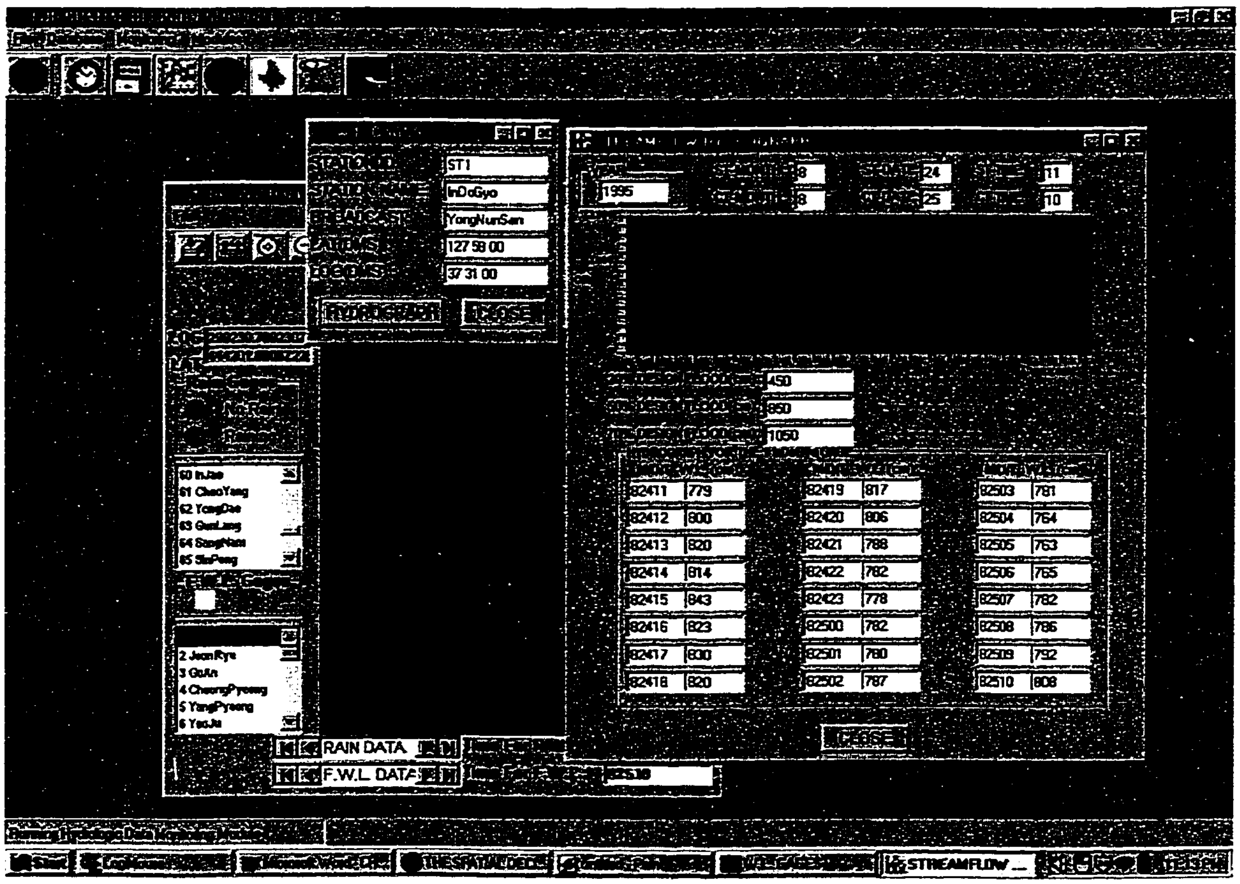


Fig. 6.12 The GDS for Water Level Gages and their Hydrograph.

6.4.3 Development of GUI for the spatial analysis module

For ease in performing the spatial analysis that was described in CH. 3, a GUI for the spatial analysis module was developed using Avenue in ArcView. First, the user has to define a base map and analysis property, such as map extension and resolution of the created isohyets. Then, the module generates an isohyet image (GRID data format in ArcView) and a table for areal estimates of rainfall by using current rainfall data from 82 gages. Finally, the results of isohyet and table could be restored in the Dynamic Database Table. The design of GUI for the spatial analysis module is shown in Fig. 6.13.

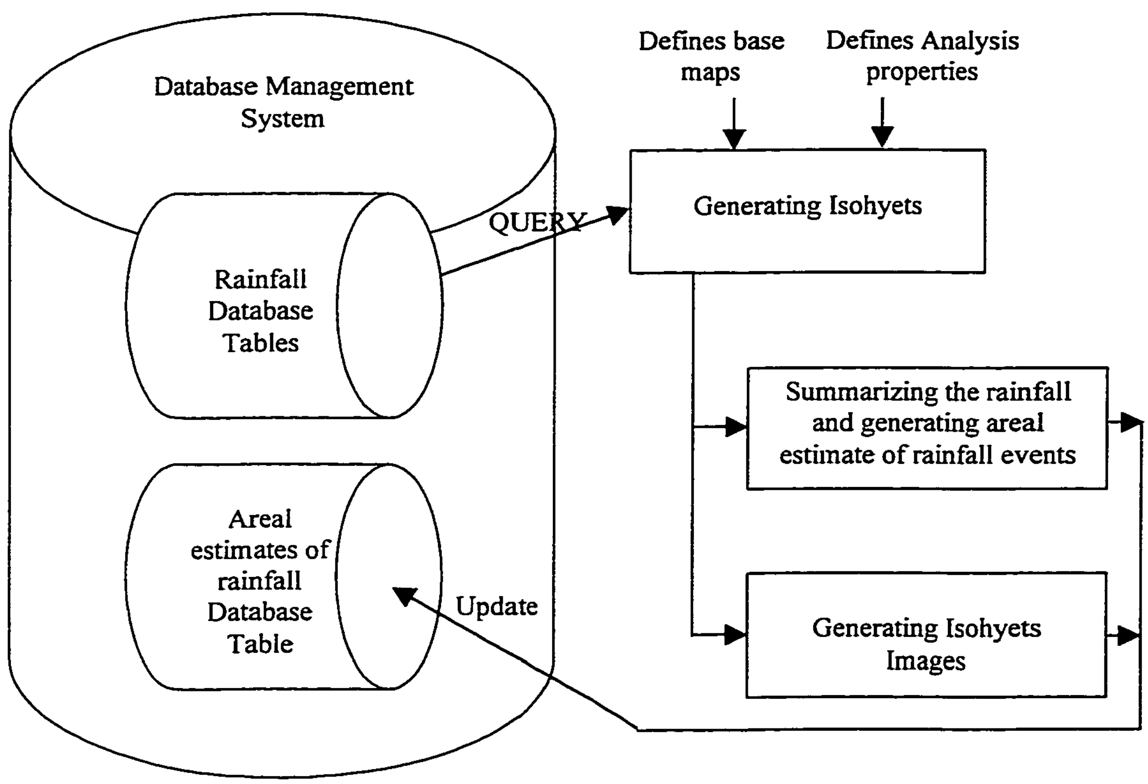


Fig. 6.13 The design of GUI for the spatial analysis module.

6.4.4 Development of the Spatial and Temporal Analysis for Rainfall Tool

The spatial and temporal rainfall distribution throughout the basin is important to understand the rainfall characteristics and its effects. In this study, rainfall data were analyzed with topographic coverage of the Han River Basin as described in Chapter 3. The spatial and temporal analysis for the rainfall tool gives to the user or decision-maker considerable information about the results of the analysis. The overall design of the tool is shown in Fig. 6.14.

In Fig. 6.14, the isohyet view screen located in the left top of the tool displays the isohyets for every time period to display rainfall conditions throughout the basin. The legend is located in the left of the isohyet view screen. There are ten frames to display numeric values of mean rainfall for each subbasin related with the catchment area of the forecasting point in the rainfall-runoff module. There are two kinds of text boxes with numeric values for each frame. The gray background textbox and the colored background textbox display the current and 24 hours accumulated rainfall of the subbasin, respectively. The background color of the textbox for accumulated rainfall changes depending on its magnitude. For example, green refers to less than 80 mm, yellow refers to greater than 80 mm and less than 150 mm, and red refers to greater than 150 mm. The user can immediately recognize the rainfall conditions using this coloring of the textbox.

This schema might be used for a flood early warning system. Using the data control, which is located in middle on the left of the tool, the user can explore the isohyets as well as view numeric values up to the current time period.

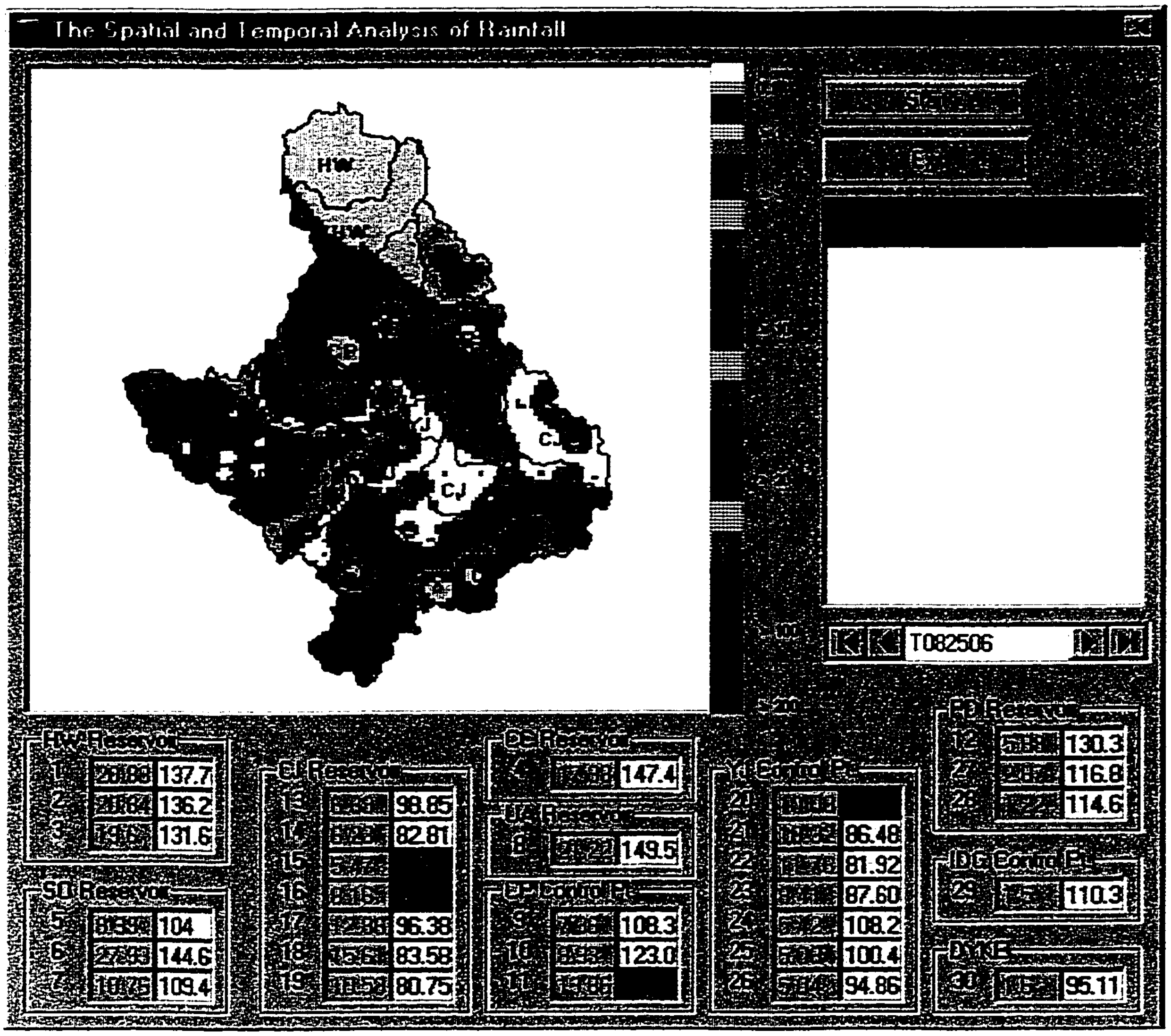


Fig. 6.14 The overall design of the spatial and temporal analysis of rainfall tool.

In addition, the meteorologist could provide notice or advice to the decision maker in order that they can be more reliable and effective in decision-making for flood control. For this purpose, the large textbox was provided, which is located in middle on the left of the tool. Finally, two command buttons were provided. The start command button is for the animation or temporal analysis of the rainfall distribution. If the user push this button, the isohyets from beginning of rainfall events up to the current time will be automatically displayed both with images and numeric values. In addition, after pushing this button, the button's caption will change to "stop" to be used stop the temporal analysis rainfall events. The "Exit" command control button is to return to the main graphical user interface.

6.4.5 The Development of a GUI/GDS for the Flood Forecasting Module

The GUI for the flood forecasting module consists of a GUI for training the ANN models, which was described in CH. 4, and a GUI for flood forecasting purposes. The overall design of GUI/GDS for flood forecasting is shown in Fig. 6.15. The GUI helps the user to easily create input data files for the models, both for the training and forecasting submodules, by automatically extracting the data from the database.

The main GUI for the flood forecasting module is shown in Fig. 6.16. The main GUI consists of five command controls. The caption for each command control is meaningful enough to be easily understood. For example, if the user click the TRAIN command control, the GUI will show the subordinate GUI, for training the flood forecasting models, as shown in Fig. 6.17.

Using the input boxes in the GUI for training the flood forecasting models, the user can input the parameters required for training. After filling in the parameters, the user can execute the training program by clicking the BEGIN TRAINING command button. At that time the GUI extracts automatically the necessary input file for training then executes the program.

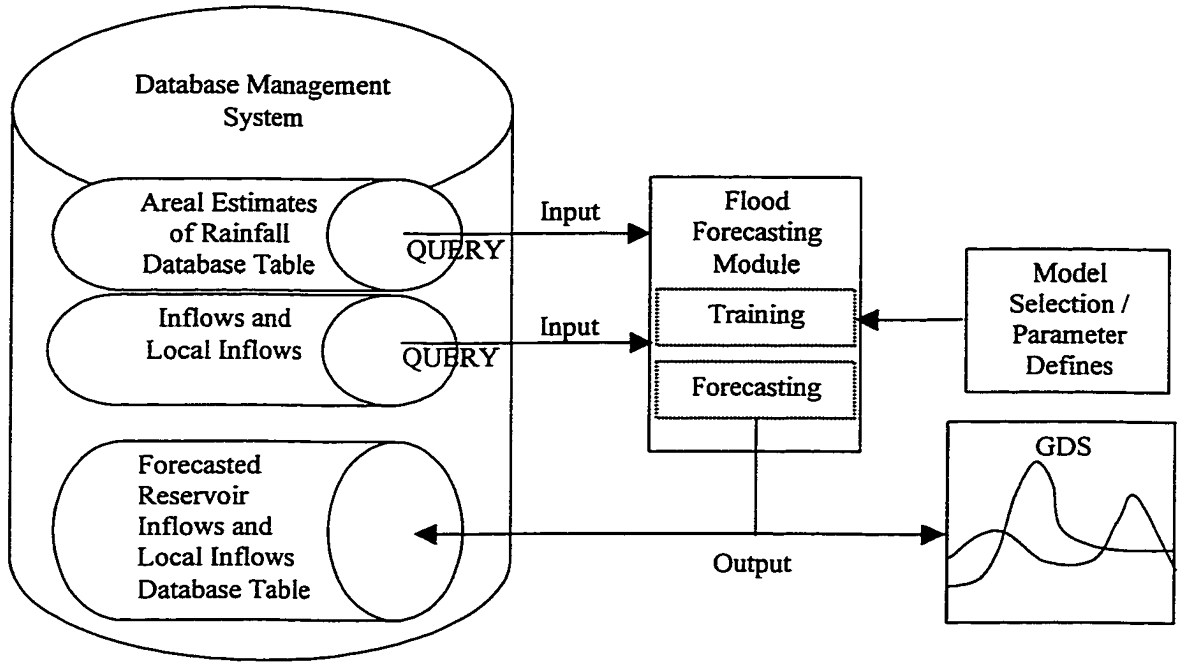


Fig. 6.15 The design of GUI/GDS for the flood forecasting module.

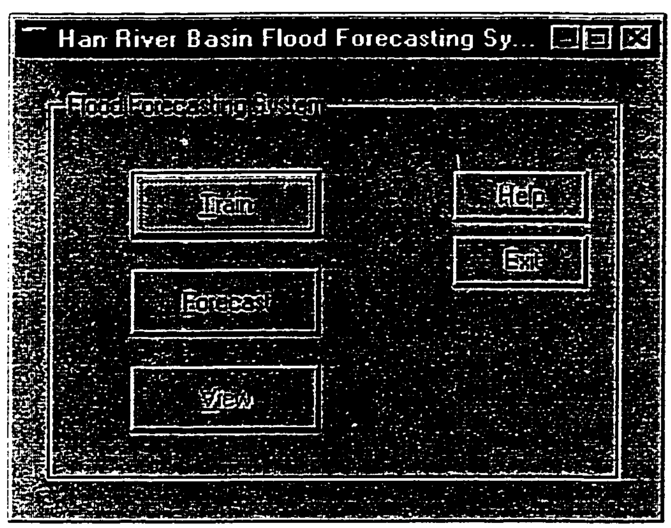


Fig. 6.16 The Main GUI for Flood Forecasting Module

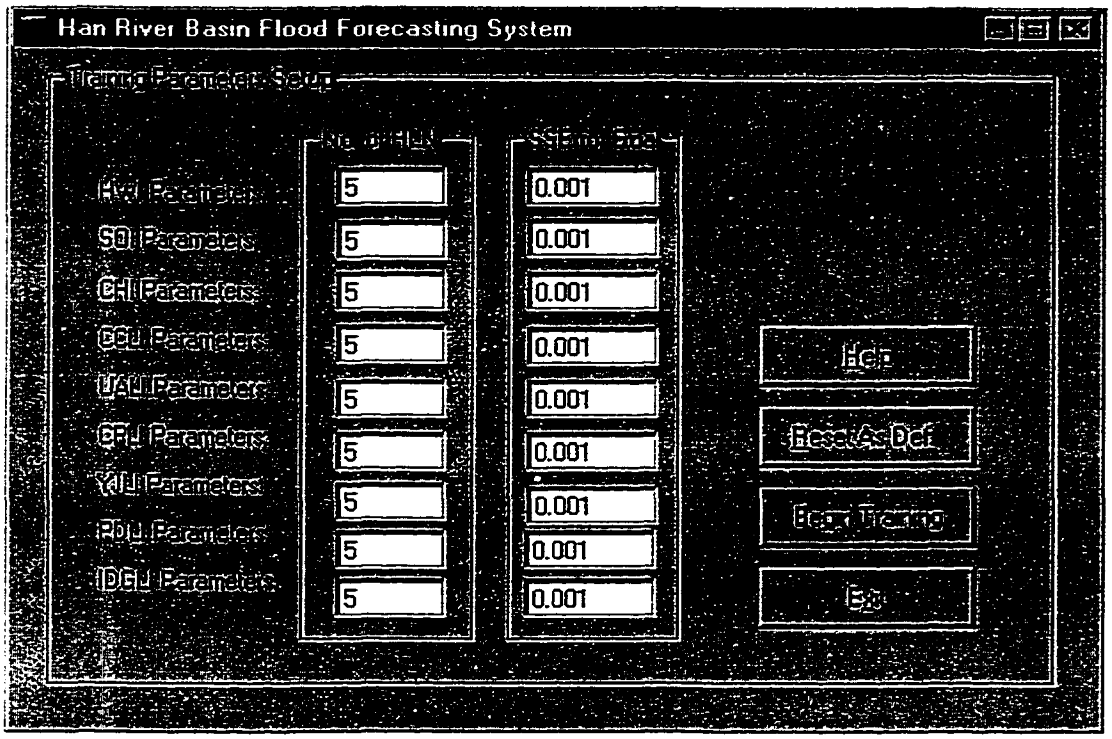


Fig. 6.17 The GUI for Training the Flood Forecasting Models

After training all models to the user's satisfaction, the user can forecast the inflows and local inflows by clicking the FORECAST command button shown in Fig. 6.16. At this moment, the GUI also automatically extracts necessary data files from the database. After executing the flood forecasting models, the user can review the results by using the Graphic Display System (GDS), shown in Fig. 6.18.

The GDS displays valuable information. First, it displays the 24 hour previous average rainfall data throughout the related catchment area on the upper portion of screen. Second, the GDS displays the comparison between the observed preceding the 24 hours and the forecasted flows on the left side of the screen. Finally, the GDS displays 24 hours forecasts for inflows or local inflows. Combining this information and user's own judgement, he should evaluate the volume and peak flow for the next 24 hour period.

There is a Frame Control captioned with Han River System on the lower portion of the screen shown in Fig. 18. It consists of nine Command Controls with captions. The user can explore the result of a model by clicking a Command Control Button.

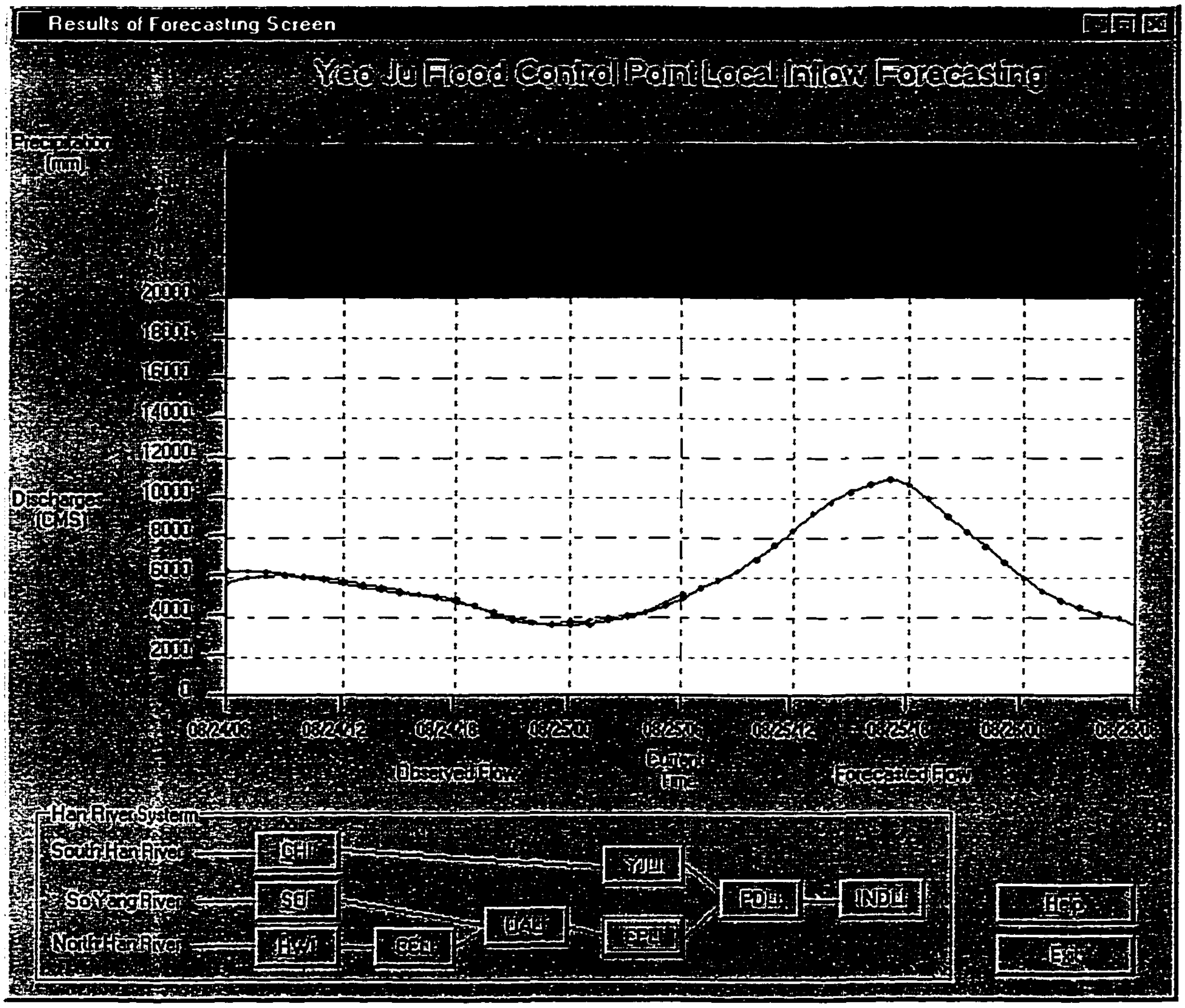


Fig. 6.18 The GDS for the Flood Forecasting Module

6.4.6 The Development of a GUI/GDS for the Multireservoir Operation Module

The GUI/GDS for the multireservoir operation module consists of four different parts: 1) creating input data files, 2) executing the HRBSDP, 3) executing the ROUT program and comparing the sum of squared errors between the previous and current routing coefficients and 4) GDS for the results of the operation module. The overall design of GUI/GDS for the multireservoir operation module is shown in Fig. 6.19.

The main GUI for the multireservoir operation module consists of six captioned Command Controls shown in Fig. 6.20. The user can go to the subordinate GUI by clicking a Command Control. For instant, if the user clicks the CREAT INPUT FILE Command Control, it will display the subordinate GUI for the input data file creation mode, shown in Fig. 6.21.

The subordinate GUI for the input data file creation mode is designed to generating input parameters for the HRBS.ADD file. This file is required by the HRBSDP to run using four different input modes (Fig. 6.22-25). Each input mode is initialized with default values develop by the author. The user can modified these values manually by using the TEXT INPUT BOXES. Each input mode has a RESET Command Control to bring up the default values and an OK Command Control to store the specified values into memory. After all the input parameters are defined, the user can extract input data files by clicking the EXIT Command Control shown in Fig. 6.21.

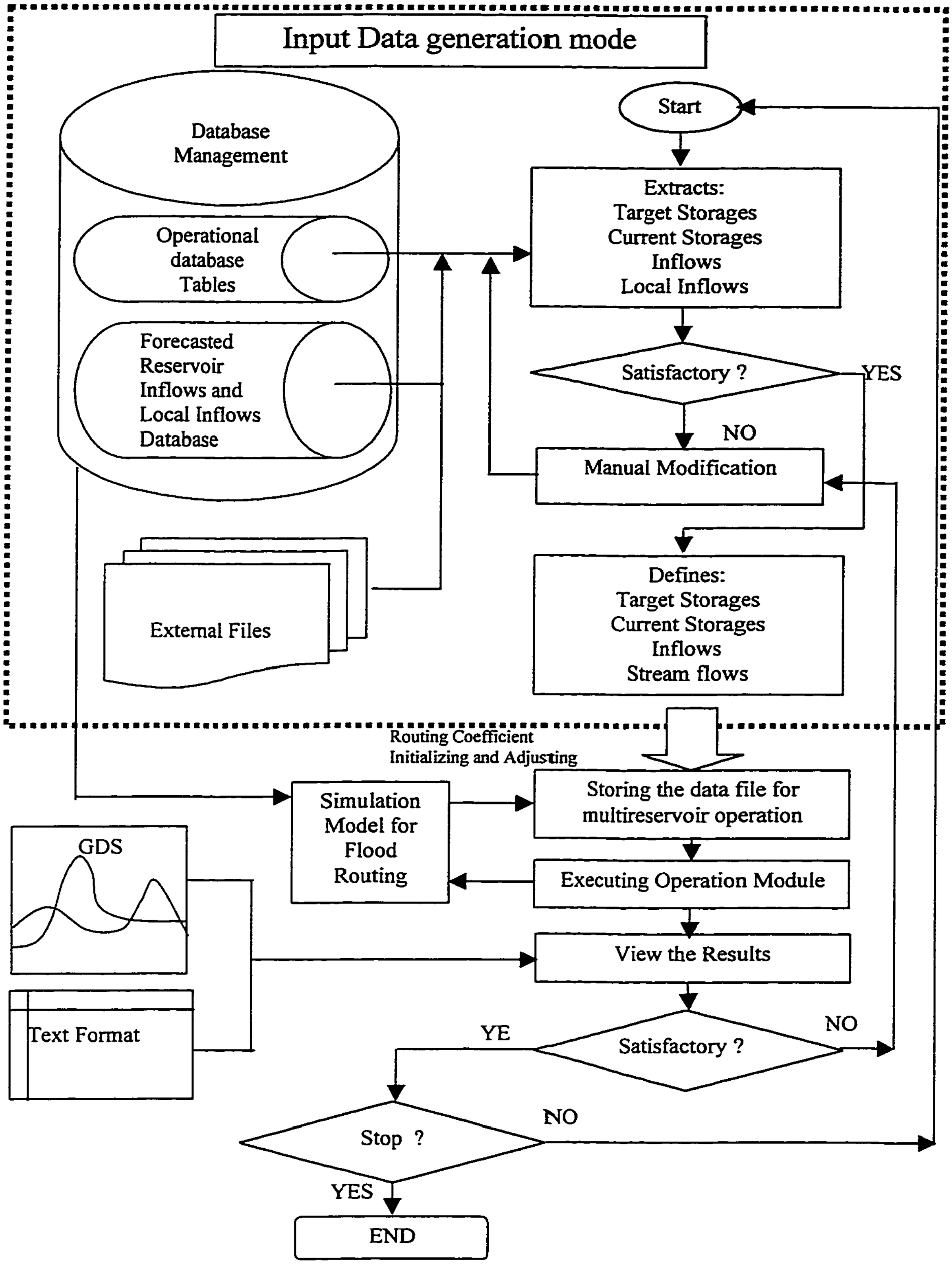


Fig. 6.19 The design of the GUI/GDS for the multireservoir operation module.

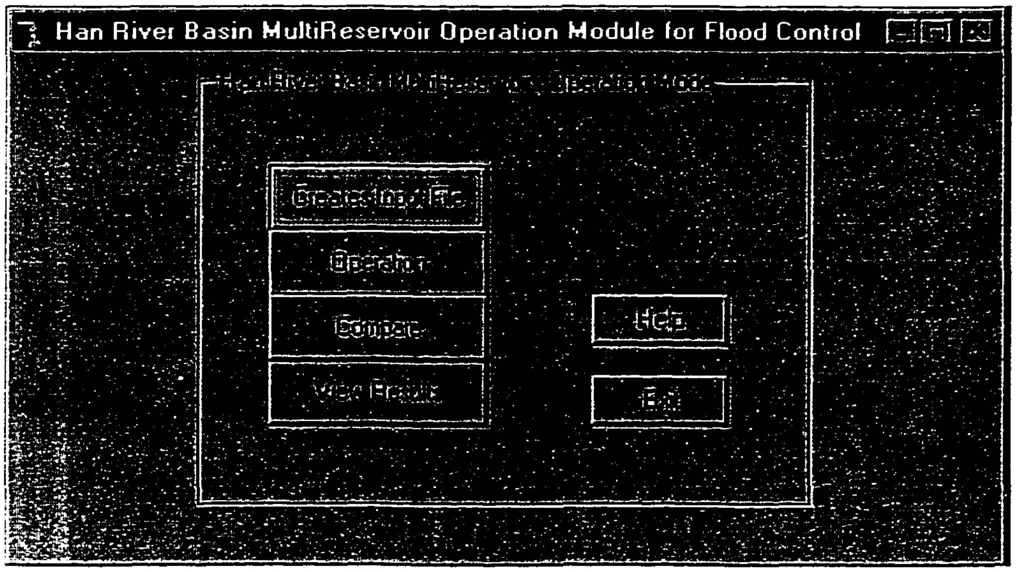


Fig. 6.20 The Main GUI for the Mutireservoir Operation Module

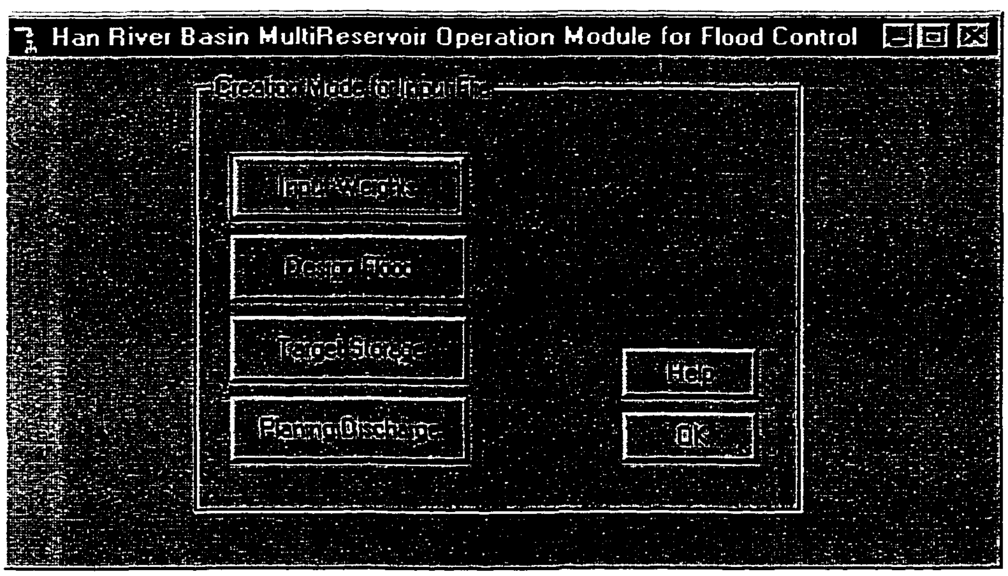


Fig. 6.21 The GUI for the Input Data File Creation Mode

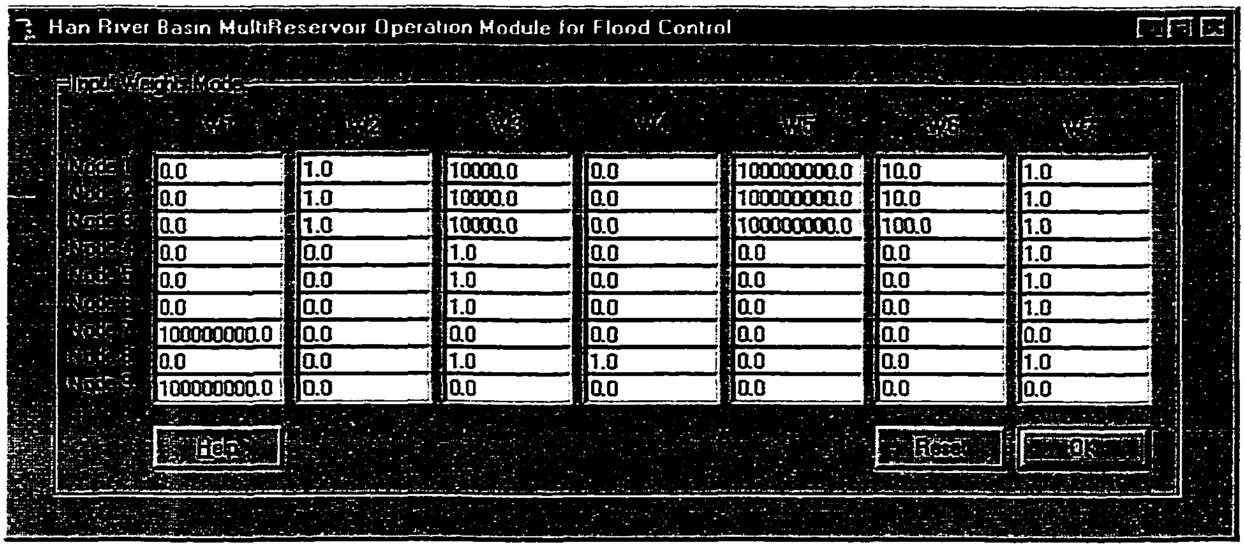


Fig. 6.22 The Weighting Factor Input Mode

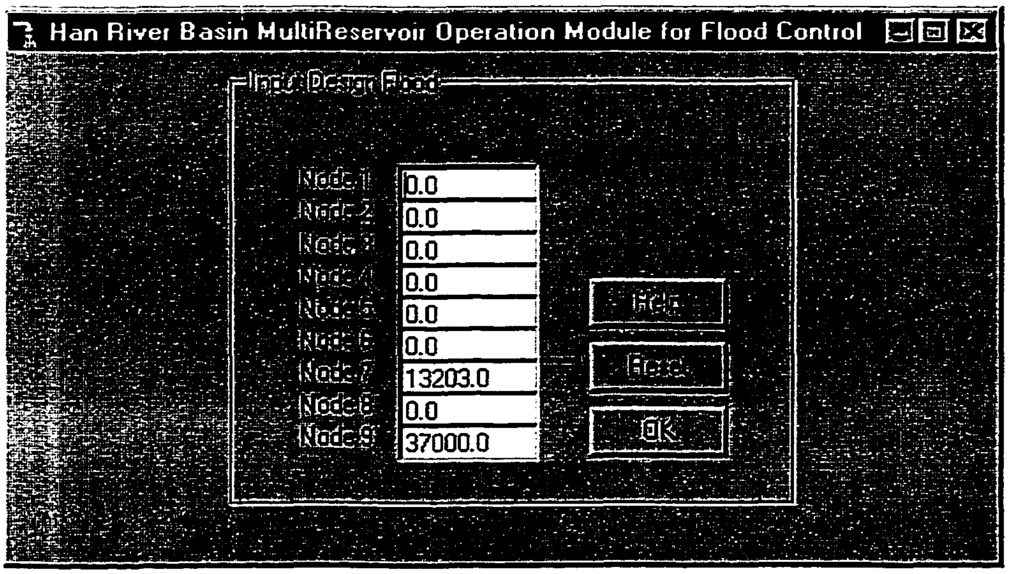


Fig. 6.23 The Design Flood Input Mode

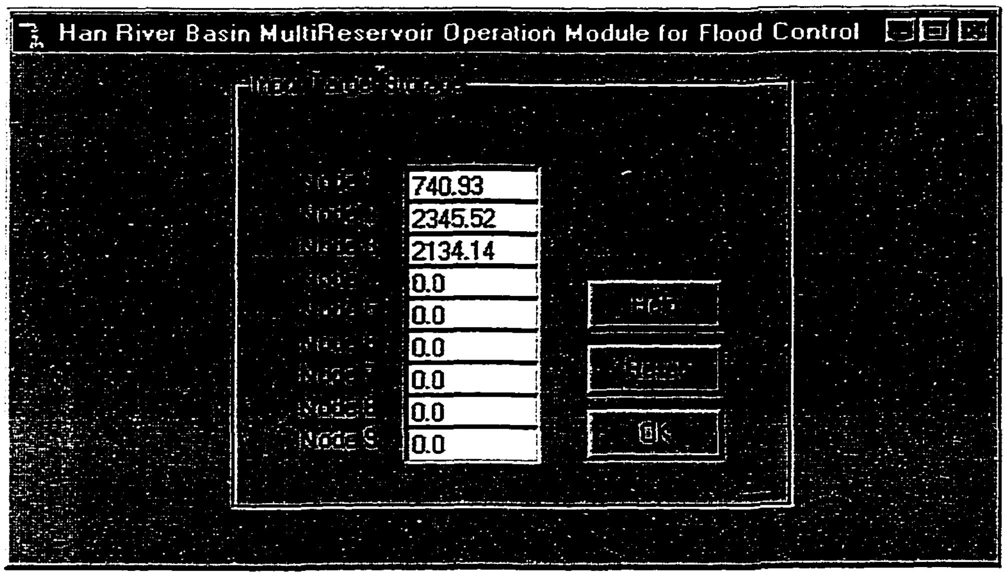


Fig. 6.24 The Target Storage Input Mode

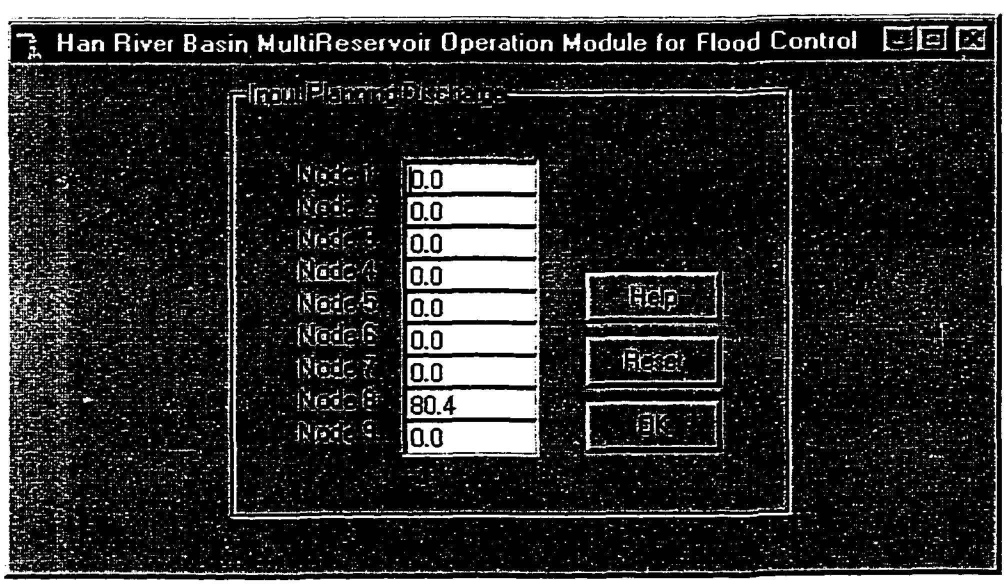


Fig. 6.25 The Planned Discharge Input Mode

Now, the user can execute the HRBSDP program by clicking the Operation Command Control shown in Fig. 6.21. Figure 6.26 shows an example display of the HRBSDP running. After executing the HRBSDP, the user must click the Compare Command Control to execute the ROUT program and calculate the sum of squared errors of the routing coefficients.

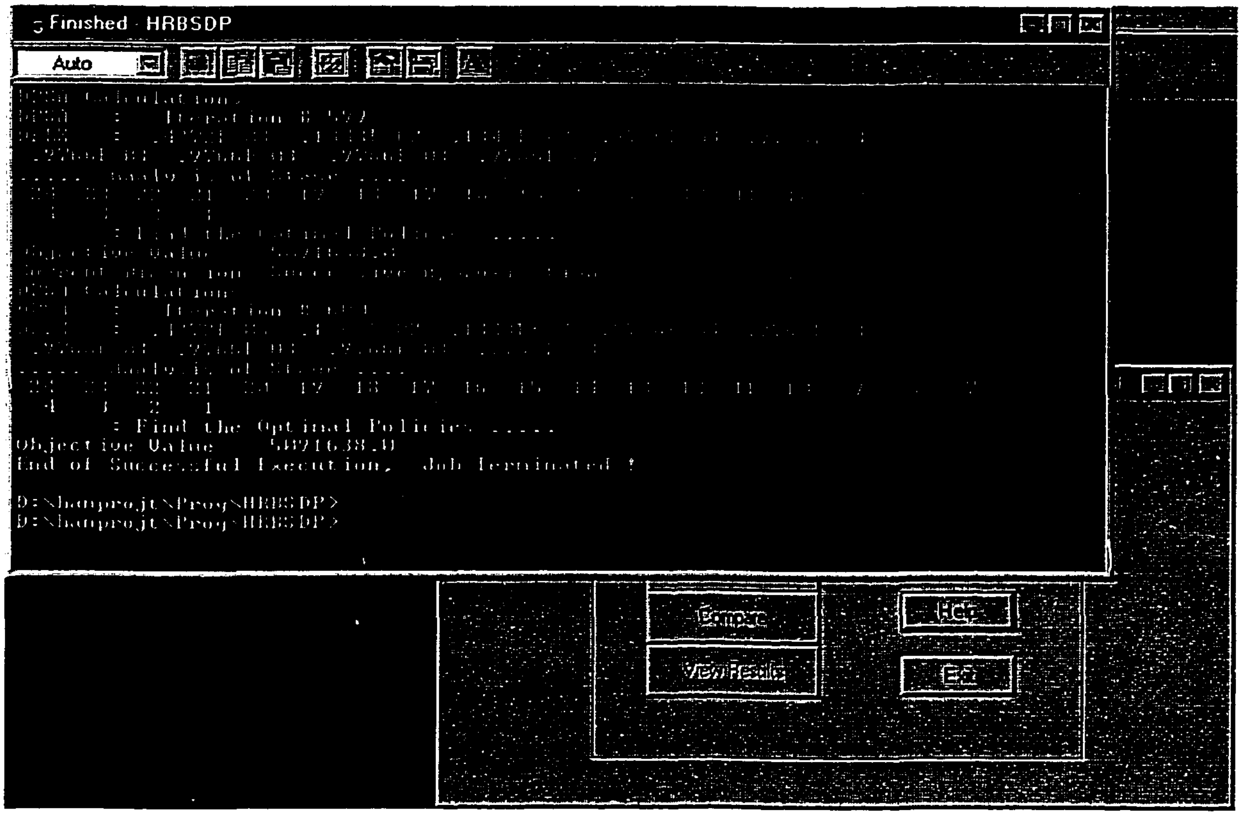


Fig. 6.26 The HRBSDP program execution

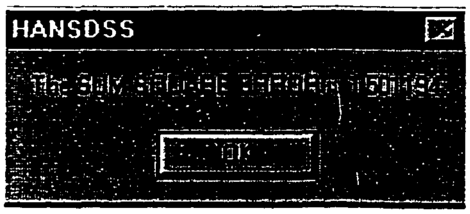


Fig. 6.27 The Message Box for Comparison of Routing Coefficients

The result of clicking the Compare Command Control popup message box with the sum of squared errors between the previous and current routing coefficients, shown in Fig. 6.27. A Graphic Display System was developed for displaying the results of the HRBSDP, shown in Fig. 6.28. The previous 24 hour observed operational data and the 24 hours forecasted operational data are plotted on the left and right side of the screen, respectively as shown in Fig. 6.28. In addition, the user can also see the result files by clicking the Values Command Control on bottom right of the screen as shown in the Fig. 6.28.

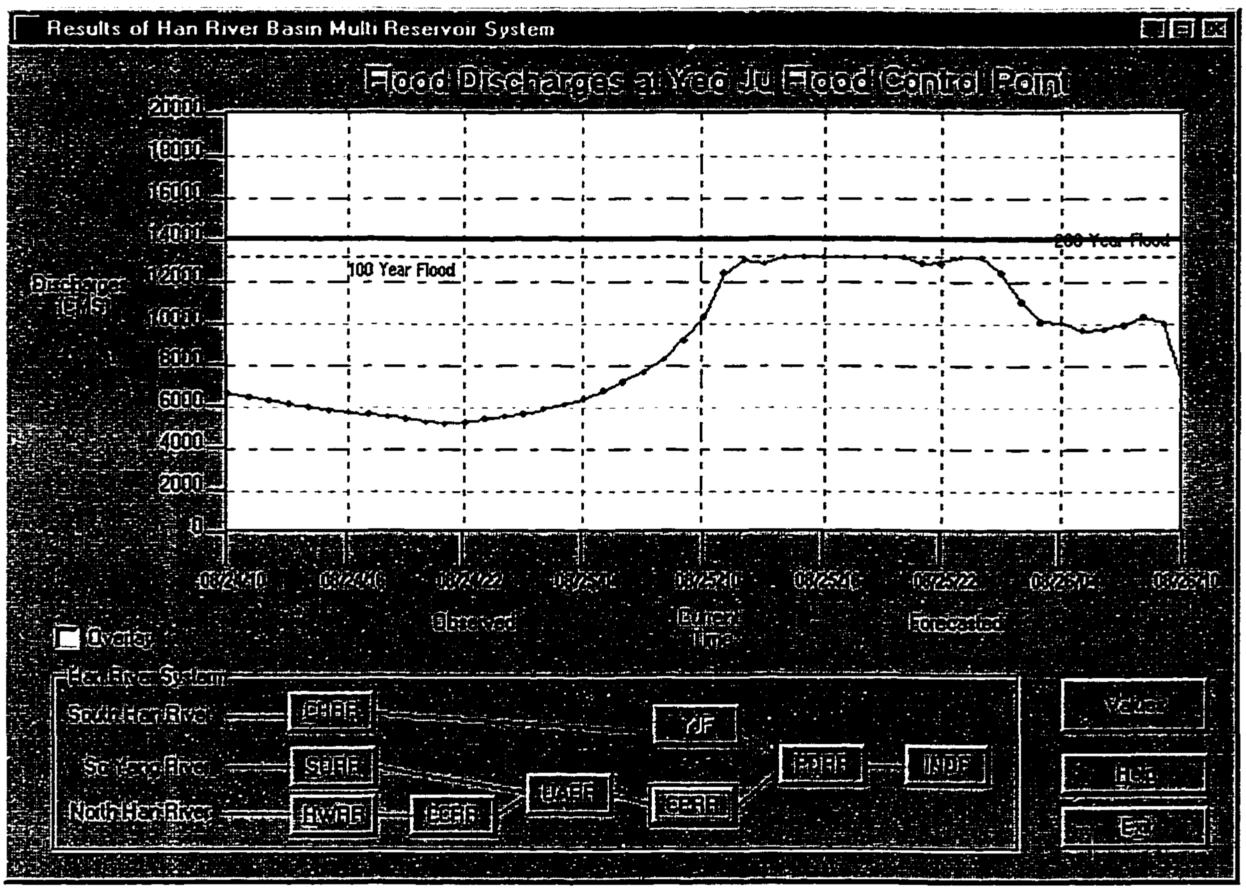


Fig. 6.28 The GDS for Multireservoir Operation Module

The result file shows the customized output file for the HRBSDP, which was described in Section 5.3.5.

HRBMRS RESULTS

MENU

So Yang Gang Reservoir Operation Results

No. of Operation Time: 5

STAGE	ST-STO(MCM)	ED-STO(MCM)	INFLOW(CMS)	RELEASE(CMS)
1	2508.680	2520.600	4481.042	1170.440
2	2520.600	2529.470	4505.532	2039.890
3	2529.470	2539.060	4722.654	2060.060
4	2539.060	2549.290	4901.435	2058.830
5	2549.290	2559.520	4901.000	2060.060
6	2559.520	2569.180	4735.088	2050.890
7	2569.180	2578.210	4569.750	2060.670
8	2578.210	2585.970	4229.472	2074.110
9	2585.970	2593.390	4127.769	2066.170
10	2593.390	2600.450	4037.170	2075.330
11	2600.450	2607.090	3903.910	2060.670
12	2607.090	2613.160	3758.121	2071.060
13	2613.160	2618.810	3639.977	2069.830
14	2618.810	2623.670	3439.442	2089.390
15	2623.670	2628.030	3299.512	2089.390
16	2628.030	2632.240	3255.613	2083.890
17	2632.240	2635.880	3098.842	2088.780
18	2635.880	2638.180	2720.975	2082.670
19	2638.180	2640.010	2589.038	2078.390
20	2640.010	2642.570	2799.530	2088.780
21	2642.570	2644.860	2724.207	2089.390
22	2644.860	2647.110	2710.089	2083.280
23	2647.110	2647.870	2306.860	2096.720
24	2647.870	2640.550	61.671	2094.280

Fig. 6.29 The Result File for the Multireservoir Operation Module

CHAPTER VII

CASE STUDY

:1995 FLOOD EVENTS IN THE HAN RIVER BASIN

7.1 Introduction

This chapter describes a validation of the developed general methodology for integrated river basin flood control to the Han River Basin in Korea. The purpose of the case study is to demonstrate how the developed Spatial Decision Support System might be applied to a specific river basin for integrated river basin flood control.

7.1.1 Proposed Case Study Method

Using the 1995 flood events that occurred in the Han River Basin, first, isohyets and areal estimates of the rainfall for the each subbasin will be generated by the spatial analysis module. Then the flood forecasting module will be used to forecast reservoir inflows and local inflows at appropriate points in the basin. The current time for flood forecasting was set to Aug. 25 10:00 A.m., 1995. Thus, the time period of Aug. 22 5:00 A.m. – 25 10:00 A.m. was used for training the flood forecasting models that were described in Section 4.2.2.3. After training the models, the calibrations are presented in this chapter. For the forecasting, the 24 hours forecast time was selected. The results of the flood forecasting module will be compared with actual telemetry data from the flood control office for the Han River Basin. Based on the results of flood forecasting module, the developed multireservoir operation module will be executed. The results of the multireservoir operation module will be compared with actual operational data from KOWACO and the flood control office.

This simulation will focus on the following points:

1) The validation and verification of the developed SDSS
2) Fast, accurate, efficient and reliable flood management using the SDSS
3) Calibration and verification of the developed flood forecasting models
4) Validation and verification of the developed real-time operation of the multireservoir system module
5) Advantages of use of the Database Management System
6) Convenient use of the GUI and GDS

7.1.2 The Rainfall Characteristics in Han River Basin

The Han River Basin, located in the middle part of the Korean peninsula, has a drainage area of approximately 26,200 Km^2 and discharges about 18,000 million m^3 (MCM) annually. The annual average precipitation of the Han River Basin is 1294 mm, which is concentrated in June to September approximately 65%. The regional distribution of the rainfall is concentrated in the downstream area that is located between ChunCheon and YeoJu. Especially, the annual average precipitation upstream of YeoJu is 800 to 900 mm. The major reasons for flooding in the Han River Basin are typhoons and depression torrential storms. Typical cases of typhoon storms are the 1925, 1936, and 1940 flood events. However, most of the flood events are due to the depression torrential storm. The representative examples of the depression torrential storm are the 1960, 1965, 1972, 1984 and 1990 flood events. Rainfall occurs continuously for several days. The severest case of the flood event is due to the both of the typhoon and depression torrential storms occur simultaneously. The 1995 flood event is an example of this severe case.

For the application of the developed spatial decision support system for integrated flood control in the Han River Basin, the 1995 flood event was selected. The characteristics of the 1995 flood events are follows as:

1) Due to typhoon and depression torrential storms occurring simultaneously
2) Began in downstream area of the basin near the West Sea.
3) Moved towards the catchment area of the reservoirs, upstream in the basin
4) The first torrential precipitation was concentrated through the 17 to 21 of August, which was 179 mm throughout the basin
5) The second torrential precipitation was concentrated through the 22 to 27 of August, which was 375 mm throughout the basin
6) The flood events occurred after severe droughts.

7.2 Spatial Analysis for 1995 flood event

Using the method of spatial analysis presented in Section 3.3, the 1995 flood event (Aug./23/05 – 27/06) is analyzed in this section. First, the event that was represented in Table A.1.(a) through Table A.1.(r) was extracted as part of a database table from the FLD1995 database table that was described in Section 6.3.1. The hourly rainfall data tables (98 tables) of 82 gages were generated to perform the spatial analysis by the indexed Han_ID field used to join the tables. Using this database table and location map of rainfall gages, the hourly isohyets (98 isohyet maps) were created, which are shown in Fig. 7.1(a) through Fig. 7.1(i). To generate the isohyets, extension of each isohyets was fixed with left at 261248.518161 m, top at 609147.564196 m, bottom at 330733.386249, right at 481958.633503. Each isohyet has 110 columns and 139 rows with 2 x 2-Km resolution of each grid. The method involved in creating isohyets is that of giving values to each cell in the output grid theme by weighting the value of each points (82 rainfall data) by the distance that point is from the cell being analyzed and then averaging the values. The 12 nearest neighbors to the cell were used.

The areal estimates of rainfall for each subbasin were generated summarizing the isohyet maps by subbasin base map. The example result of areal estimates of rainfall are described in Section 3.3 with Table. 3.1. The hourly areal estimates of the rainfall database table was stored as a record in the Dynamic Database Tables are shown in Table 7.1.(a) through Table 7.1.(f) by using the Relational Database Management System.

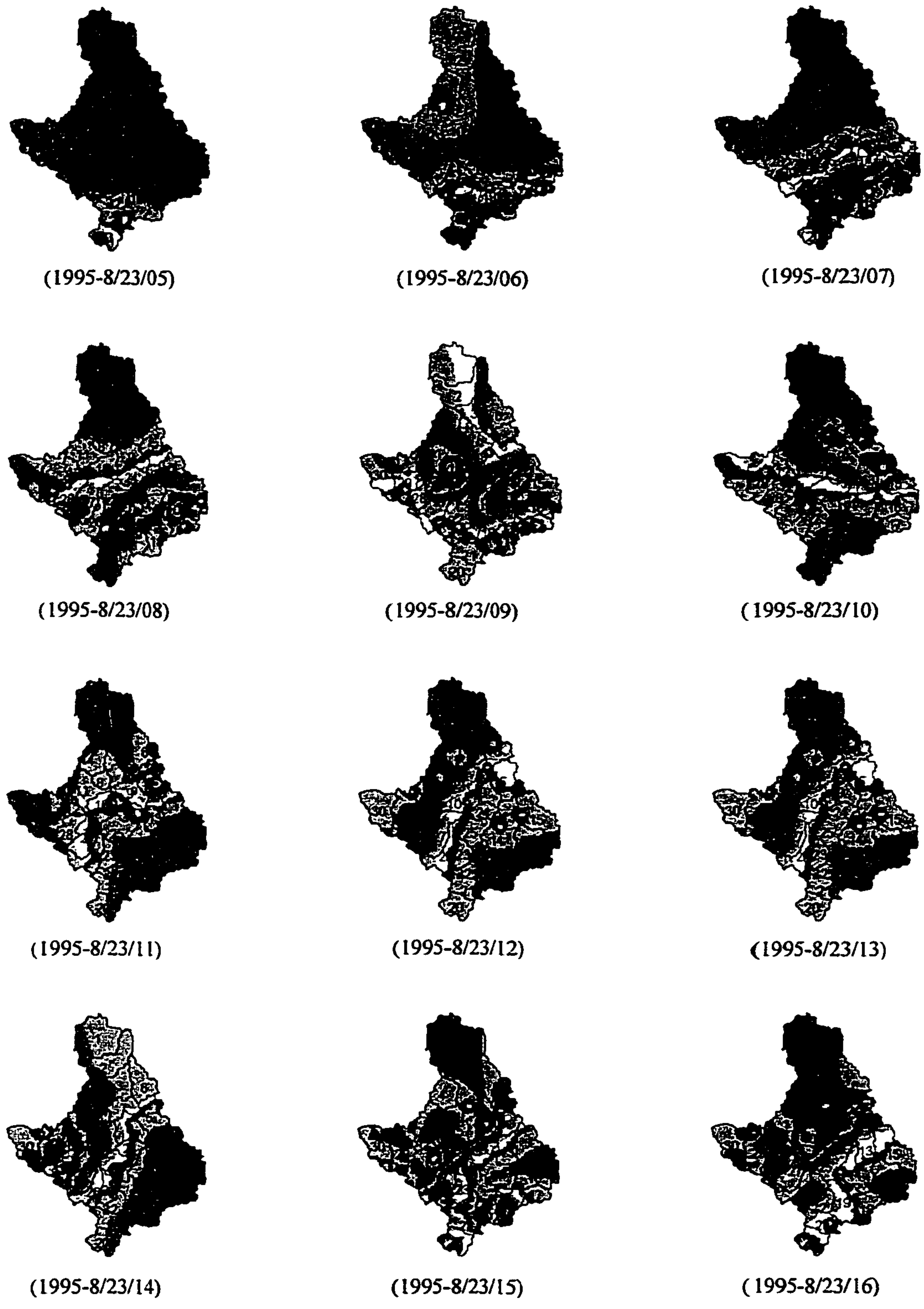


Fig. 7.1.(a) The Isohyets resulting from the Spatial Analysis (1995-8/23/05 – 23/16)

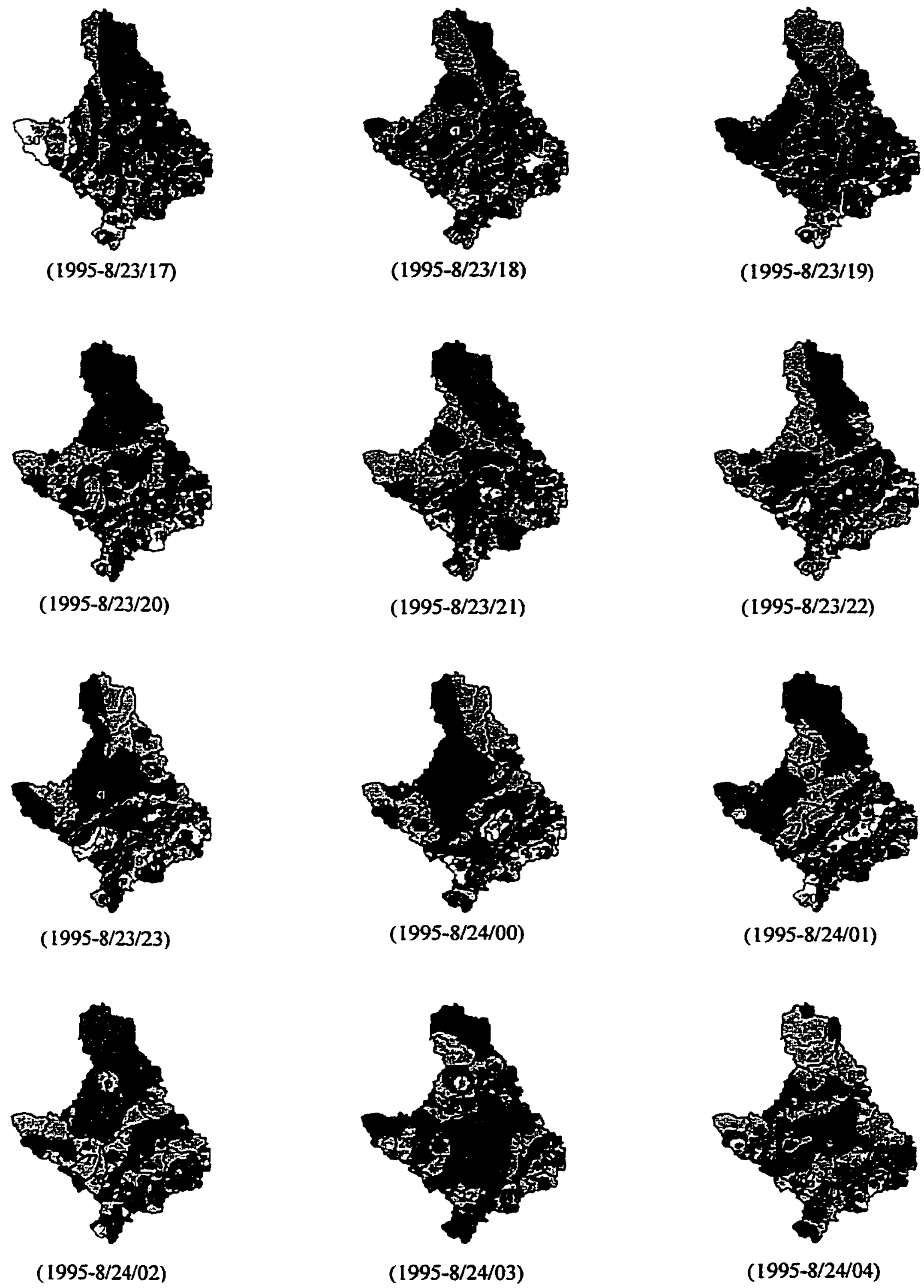
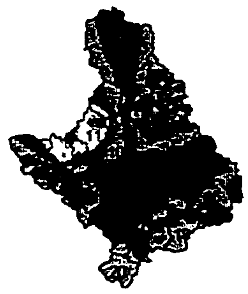
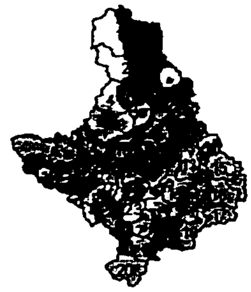


Fig. 7.1.(b) The Isohyets resulting from the Spatial Analysis (1995-8/23/17 – 24/04)



(1995-8/24/05)

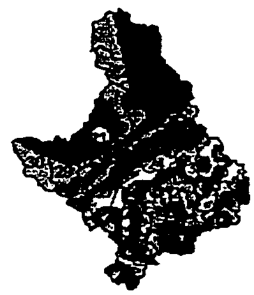


(1995-8/24/06)

(1995-8/24/07)

(1995-8/24/08)

(1995-8/24/09)



(1995-8/24/10)

(1995-8/24/11)

(1995-8/24/12)

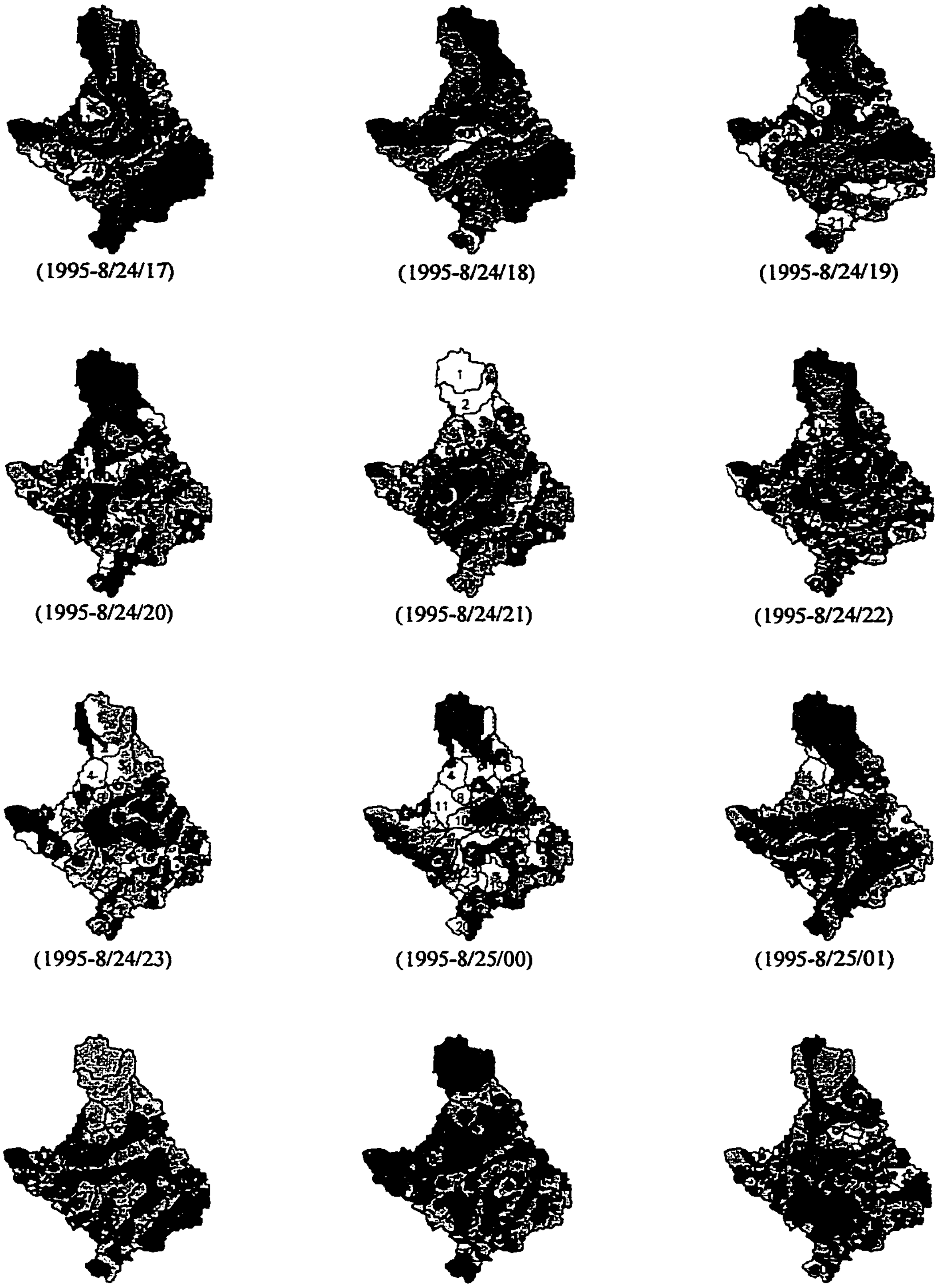
(1995-8/24/13)

(1995-8/24/14)

(1995-8/24/15)

(1995-8/24/16)

Fig. 7.1.(c) The Isohyets resulting from the Spatial Analysis (1995-8/24/05– 24/16)



(1995-8/24/17) (1995-8/24/18) (1995-8/24/19)

(1995-8/24/20) (1995-8/24/21) (1995-8/24/22)

(1995-8/24/23) (1995-8/25/00) (1995-8/25/01)

(1995-8/25/02) (1995-8/25/03) (1995-8/25/04)

Fig. 7.1.(d) The Isohyets resulting from the Spatial Analysis (1995-8/24/17 – 25/04)


(1995-8/25/05)


(1995-8/25/06)

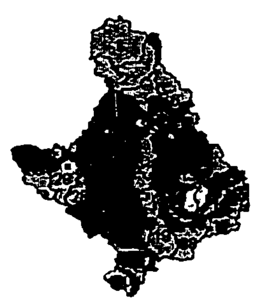

(1995-8/25/07)

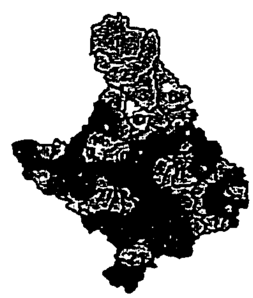

(1995-8/25/08)


(1995-8/25/09)


(1995-8/25/10)


(1995-8/25/11)


(1995-8/25/12)


(1995-8/25/13)


(1995-8/25/14)


(1995-8/25/15)

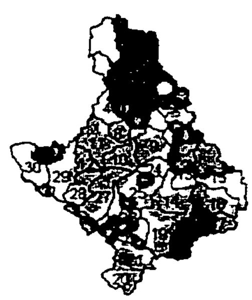

(1995-8/25/16)

Fig. 7.1.(e) The Isohyets resulting from the Spatial Analysis (1995-8/25/05 – 25/16)

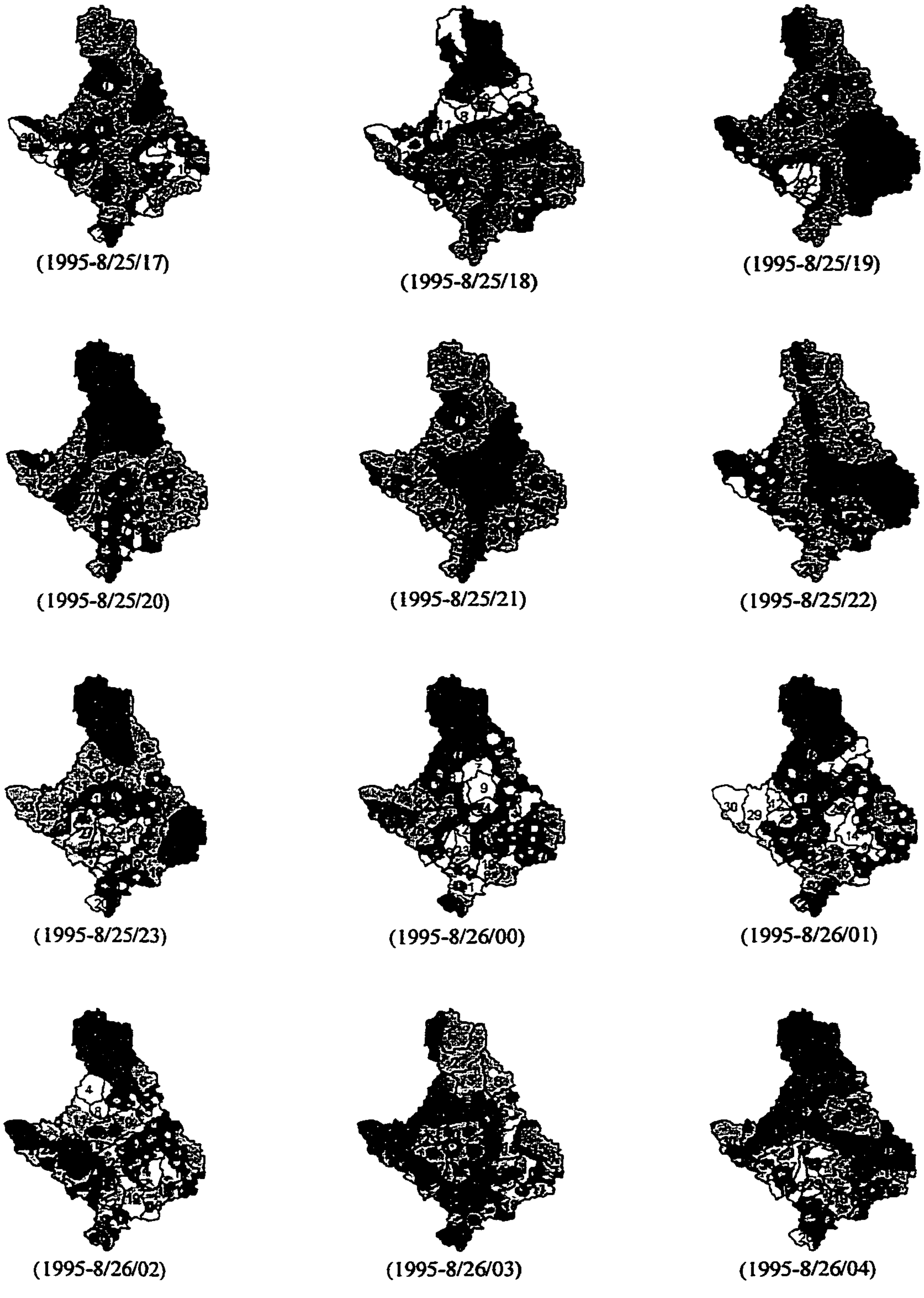


Fig. 7.1.(f) The Isohyets resulting from the Spatial Analysis (1995-8/25/17 – 26/04)

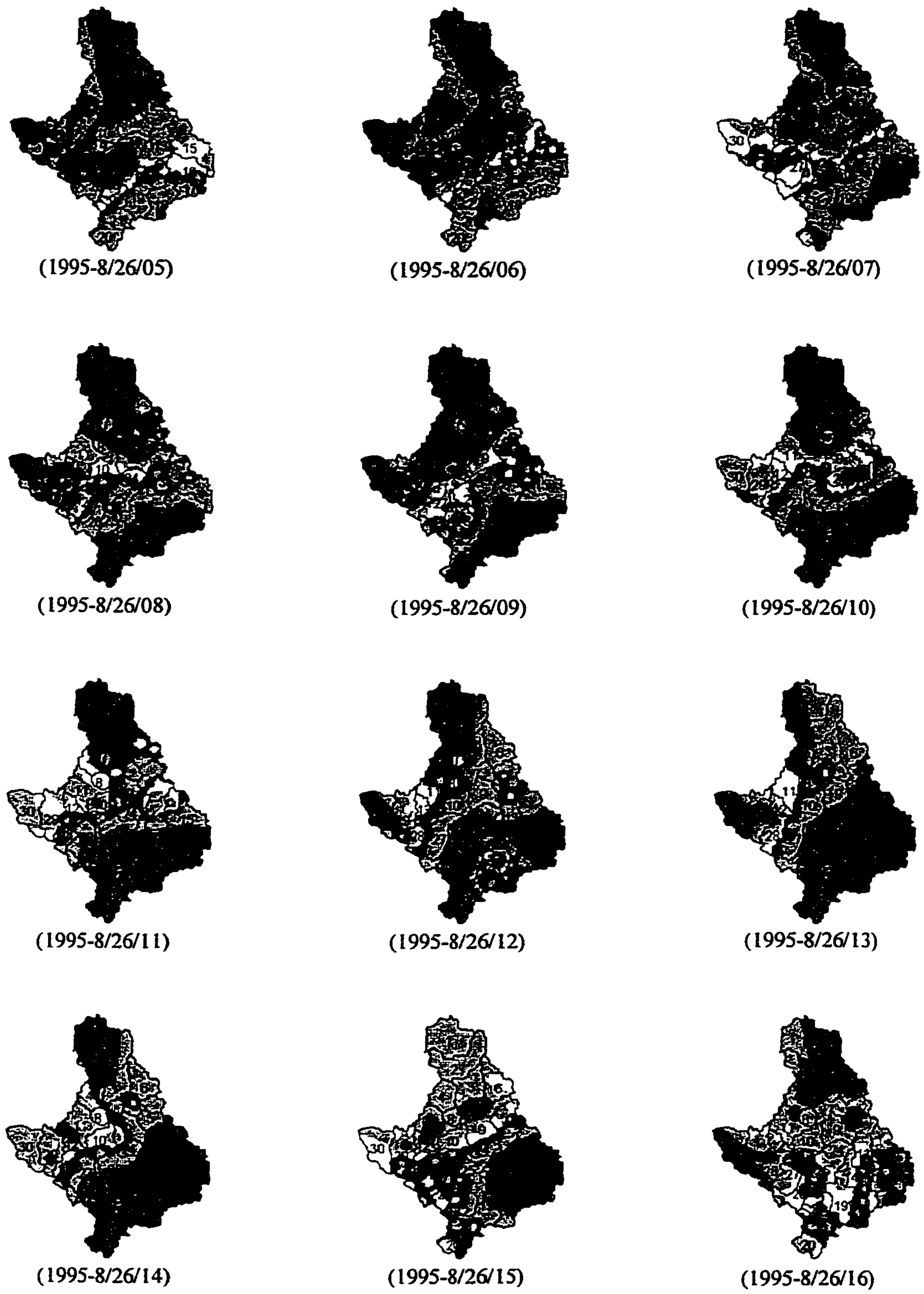


Fig. 7.1.(g) The Isohyets resulting from the Spatial Analysis (1995-8/26/05 – 26/16)

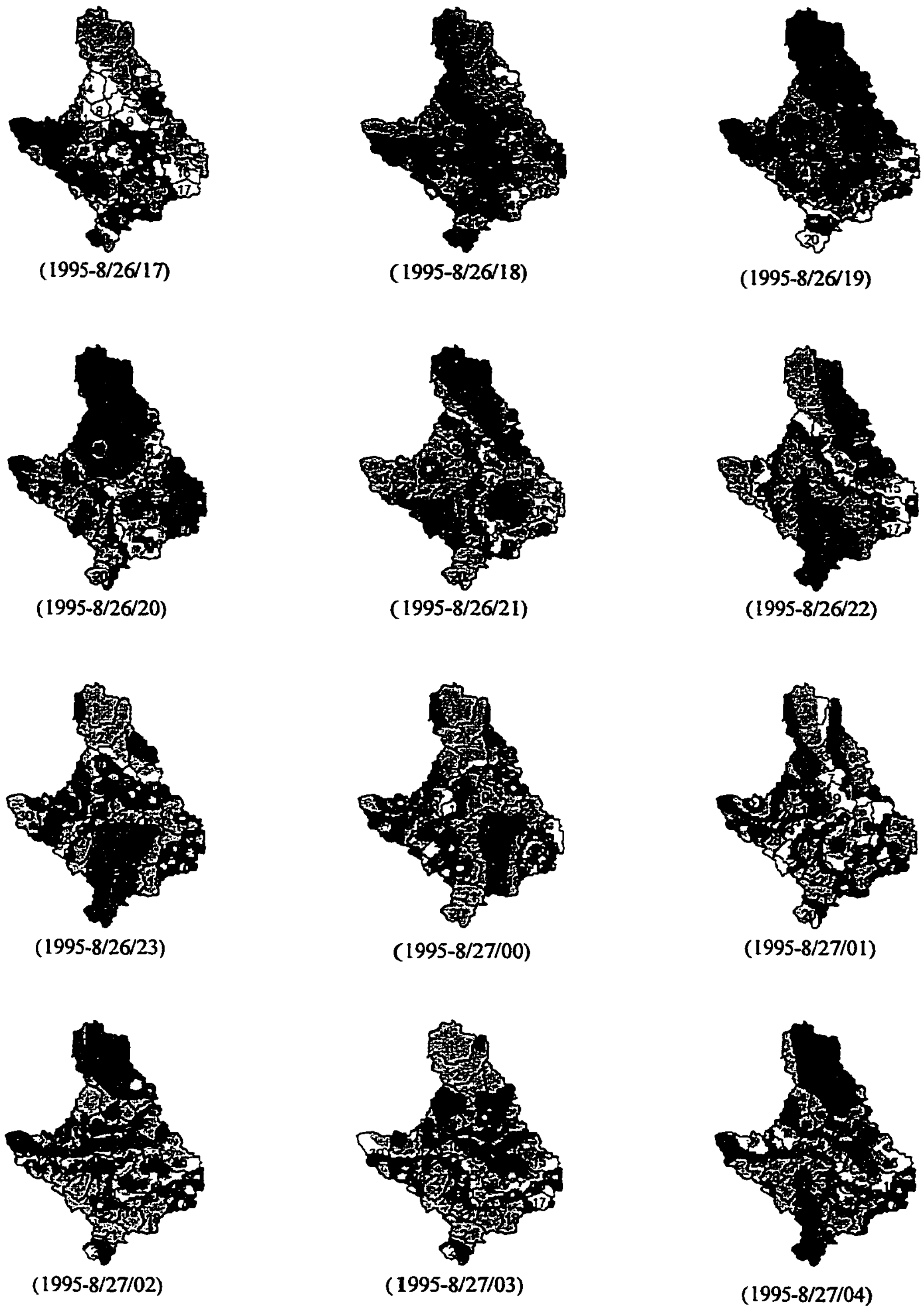
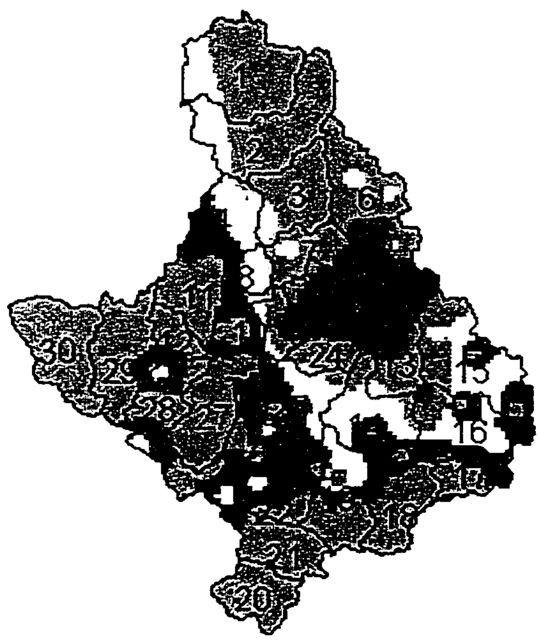


Fig. 7.1.(h) The Isohyets resulting from the Spatial Analysis (1995-8/26/17 – 27/04)

(1995-8/27/05)



(1995-8/27/05)

Fig. 7.1.(i) The Isohyets resulting from the Spatial Analysis (1995-8/27/05 – 27/06)

Table 7.1.(a) Dynamic Database File for the 1995 Rainfall Event in the Han River Basin

(Subbasin 1 to 10; 1995/8/23/05 – 25/05)

MDTIME	SB01	SB02	SB03	SB04	SB05	SB06	SB07	SB08	SB09	SB10
T082305	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T082306	0.1	0.1	0.0	0.2	0.0	0.0	0.0	0.2	0.0	0.0
T082307	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T082308	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.3	0.3
T082309	1.3	1.1	0.9	2.9	1.0	0.2	1.5	4.0	1.9	7.7
T082310	4.7	4.7	4.9	4.3	5.2	4.2	7.1	4.1	5.6	2.7
T082311	3.9	3.8	3.5	2.0	3.6	5.3	3.1	1.8	1.1	0.7
T082312	3.2	3.4	3.8	4.9	0.7	2.8	1.4	2.9	0.3	1.2
T082313	2.1	2.1	2.0	3.0	0.3	1.7	1.6	2.3	0.8	2.8
T082314	4.8	4.9	5.6	8.3	1.1	2.2	5.5	6.0	3.1	8.5
T082315	8.3	8.5	9.5	11.2	3.3	5.5	11.8	10.4	8.8	10.0
T082316	7.8	7.6	7.8	8.2	5.8	6.7	8.7	8.9	7.4	11.0
T082317	5.0	4.8	4.1	6.5	4.1	4.2	4.0	5.8	2.7	4.6
T082318	10.8	10.8	12.2	15.5	3.7	7.0	13.1	13.4	8.1	16.1
T082319	11.6	11.4	11.0	6.7	9.1	14.9	11.4	6.1	11.6	9.8
T082320	4.3	4.3	4.1	4.0	7.7	4.7	4.4	4.4	7.2	8.0
T082321	4.4	4.3	4.3	6.2	4.6	2.8	5.3	7.0	7.7	7.4
T082322	5.1	5.0	4.8	5.7	5.6	4.6	5.1	6.4	6.0	7.2
T082323	6.9	6.7	6.6	7.8	6.2	5.5	8.3	8.9	9.2	8.2
T082400	7.3	7.1	7.0	8.0	9.1	6.3	7.5	8.7	8.5	8.0
T082401	4.8	4.8	5.2	5.7	6.2	4.3	4.9	5.3	6.1	5.5
T082402	3.2	3.0	2.6	2.6	5.7	3.4	3.6	2.8	5.8	4.1
T082403	9.7	10.5	13.4	15.5	3.2	7.6	6.5	8.7	3.8	4.6
T082404	10.4	10.6	11.1	10.8	3.6	11.6	7.4	7.4	4.4	4.6
T082405	11.9	11.9	12.4	15.6	3.8	10.7	7.7	9.3	3.3	3.3
T082406	20.3	19.5	18.0	22.2	4.8	18.8	19.3	26.0	6.8	8.1
T082407	10.3	10.7	10.6	7.2	7.4	15.5	5.5	5.8	3.7	3.1
T082408	10.2	10.0	10.1	12.4	5.7	7.6	11.6	13.6	7.6	11.6
T082409	11.4	11.1	10.5	8.5	8.0	12.8	13.0	14.4	8.5	8.6
T082410	10.5	9.9	8.9	13.1	4.3	7.8	9.3	13.9	4.4	5.9
T082411	8.8	8.8	9.8	11.7	2.8	6.5	8.8	8.7	3.6	5.3
T082412	8.2	7.9	7.5	3.2	4.0	10.1	10.9	4.0	4.2	2.4
T082413	4.4	4.3	4.7	5.1	1.3	3.9	4.3	2.5	1.1	0.5
T082414	1.7	1.7	1.6	1.0	0.5	3.0	0.5	0.5	0.3	2.6
T082415	2.0	1.8	1.3	3.3	1.4	1.4	1.1	2.4	1.5	0.8
T082416	2.0	1.9	1.9	4.0	0.3	0.7	1.4	3.2	1.0	5.2
T082417	7.0	6.0	4.0	13.4	3.4	1.4	4.8	22.8	4.8	10.6
T082418	10.0	10.2	11.2	12.0	6.4	10.2	6.3	6.3	3.2	1.6
T082419	4.1	4.3	4.1	1.9	1.1	7.5	1.1	1.0	0.5	0.5
T082420	0.4	0.4	0.3	0.3	2.9	0.7	0.2	0.3	1.9	1.2
T082421	0.9	1.0	1.1	1.3	4.0	0.8	3.2	1.6	7.6	14.2
T082422	1.8	1.9	2.0	1.0	10.0	2.1	3.8	1.9	14.8	7.5
T082423	1.1	1.2	1.2	1.0	7.9	1.5	1.5	1.3	6.3	4.6
T082500	0.7	0.8	0.8	0.9	5.3	0.9	1.0	1.1	3.3	1.7
T082501	0.6	0.6	0.6	1.1	1.5	0.2	0.7	1.6	2.3	2.9
T082502	1.7	1.7	1.6	1.8	4.7	1.7	2.3	1.6	5.8	5.3
T082503	4.5	4.8	5.6	5.4	5.6	4.8	2.9	3.9	5.6	3.8
T082504	5.4	5.7	5.7	5.0	3.2	8.1	1.3	2.3	3.3	3.3
T082505	9.5	8.7	6.9	15.5	4.2	7.4	3.4	13.8	5.5	10.9

Table 7.1.(b) Dynamic Database File for 1995 Rainfall Event in the Han River Basin

(Subbasin 11 to 20; 1995/8/23/05 – 25/05)

MDTIME	SB11	SB12	SB13	SB14	SB15	SB16	SB17	SB18	SB19	SB20
T082305	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6
T082306	0.2	0.0	0.0	0.1	0.0	0.3	5.3	4.9	1.5	4.5
T082307	0.0	0.0	0.3	2.9	1.0	5.5	10.8	11.8	4.3	2.4
T082308	0.1	0.2	3.8	5.0	3.9	9.1	5.5	2.9	4.2	2.7
T082309	5.1	3.7	7.9	6.8	6.0	3.2	0.6	0.4	2.0	0.1
T082310	3.0	1.3	5.3	0.6	4.3	0.3	0.0	0.0	0.0	0.0
T082311	1.9	2.2	0.3	0.0	0.2	0.0	0.0	0.0	0.0	0.0
T082312	4.1	4.1	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.1
T082313	4.9	9.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T082314	8.4	9.0	0.1	0.2	0.0	0.0	0.0	0.0	0.2	0.0
T082315	10.1	10.9	0.5	0.2	0.1	0.0	0.2	3.2	0.5	0.7
T082316	7.2	4.6	1.1	0.4	0.5	0.0	0.0	0.2	0.8	0.6
T082317	11.4	17.0	6.4	9.8	4.5	8.1	11.2	9.0	3.9	0.9
T082318	13.4	12.9	5.8	5.7	5.2	2.5	2.1	0.3	3.1	0.2
T082319	4.7	4.7	3.1	4.9	2.5	2.3	0.4	0.5	1.8	1.1
T082320	5.4	6.6	10.8	10.1	5.7	3.3	0.7	1.4	2.3	0.8
T082321	7.2	6.1	6.8	8.6	3.6	2.3	0.3	0.0	1.9	2.2
T082322	6.8	7.5	12.4	10.5	5.6	1.4	0.1	0.2	3.7	1.7
T082323	8.4	7.3	17.3	11.5	7.2	1.7	0.2	0.5	3.1	4.6
T082400	8.4	7.1	17.8	16.1	7.5	2.7	0.9	1.7	9.6	9.5
T082401	4.7	3.9	18.6	18.8	13.5	9.5	6.1	5.2	12.8	22.1
T082402	4.1	4.9	9.8	11.0	12.0	10.8	5.9	8.8	14.4	18.5
T082403	7.2	4.1	5.1	4.9	8.2	12.0	11.1	9.5	4.0	3.9
T082404	7.0	5.4	2.2	2.8	2.3	6.6	14.3	21.0	5.2	7.0
T082405	13.6	10.6	2.3	2.9	4.8	9.1	14.8	8.0	2.8	2.9
T082406	22.6	10.0	1.5	2.4	1.3	3.0	2.0	1.8	2.5	1.6
T082407	4.5	5.8	3.2	1.5	3.1	1.6	1.1	2.3	2.4	19.6
T082408	15.2	15.4	6.4	8.2	2.5	4.3	4.2	7.8	8.3	3.5
T082409	8.6	10.2	4.8	2.4	4.6	5.7	11.8	4.8	1.9	1.9
T082410	18.1	14.6	0.9	0.9	1.5	2.2	6.0	2.7	4.1	3.1
T082411	10.1	6.7	0.7	1.2	0.3	0.9	1.7	1.8	1.8	1.9
T082412	1.2	1.0	0.3	1.1	0.8	2.2	2.4	1.8	0.7	1.0
T082413	2.7	0.6	0.1	0.3	0.1	0.3	0.6	0.7	0.6	2.1
T082414	1.1	0.7	0.8	1.5	0.3	1.1	1.1	1.8	1.7	0.9
T082415	4.3	2.6	1.2	1.7	0.5	0.8	0.2	0.1	0.4	0.1
T082416	6.8	6.8	0.8	0.5	0.3	0.2	0.0	0.0	0.0	0.0
T082417	19.3	8.5	1.2	0.3	0.3	0.0	0.0	0.0	0.0	0.0
T082418	6.6	3.1	0.9	0.0	0.3	0.0	0.0	0.0	0.0	1.5
T082419	0.8	1.0	0.0	0.2	0.0	0.2	1.1	1.5	1.2	2.0
T082420	0.8	1.1	1.5	0.5	0.4	0.3	0.5	0.1	1.1	0.5
T082421	3.2	5.7	2.0	1.5	0.7	0.2	0.6	0.4	0.8	0.1
T082422	1.0	1.0	6.2	2.8	1.4	0.4	1.5	0.6	1.1	2.4
T082423	1.2	1.5	5.5	1.5	2.1	2.0	6.4	0.6	0.3	0.2
T082500	1.0	1.1	1.8	0.6	0.9	0.6	0.2	0.2	0.8	0.7
T082501	1.9	2.8	2.0	4.1	1.7	3.1	1.1	1.7	4.1	7.4
T082502	3.3	5.5	9.1	8.7	7.0	5.3	3.9	4.3	7.4	13.9
T082503	3.0	2.6	16.0	16.1	8.5	11.0	14.1	10.7	11.6	54.3
T082504	5.3	7.0	18.6	13.7	18.7	14.9	8.5	13.6	11.0	20.9
T082505	23.1	19.3	8.0	7.5	10.2	11.9	16.6	10.5	9.1	10.6

Table 7.1.(c) Dynamic Database File for 1995 Rainfall Event in the Han River Basin

(Subbasin 21 to 30; 1995/8/23/05 – 25/05)

MDTIME	SB21	SB22	SB23	SB24	SB25	SB26	SB27	SB28	SB29	SB30
T082305	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T082306	4.4	2.0	0.6	0.0	0.0	0.2	0.0	0.0	0.0	0.0
T082307	3.4	4.4	2.2	0.2	0.7	1.5	0.2	0.0	0.0	0.0
T082308	2.5	4.4	2.8	1.3	2.6	1.9	2.2	2.8	0.3	0.4
T082309	0.1	0.9	1.4	3.6	4.2	1.1	4.5	2.0	1.6	1.8
T082310	0.0	0.0	0.1	3.2	0.6	0.2	0.4	0.1	0.5	0.5
T082311	0.0	0.0	0.0	0.5	0.1	0.7	0.8	1.8	4.0	3.3
T082312	0.1	0.1	0.1	0.1	0.2	1.2	2.0	3.3	5.4	5.9
T082313	0.0	0.1	0.5	0.5	0.8	1.7	4.3	11.6	14.4	10.3
T082314	0.1	0.2	0.7	1.9	2.5	2.0	8.5	7.7	9.0	9.8
T082315	1.0	0.6	1.3	3.0	1.7	3.8	8.9	11.8	11.1	10.0
T082316	1.0	1.6	2.6	3.5	2.7	2.5	3.7	3.1	5.7	7.1
T082317	1.7	3.2	5.6	2.8	5.3	5.3	7.2	16.7	27.2	24.4
T082318	0.5	2.5	2.0	5.6	5.6	3.7	10.6	15.0	8.9	5.9
T082319	3.0	6.0	6.9	12.5	11.4	9.6	13.2	8.4	3.5	3.5
T082320	1.1	1.9	8.0	9.5	12.3	15.2	12.9	7.3	5.9	6.5
T082321	2.7	4.5	15.5	14.9	18.1	22.0	11.7	6.5	6.6	6.8
T082322	3.0	5.9	16.5	11.3	13.6	22.0	13.2	7.8	6.2	5.2
T082323	4.1	7.2	21.3	14.0	16.6	21.8	14.3	7.8	6.9	7.6
T082400	15.5	21.2	15.5	13.6	13.8	11.7	7.7	6.0	6.5	5.7
T082401	14.9	14.8	10.9	7.4	8.4	8.1	6.1	3.9	3.4	3.0
T082402	14.9	12.1	7.3	7.1	6.2	6.4	6.1	5.6	5.7	5.2
T082403	2.9	1.9	3.0	4.1	3.9	4.1	5.8	4.8	2.3	2.4
T082404	3.9	2.7	1.4	4.3	3.1	1.8	4.3	3.1	9.3	14.6
T082405	2.6	1.1	0.2	2.4	0.8	0.2	0.9	3.3	15.0	16.1
T082406	1.3	1.1	0.8	3.0	1.7	0.6	1.6	4.4	8.0	5.1
T082407	4.5	2.7	1.9	2.7	1.8	3.7	3.7	6.2	4.9	5.3
T082408	2.7	5.3	7.9	6.5	14.4	6.9	10.3	11.1	7.8	5.1
T082409	0.8	1.3	1.1	7.7	6.1	1.5	5.5	8.4	10.8	8.4
T082410	0.5	0.8	0.7	1.4	0.9	0.7	3.2	7.6	14.3	13.1
T082411	0.8	1.4	0.7	0.8	0.6	1.0	1.8	3.8	2.9	1.8
T082412	0.1	0.3	0.7	1.0	0.7	0.3	0.3	0.6	1.0	1.0
T082413	1.2	0.7	1.1	0.1	0.3	1.5	1.0	0.4	0.4	0.3
T082414	0.6	1.2	2.0	0.9	1.1	2.6	1.3	0.5	1.2	1.0
T082415	0.1	0.3	0.9	1.1	1.1	1.2	1.8	5.0	5.4	3.3
T082416	0.0	0.0	0.1	0.9	1.4	1.1	5.8	8.3	5.4	3.3
T082417	0.0	0.0	0.1	4.2	1.5	0.6	2.0	1.2	3.1	2.7
T082418	0.3	0.3	0.1	0.6	0.1	0.3	0.5	1.2	3.0	2.7
T082419	1.0	1.1	0.2	0.1	0.1	0.3	0.1	0.2	0.7	0.7
T082420	0.8	1.5	1.6	4.2	1.7	5.0	6.5	8.9	0.9	1.2
T082421	0.3	0.7	3.3	6.1	6.4	5.0	18.6	9.9	1.1	0.9
T082422	6.9	1.2	1.5	14.0	7.0	1.1	3.2	2.0	1.1	0.7
T082423	0.3	0.7	1.6	3.8	2.0	1.6	2.3	0.9	0.6	0.7
T082500	0.4	0.8	0.8	1.7	0.7	2.7	2.8	2.3	1.6	2.8
T082501	6.7	8.3	13.2	5.1	7.4	17.5	11.1	8.6	4.6	6.4
T082502	11.0	13.8	14.5	8.9	11.4	12.1	11.3	11.0	8.2	6.8
T082503	17.8	11.9	9.2	11.6	11.0	6.7	6.6	4.0	3.4	3.7
T082504	9.6	8.0	8.0	11.7	9.7	9.0	7.1	5.2	11.2	11.1
T082505	10.0	8.0	8.0	7.8	8.1	7.6	7.2	6.3	15.4	10.6

Table 7.1.(d) Dynamic Database File for 1995 Rainfall Event in the Han River Basin (Subbasin 1 to 10; 1995/8/25/06 – 27/06)

MDTIME	SB01	SB02	SB03	SB04	SB05	SB06	SB07	SB08	SB09	SB10
T082506	20.8	20.8	19.6	17.4	8.4	27.9	10.8	21.2	7.4	8.9
T082507	11.7	11.9	12.3	7.2	7.0	16.4	7.7	3.0	4.5	2.8
T082508	4.2	4.0	3.2	4.6	5.5	4.2	3.8	6.1	7.0	10.3
T082509	6.6	6.1	5.6	10.0	8.7	3.7	6.4	11.7	12.1	15.4
T082510	10.9	10.8	10.2	6.6	13.0	13.7	10.3	7.6	13.0	7.0
T082511	8.4	8.3	9.4	10.2	12.0	6.2	6.8	7.8	8.7	7.1
T082512	6.1	6.0	6.0	4.0	9.2	6.9	6.7	3.7	7.0	4.0
T082513	1.8	1.7	1.4	2.1	3.3	1.7	1.4	2.3	3.0	2.2
T082514	1.2	1.2	1.1	2.6	2.2	0.5	1.5	2.6	4.7	5.5
T082515	1.8	1.6	1.2	2.4	2.0	0.9	2.2	3.5	2.6	2.9
T082516	0.8	0.7	0.6	0.8	0.6	0.6	0.7	1.5	1.3	1.8
T082517	0.1	0.2	0.3	0.4	0.0	0.0	0.1	0.1	0.0	0.4
T082518	0.8	0.7	0.7	0.7	0.4	0.7	1.1	0.9	0.4	0.2
T082519	0.2	0.2	0.2	0.2	0.0	0.2	0.3	0.1	0.1	0.1
T082520	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
T082521	0.1	0.2	0.3	0.3	0.0	0.0	0.1	0.1	0.0	0.0
T082522	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
T082523	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	0.3	0.7
T082600	0.6	0.6	0.6	0.4	0.4	0.6	0.9	0.7	0.9	0.4
T082601	0.6	0.6	0.5	0.5	0.5	0.6	0.8	0.3	0.4	0.6
T082602	0.5	0.5	0.6	1.0	0.8	0.2	0.6	1.1	1.5	2.1
T082603	2.0	1.9	1.8	2.6	1.8	1.7	2.5	3.2	4.7	6.0
T082604	3.7	3.6	3.6	3.4	5.6	2.9	5.3	4.8	5.8	2.6
T082605	4.4	4.2	3.9	5.9	2.4	2.9	4.0	5.1	2.2	2.2
T082606	4.5	4.3	4.2	6.5	2.3	2.8	4.6	8.0	3.2	4.8
T082607	7.5	7.4	7.5	4.5	7.9	8.4	10.6	4.6	10.8	5.2
T082608	3.2	3.1	3.7	3.6	3.6	2.4	2.7	2.3	2.2	1.1
T082609	3.5	3.4	3.1	3.2	0.8	3.7	3.7	3.9	1.6	3.8
T082610	3.6	3.5	3.5	2.7	1.2	4.0	4.6	2.9	1.9	0.7
T082611	0.5	0.5	0.4	0.7	0.6	0.5	0.4	1.0	0.3	1.3
T082612	0.3	0.3	0.3	0.6	0.3	0.1	0.1	0.6	0.1	0.2
T082613	0.2	0.2	0.1	0.4	0.0	0.0	0.3	0.3	0.1	0.2
T082614	0.4	0.3	0.2	0.8	0.0	0.1	0.3	1.0	0.5	1.0
T082615	1.8	1.7	1.7	1.8	0.9	1.3	2.5	2.1	1.2	1.4
T082616	2.2	2.3	2.4	2.3	2.2	2.6	1.8	1.6	1.9	1.6
T082617	1.4	1.4	1.3	1.1	2.1	1.5	1.2	1.0	0.9	1.1
T082618	2.2	2.1	1.9	3.5	2.1	1.3	2.2	3.6	2.8	5.3
T082619	4.4	4.2	3.9	5.0	3.7	3.9	4.6	5.9	5.1	7.4
T082620	4.1	4.0	3.7	3.9	1.7	4.4	3.4	6.8	3.0	3.4
T082621	2.8	2.8	2.4	0.4	3.3	5.3	1.3	0.1	1.1	0.1
T082622	2.0	2.1	2.0	0.8	2.3	3.3	1.6	0.2	1.3	0.1
T082623	1.8	1.7	1.1	1.6	0.8	2.6	0.5	0.9	0.4	0.7
T082700	2.0	2.0	1.5	1.7	0.4	3.3	0.2	0.7	0.1	0.5
T082701	1.7	1.5	1.3	4.2	0.3	0.2	1.2	2.9	1.3	3.9
T082702	14.6	14.8	14.6	12.4	6.7	17.4	13.3	10.6	5.9	4.0
T082703	13.0	12.8	12.6	9.1	10.1	13.9	14.7	11.6	8.9	3.3
T082704	7.8	7.9	7.8	5.3	8.0	9.0	7.7	6.2	5.2	1.1
T082705	3.8	3.9	4.1	3.3	3.5	4.3	4.1	2.8	4.0	2.9
T082706	1.3	1.4	1.5	0.8	2.6	1.6	1.7	0.9	2.6	0.9

Table 7.1.(e) Dynamic Database File for 1995 Rainfall Event in the Han River Basin (Subbasin 11 to 20; 1995/8/25/06 – 27/06)

MDTIME	SB11	SB12	SB13	SB14	SB15	SB16	SB17	SB18	SB19	SB20
T082506	13.9	5.9	6.9	6.2	5.5	8.2	12.9	15.6	10.6	10.1
T082507	2.4	1.9	6.2	9.4	6.6	10.2	23.2	22.5	17.4	12.7
T082508	8.6	11.1	9.9	9.0	10.1	13.1	23.6	14.9	10.1	4.6
T082509	12.4	7.7	6.5	4.2	5.9	5.8	8.3	5.0	4.5	1.4
T082510	4.3	2.8	10.5	5.3	5.9	2.6	2.9	2.9	4.8	8.5
T082511	6.9	5.4	13.5	11.5	9.3	4.0	3.3	5.0	11.3	13.7
T082512	3.2	3.0	10.0	14.4	11.2	13.3	5.7	6.4	6.4	20.7
T082513	2.3	2.2	5.7	5.1	6.5	8.0	6.7	4.7	3.1	3.0
T082514	4.9	6.0	4.4	2.7	3.8	1.6	0.9	0.4	1.9	7.0
T082515	4.1	4.7	1.5	1.8	0.3	0.4	0.3	1.6	2.6	5.8
T082516	1.6	1.7	0.6	1.5	0.6	1.7	2.2	2.8	1.5	1.3
T082517	0.1	0.3	0.6	0.6	0.4	0.9	1.6	1.5	0.4	0.6
T082518	0.8	0.6	0.0	0.1	0.1	0.2	0.1	0.4	0.0	0.0
T082519	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
T082520	0.0	0.0	0.3	0.2	0.1	0.1	0.0	0.2	0.6	0.2
T082521	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.2	0.0	0.0
T082522	0.1	0.3	0.0	0.1	0.0	0.0	0.0	0.3	0.7	0.1
T082523	0.2	0.3	0.4	0.6	0.0	0.0	0.0	0.1	0.5	0.8
T082600	0.4	0.1	0.7	0.5	0.4	0.4	0.4	1.1	0.9	2.4
T082601	0.6	1.0	0.6	0.9	0.3	0.4	0.5	0.7	1.5	4.1
T082602	1.5	2.0	0.4	0.7	0.3	0.7	1.1	1.4	1.1	8.3
T082603	4.3	5.3	1.1	2.3	0.2	0.8	1.0	1.6	3.9	3.7
T082604	3.2	2.5	4.2	2.9	4.8	5.3	6.4	5.4	1.7	0.7
T082605	7.0	6.7	1.7	1.0	1.4	0.8	0.2	0.0	0.4	0.2
T082606	8.0	6.7	2.9	0.7	0.7	0.2	0.0	0.1	0.1	0.1
T082607	2.7	2.1	0.9	0.3	0.3	0.0	0.0	0.0	0.1	0.5
T082608	1.7	2.8	0.5	0.1	0.3	0.0	0.0	0.0	0.0	0.0
T082609	4.0	3.7	0.4	0.0	0.2	0.0	0.0	0.0	0.1	0.0
T082610	1.4	1.1	1.5	0.2	0.1	0.0	0.0	0.0	0.0	0.0
T082611	1.4	1.0	0.8	0.0	0.3	0.0	0.0	0.0	0.0	0.0
T082612	0.6	0.8	0.1	0.2	0.0	0.0	0.0	0.5	1.1	0.0
T082613	0.9	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T082614	1.6	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T082615	2.2	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
T082616	1.6	1.4	1.0	0.9	2.9	3.4	3.1	0.6	0.9	1.2
T082617	1.5	2.3	0.7	0.5	1.7	1.1	0.9	0.2	0.4	1.7
T082618	5.7	5.4	1.7	2.6	2.7	1.9	1.6	1.4	3.4	3.1
T082619	6.8	6.0	3.2	3.7	1.8	1.5	3.0	1.1	2.3	0.9
T082620	3.2	0.5	1.9	2.3	3.1	2.7	4.4	1.2	1.3	0.1
T082621	0.2	0.4	2.4	3.0	1.7	1.6	2.0	1.3	0.9	0.1
T082622	0.1	0.2	1.6	0.2	1.5	0.7	0.8	0.1	0.0	0.0
T082623	4.3	6.3	0.1	0.0	0.2	0.3	0.4	0.2	0.0	0.0
T082700	2.1	2.7	0.0	0.0	0.4	0.9	1.1	0.2	0.0	0.1
T082701	6.7	7.0	1.2	1.2	0.4	0.5	0.5	0.2	0.7	1.0
T082702	8.0	5.6	2.3	1.6	1.5	0.9	0.5	0.1	0.5	0.5
T082703	4.3	1.7	2.7	1.8	1.5	1.1	0.8	0.1	0.6	0.5
T082704	2.2	0.6	3.0	1.0	1.3	0.9	0.5	0.2	0.5	0.0
T082705	2.4	3.0	1.5	0.7	1.5	1.1	0.6	0.2	0.2	0.1
T082706	0.2	0.1	2.1	0.9	1.0	1.0	0.3	0.2	0.5	0.1

Table 7.1.(f) Dynamic Database File for 1995 Rainfall Event in the Han River Basin (Subbasin 21 to 30; 1995/8/25/06 – 27/06)

MDTIME	SB21	SB22	SB23	SB24	SB25	SB26	SB27	SB28	SB29	SB30
T082506	10.3	11.8	8.4	5.4	5.1	5.0	2.7	1.2	1.5	1.6
T082507	20.5	19.8	11.5	4.6	6.2	9.5	6.1	3.9	2.7	3.9
T082508	5.0	6.2	6.6	9.0	8.5	7.9	16.2	14.0	9.6	8.0
T082509	1.5	3.2	7.7	10.7	17.0	9.3	12.2	4.8	4.2	3.4
T082510	15.6	7.8	10.9	25.5	18.3	11.3	6.8	4.3	3.4	3.8
T082511	15.2	12.9	12.8	10.6	10.8	7.6	6.4	4.7	4.8	4.3
T082512	7.9	4.5	4.0	7.6	5.8	4.3	3.8	2.3	2.5	2.4
T082513	2.2	3.1	4.6	5.4	5.0	4.6	5.1	4.5	3.2	2.2
T082514	2.6	3.0	3.0	5.2	4.5	3.4	5.3	4.9	4.0	4.0
T082515	3.2	3.1	2.7	2.3	2.7	2.7	3.5	3.8	4.1	3.3
T082516	1.4	0.8	0.6	0.9	1.0	0.7	1.5	1.2	0.9	0.8
T082517	0.1	0.0	0.0	0.1	0.1	0.1	0.3	0.6	0.6	1.2
T082518	0.0	0.0	0.1	0.0	0.0	0.5	0.2	0.3	0.7	1.6
T082519	0.3	0.5	0.8	0.0	0.2	0.9	0.5	0.2	0.2	0.4
T082520	0.5	0.7	0.4	0.2	0.5	0.1	0.0	0.0	0.2	0.2
T082521	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.1	0.2	0.2
T082522	0.2	0.2	0.1	0.0	0.0	0.8	0.1	0.3	0.6	0.7
T082523	0.6	0.7	1.7	0.3	1.0	1.7	1.4	0.8	0.1	0.1
T082600	1.0	1.2	1.2	0.8	0.7	0.8	0.3	0.0	0.0	0.0
T082601	1.9	1.6	0.6	1.1	0.6	0.6	0.6	0.9	1.0	1.2
T082602	1.1	1.4	2.5	0.6	1.2	5.3	3.7	4.6	3.8	4.3
T082603	4.0	3.0	4.8	5.5	5.4	3.7	4.4	3.9	3.6	2.9
T082604	0.3	0.8	1.2	3.0	1.2	0.8	0.8	1.3	4.2	6.2
T082605	0.3	0.8	3.1	2.0	2.9	2.4	2.1	3.7	9.6	9.4
T082606	0.1	0.1	1.3	3.6	4.4	2.3	3.0	4.5	4.9	3.9
T082607	0.1	0.1	0.4	3.4	1.1	0.8	0.9	0.7	1.0	1.0
T082608	0.0	0.0	0.2	0.8	0.2	0.2	0.8	4.1	5.3	4.8
T082609	0.1	0.2	1.7	0.4	0.6	0.8	1.1	2.9	3.1	2.8
T082610	0.0	0.0	0.0	2.1	0.4	0.0	0.1	0.7	1.5	1.9
T082611	0.0	0.0	0.0	0.2	0.1	0.0	0.1	0.3	1.2	1.3
T082612	0.0	0.1	0.0	0.0	0.0	0.0	0.1	1.0	2.1	3.0
T082613	0.0	0.0	0.0	0.0	0.0	0.1	0.2	1.3	2.2	2.7
T082614	0.0	0.0	0.0	0.2	0.1	0.0	0.1	0.6	1.8	1.7
T082615	0.4	0.2	0.5	0.2	0.2	0.5	0.5	0.6	1.1	1.1
T082616	0.4	0.7	0.5	1.8	0.9	0.8	1.0	2.1	2.1	2.6
T082617	0.5	0.9	2.0	0.6	0.9	2.3	2.3	2.4	3.5	4.3
T082618	2.2	4.4	6.2	2.6	3.4	5.1	4.5	3.7	5.2	5.0
T082619	0.7	1.8	2.2	5.0	3.8	1.5	2.5	2.5	4.1	3.8
T082620	0.1	0.5	0.2	1.7	1.3	0.0	0.2	0.1	0.2	0.3
T082621	0.1	0.1	0.1	1.0	0.7	0.0	0.0	0.0	0.0	0.0
T082622	0.0	0.0	0.0	0.7	0.1	0.0	0.0	0.4	1.1	1.6
T082623	0.0	0.0	0.0	0.1	0.0	0.1	0.3	1.6	5.6	6.5
T082700	0.1	0.1	0.3	0.0	0.1	0.5	0.5	1.2	5.4	5.3
T082701	0.1	0.2	0.2	0.9	1.0	0.5	0.9	2.5	9.3	7.2
T082702	0.1	0.2	0.4	1.2	0.9	0.1	0.3	0.5	3.8	2.5
T082703	0.1	0.3	0.4	2.8	1.2	0.1	0.2	0.3	1.2	0.9
T082704	0.0	0.1	0.0	1.4	0.2	0.0	0.1	0.2	0.6	0.5
T082705	0.2	0.2	0.1	1.6	0.4	0.2	0.2	0.5	2.0	1.4
T082706	0.1	0.2	0.5	1.8	0.7	0.3	0.1	0.3	0.1	0.1

7.3 The Flood Forecasting

7.3.1 Local Inflow Calculation Process and I/O Data Setup

The collected natural inflows of the upstream reservoirs in the Han River Basin are represented in Fig. 7.2. To set the output data for training the flood forecasting models, local inflow must be calculated at the proposed downstream forecast points in the Han River Basin using the method that was described in Section 4.2.2.1. The results of the local inflow calculation are shown in Fig. 7.3 to Fig. 7.8. The inflows or local inflow and areal estimates of rainfall data from beginning of the flood event time up to the current time were used as a set of input and output data to train the flood forecasting models.

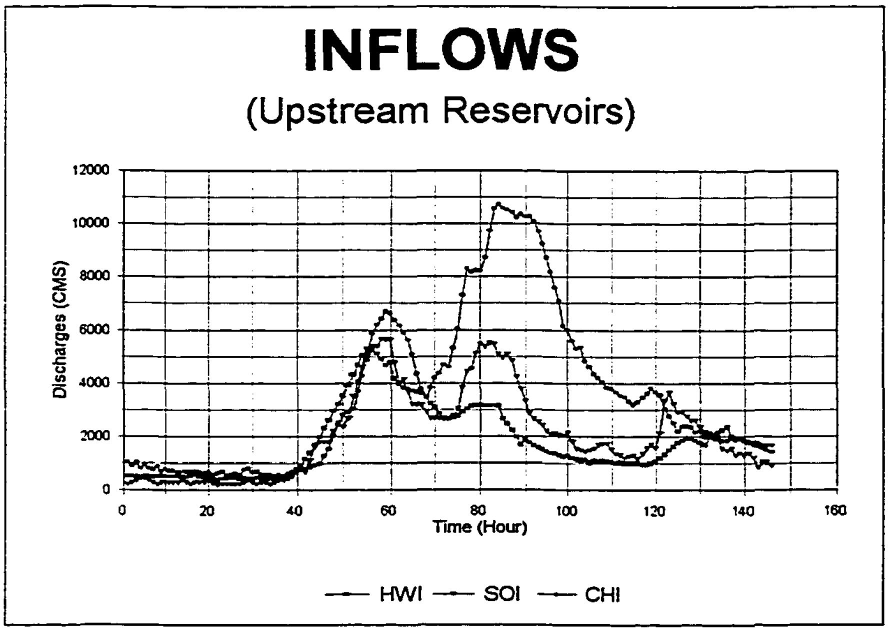


Fig. 7.2 The Collected Natural Inflow of upstream reservoirs

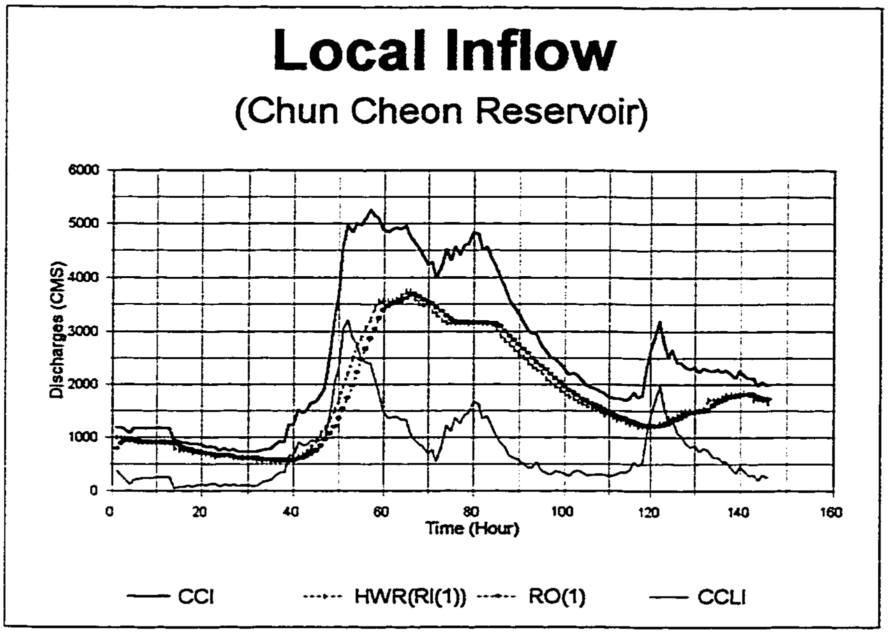


Fig. 7.3 The Results of Local Inflow Calculation at Chun Cheon Reservoir

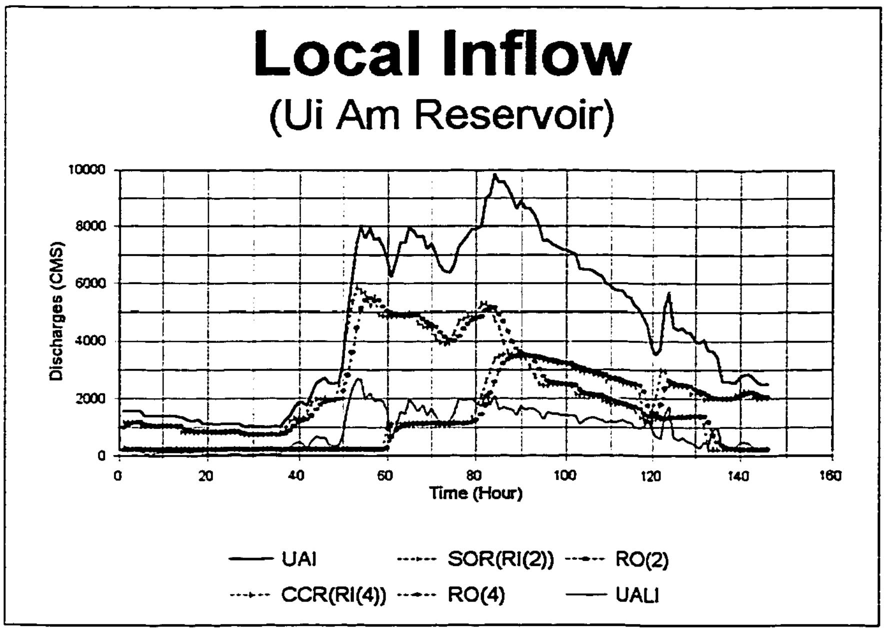


Fig. 7.4 The Results of Local Inflow Calculation at UiAm Reservoir

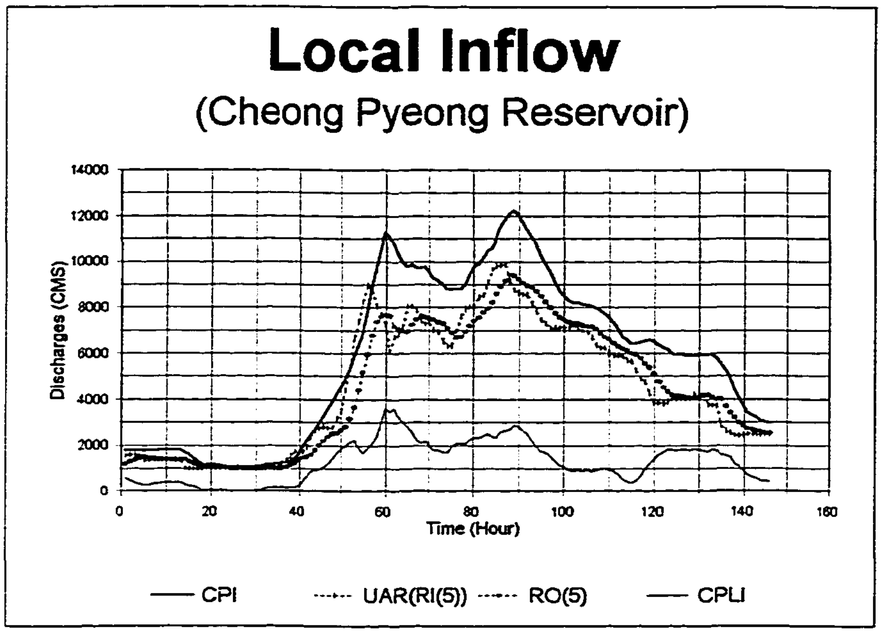


Fig. 7.5 The Results of Local Inflow Calculation at CheongPyeong Reservoir

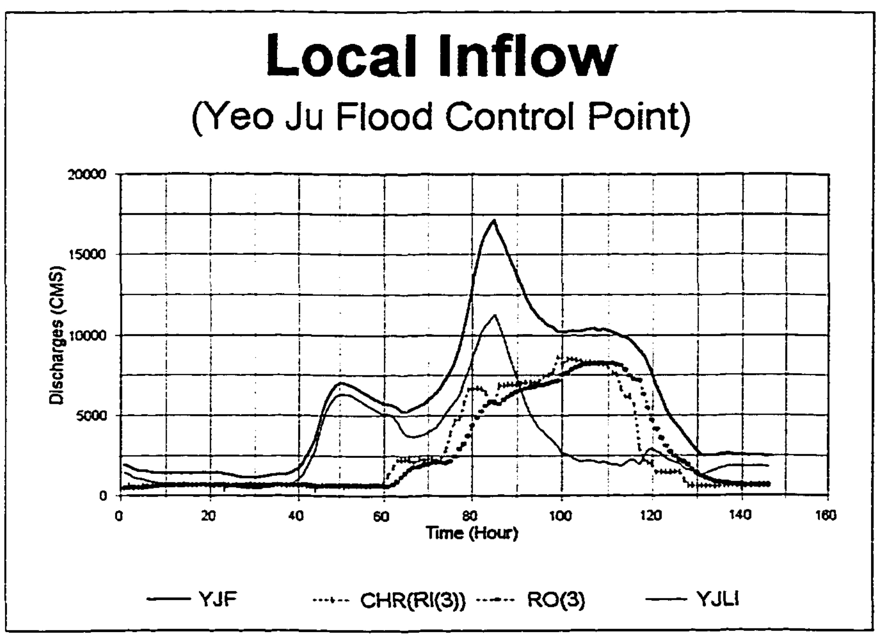


Fig. 7.6 The Results of Local Inflow Calculation at YeoJu Flood Control Point

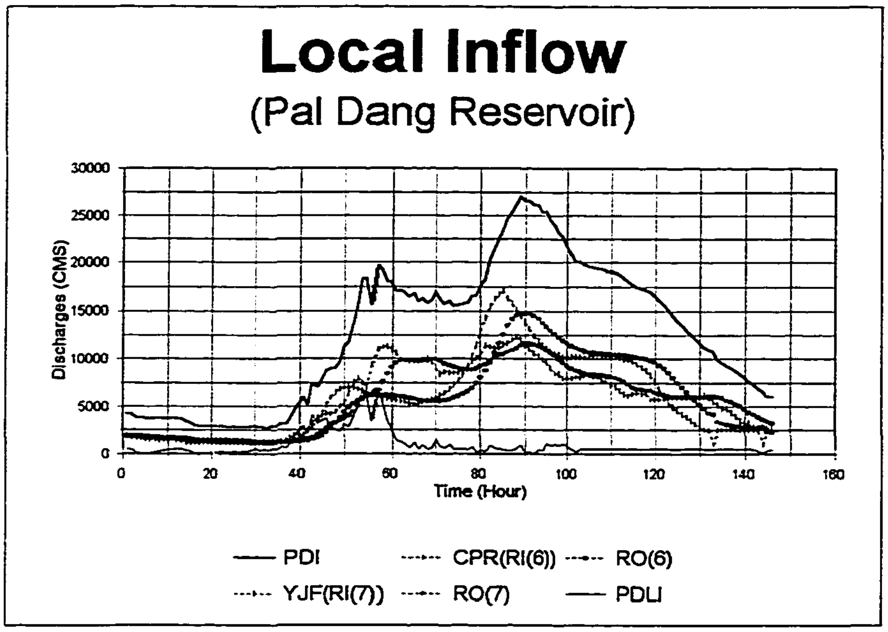


Fig. 7.7 The Results of Local Inflow Calculation at PalDang Reservoir

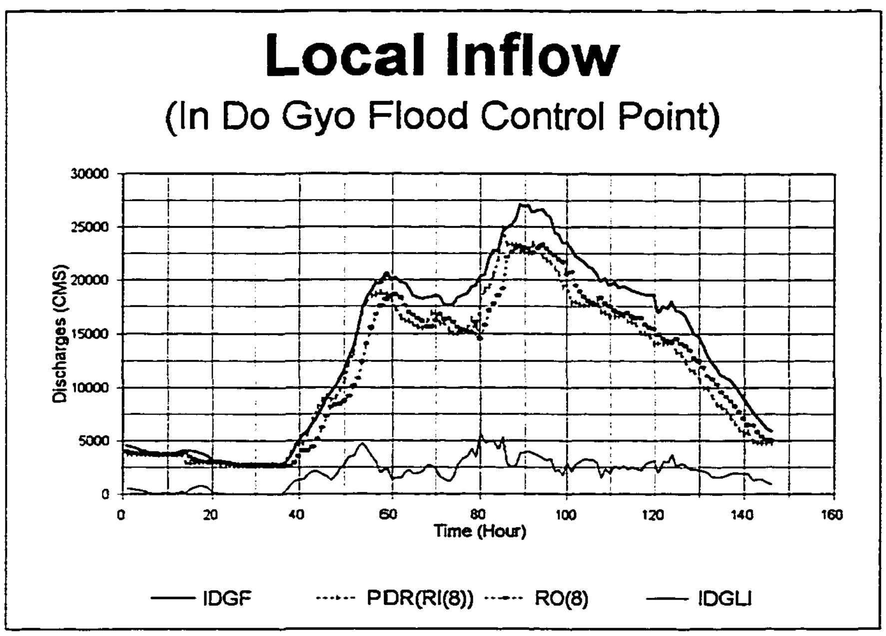


Fig. 7.8 The Results of Local Inflow Calculation at InDoGyo Flood Control Point

7.3.2 Selection of Lag-Time and Forecasting Model Structures

To set k, the parameter of the ANN model structure, the determination of Lag-Time was involved. To do this, effective rainfall of each subbasin was determined based upon author's judgement and information in hydrologic textbooks. Then the effective rainfall and the inflow or local inflow of the related outlet were drawn using the same time horizon. Finally, the Lag-times were selected based on the drawn pictures. All pictures are shown in Fig. B.1 – B.9. The summary of selection for Lag-Time is given in Table 7.2.

Table. 7.2 The Summary of Selection the Lag-Time

Subbasin ID	1	2	3	4	5	6	7	8	9	10
Lag-Time (Hr)	9	8	8	8	13	10	10	10	18	18
Subbasin ID	11	12	13	14	15	16	17	18	19	20
Lag-Time (Hr)	14	10	15	15	14	12	10	11	13	17
Subbasin ID	21	22	23	24	25	26	27	28	29	
Lag-Time (Hr)	16	14	9	10	10	9	16	13	10	

Based on the selection of the Lag-Time, k, the parameter of model structure was identified. The structure of each model is represented as follows;

- HwaCheon Reservoir Inflow Forecasting Model

$$HCI(t+i) = f[R_1(\cdot), R_2(\cdot), R_3(\cdot), HCI(t-j)] \qquad (7\text{-}1)$$

$$R(\cdot) = R(t-k) \text{ For i} = 1\ldots24, \text{j} = 0\ldots6$$

where, $HCI(t+i)$; The Forecasted HwaCheon Reservoir Inflow series

$HCI(t-j)$; The given Hwa Cheon Reservoir Inflow series

$R_1(t-k)$; The given rainfall data series of subbasin 1, k=4...9.

$R_2(t-k)$; The given rainfall data series of subbasin 2, k=3...8.

$R_3(t-k)$; The given rainfall data series of subbasin 3, k=3...8.

- SoYangGang Reservoir Inflow Forecasting Model

$$SOI(t+i) = f[R_5(\cdot), R_6(\cdot), R_7(\cdot), SOI(t-j)] \tag{7-2}$$

$$R(\cdot) = R(t-k) \text{ For i} = 1\ldots24, \text{j} = 0\ldots6$$

where, $SOI(t+i)$; The Forecasted SoYangGang Reservoir Inflow series

$SOI(t-j)$; The given SoYangGang Reservoir Inflow series

$R_5(t-k)$; The given rainfall data series of subbasin 5, k=8...13.

$R_6(t-k)$; The given rainfall data series of subbasin 6, k=5...10.

$R_7(t-k)$; The given rainfall data series of subbasin 7, k=5...10.

- ChungJu Reservoir Inflow Forecasting Model

$$CJI(t+i) = f[R_{13}(\cdot), R_{14}(\cdot), R_{15}(\cdot), R_{16}(\cdot), R_{17}(\cdot), R_{18}(\cdot), R_{19}(\cdot), CJI(t-j)] \tag{7-3}$$

$$R(\cdot) = R(t-k) \text{ For i} = 1\ldots24, \text{j} = 0\ldots6$$

where, $CJI(t+i)$; The Forecasted ChungJu Reservoir Inflow series

$CJI(t-j)$; The given ChungJu Reservoir Inflow series

$R_{13}(t-k)$; The given rainfall data series of subbasin 13, k=10...15.

$R_{14}(t-k)$; The given rainfall data series of subbasin 14, k=10...15.

$R_{15}(t-k)$; The given rainfall data series of subbasin 15, k=9...14.

$R_{16}(t-k)$; The given rainfall data series of subbasin 16, k=7...12.

$R_{17}(t-k)$; The given rainfall data series of subbasin 17, k=5...10.

$R_{18}(t-k)$; The given rainfall data series of subbasin 18, k=6...11.

$R_{19}(t-k)$; The given rainfall data series of subbasin 19, k=8...13.

- Chun Cheon Reservoir Local Inflow Forecasting Model

$$CCLI(t+i) = f[R_4(\cdot), CCLI(t-j)] \quad (7\text{-}4)$$

$$R(\cdot) = R(t-k) \text{ For } i = 1\ldots24, j = 0\ldots6$$

where, $CCLI(t+i)$; The Forecasted Chun Cheon Reservoir Local Inflow series

$CCLI(t-j)$; The given Chun Cheon Reservoir Local Inflow series

$R_4(t-k)$; The given rainfall data series of subbasin 4, k=3...8.

- Ui Am Reservoir Local Inflow Forecasting Model

$$UALI(t+i) = f[R_8(\cdot), UALI(t-j)] \tag{7-5}$$

$R(\cdot) = R(t-k)$ For i = 1...24, j = 0...6

where, $UALI(t+i)$; The Forecasted Ui Am Reservoir Local Inflow series

$UALI(t-j)$; The given Ui Am Reservoir Local Inflow series

$R_8(t-k)$; The given rainfall data series of subbasin 8, k=5...10.

- CheongPyeong Reservoir Local Inflow Forecasting Model

$$CPLI(t+i) = f[R_9(\cdot), R_{10}(\cdot), R_{11}(\cdot), CPLI(t-j)] \tag{7-6}$$

$R(\cdot) = R(t-k)$ For i = 1...24, j = 0...6

where, $CPLI(t+i)$; The Forecasted CheongPyeong Reservoir Local Inflow series

$CPLI(t-j)$; The given CheongPyeong Reservoir Local Inflow series

$R_9(t-k)$; The given rainfall data series of subbasin 9, k=13...18.

$R_{10}(t-k)$; The given rainfall data series of subbasin10, k=13...18.

$R_{11}(t-k)$; The given rainfall data series of subbasin 11, k=9...14.

- YeoJu Local Inflow Forecasting Model

$$YJLI(t+i) = f[R_{20}(\cdot), R_{21}(\cdot), R_{22}(\cdot), R_{23}(\cdot), R_{24}(\cdot), R_{25}(\cdot), R_{26}(\cdot), YJLI(t-j)] \qquad (7\text{-}7)$$

$R(\cdot) = R(t-k)$ For i = 1…24, j = 0…6

where, $YJLI(t+i)$; The Forecasted Local Inflow Series of YeoJu Station

$YJLI(t+i)$; The given Local Inflow Series of YeoJu Station

$R_{20}(t-k)$; The given rainfall data series of subbasin 20, k=12...17.

$R_{21}(t-k)$; The given rainfall data series of subbasin 21, k=11...16.

$R_{22}(t-k)$; The given rainfall data series of subbasin 22, k=9...14.

$R_{23}(t-k)$; The given rainfall data series of subbasin 23, k=3...9.

$R_{24}(t-k)$; The given rainfall data series of subbasin 24, k=5...10.

$R_{25}(t-k)$; The given rainfall data series of subbasin 25, k=5...10.

$R_{26}(t-k)$; The given rainfall data series of subbasin 26, k=3...9.

- PalDang Reservoir Local Inflow Forecasting Model

$$PDLI(t+i) = f[R_{12}(\cdot), R_{27}(\cdot), R_{28}(\cdot), PDLI(t-j)] \qquad (7\text{-}8)$$

$R(\cdot) = R(t-k)$ For i = 1…24, j = 0…6

where, $PDLI(t+i)$; The Forecasted Pal Dang Reservoir Local Inflow series

$PDLI(t-j)$; The Given PalDang Reservoir Local Inflow series

$R_{12}(t-k)$; The given rainfall data series of subbasin 12, k=5...10.

$R_{27}(t-k)$; The given rainfall data series of subbasin 27, k=11...16.

$R_{28}(t-k)$; The given rainfall data series of subbasin 28, k=8...13.

- InDoGyo stream flow Forecasting Model

$$IDGLI(t+i) = f[R_{29}(\cdot), IDGLI(t-j)] \tag{7-9}$$

$$R(\cdot) = R(t-k) \quad \text{For } i = 1\ldots24, j = 0\ldots6$$

where, $IDGLI(t+i)$; The Forecasted Local Inflow series of In Do Gyo Station.

$R_{29}(t-k)$; The given rainfall data series of subbasin 29, k=5...10.

$IDGLI(t-j)$; The given Local Inflow series of InDoGyo Station

7.3.3 Model Training and Calibration

Each model was trained considering the results of 2 experiments that were described in Section 4.2.2.4. The conditions and performance measurements of the models are given in Table C.1 to Table C.9. The entire training time of the models was approximately 1000 seconds, which means that it is possible to retrain the models every time step (in this study 1 hour) when fresh observations are available.

The statistical performance of the identified models for the period from Aug. 22:05 to 25:10 in 1995 is summarized in Table 7.3. The TTT statistic measures the total training time of each model. Most of total training times of models was fast enough except the CHI and YJLI models. The ARMSE statistic measures the residual variance. All of the ARMSE were quietly small. The COR statistic measures the linear correlation between the observed and simulated flows. All of the models were well fitted based on COR statistics. The %PD statistic and %VD measures the percent error in matching the peak flow and volume under the observed and simulated hydrographs respectively: 0.0 is best, a negative value means underestimated, a positive value means overestimated. Only the Pal Dang reservoir local inflow forecasting model had more different errors while the others had only a few. Based on the overall statistics, all of the models were well trained and ready to forecast.

Table 7.3 Calibration Statistics (Data Set;1995 08/22/05 – 08/25/10)

Model Name	TTT(Sec)	ARMSE	COR	%PD	%VD
HWI	12.13	0.03321	0.99685	-0.540	-6.896
SOI	37.86	0.00343	0.99975	0.355	-0.572
CHI	223.74	0.00096	0.99971	0.682	-0.545
CCLI	76.97	0.00830	0.99920	0.182	-0.548
UALI	34.61	0.01798	0.99796	0.567	-0.241
CPLI	22.65	0.00349	0.99720	1.251	-4.960
YJLI	514.45	0.00673	0.99854	0.565	-0.728
PDLI	63.75	0.05968	0.99396	-1.056	-12.879
IDGLI	14.39	0.03393	0.99539	0.212	-3.824

7.3.4 Model Validation and Forecasting

After training the models, the trained or optimized weights and biases were used to forecast an inflow hydrograph for a 24 hour future period. The results of each segment model predictions were used to synthesize the entire hydrograph with 24 one hour, time steps.

Table 7.4 shows the correlation coefficients between the predicted and observed streamflows. Analysis of this table for the columns labeled M-1 shows that the correlation for the last part of the 24 hour period is less than for the first part of the period. In an attempt to improve the accuracy of the predicted hydrograph, EQ. (7-10) was developed based on a heuristic developed by author.

$$X(t+i) = \frac{1}{25-i}\sum_{j=i}^{24} O_j \qquad \text{for } i = 1...24, j = i...24 \qquad (7\text{-}10)$$

where, $X(t+i)$; i-step ahead forecasted inflow or local inflow

O_j ; Simulated output from j^{th} segment module

In Table 7.4, the columns labeled M-2 represent the predicted hydrograph for 24 hour-steps ahead based on EQ. (7-10). The correlation for M-2 shows this that approach improved correlation for the later periods and overall improved the forecast accuracy. The 24-Step-Ahead Forecasted hydrographs for the identified models are shown in Fig. 7.9 to Fig. 7.17.

TABLE 7.4.(a) Model Validation Statistic (Inflow Forecasting for Hwa Cheon, So Yang Gang and Chung Ju)

Model	HWI		SOI		CHI	
Method	M-1	M-2	M-1	M-2	M-1	M-2
Ser01	0.9955	0.9969	0.9991	0.9987	0.9504	0.9997
Ser02	0.9888	0.9969	0.9997	0.9965	0.9523	0.9997
Ser03	0.9830	0.9968	0.9975	0.9958	0.9528	0.9996
Ser04	0.9739	0.9968	0.9969	0.9954	0.9365	0.9987
Ser05	0.9718	0.9968	0.9971	0.9952	0.9187	0.9971
Ser06	0.9707	0.9968	0.9969	0.9952	0.9107	0.9963
Ser07	0.9534	0.9960	0.9955	0.9952	0.9127	0.9963
Ser08	0.9642	0.9947	0.9789	0.9942	0.9265	0.9964
Ser09	0.9380	0.9921	0.9834	0.9936	0.9330	0.9966
Ser10	0.9413	0.9876	0.9745	0.9936	0.9378	0.9968
Ser11	0.9080	0.9807	0.9559	0.9935	0.9416	0.9968
Ser12	0.9062	0.9752	0.9377	0.9929	0.9448	0.9969
Ser13	0.8770	0.9689	0.9237	0.9912	0.9443	0.9968
Ser14	0.8798	0.9619	0.9229	0.9896	0.9423	0.9965
Ser15	0.8546	0.9545	0.9382	0.9881	0.9422	0.9961
Ser16	0.8305	0.9477	0.9560	0.9864	0.9428	0.9955
Ser17	0.7957	0.9410	0.9462	0.9845	0.9472	0.9947
Ser18	0.7949	0.9347	0.9133	0.9837	0.9526	0.9941
Ser19	0.7760	0.9290	0.9392	0.9833	0.9622	0.9939
Ser20	0.8041	0.9238	0.9432	0.9821	0.9695	0.9939
Ser21	0.8235	0.9187	0.9027	0.9813	0.9744	0.9935
Ser22	0.8540	0.9137	0.8511	0.9807	0.9627	0.9933
Ser23	0.8650	0.9064	0.7796	0.9803	0.9360	0.9924
Ser24	0.8837	0.8978	0.6874	0.9749	0.8357	0.9923

TABLE 7.4.(b) Model Validation Statistic (Local Inflow Forecasting for Chun Cheon, Ui Am and Cheong Pyeong)

Model	CCLI		UALI		CPLI	
Method	M-1	M-2	M-1	M-2	M-1	M-2
Ser01	0.9948	0.9989	0.9926	0.9976	0.9967	0.9969
Ser02	0.9939	0.9950	0.9625	0.9973	0.9937	0.9959
Ser03	0.9644	0.9914	0.8485	0.9963	0.9919	0.9951
Ser04	0.9105	0.9897	0.8463	0.9963	0.9876	0.9942
Ser05	0.9110	0.9882	0.8483	0.9900	0.9870	0.9931
Ser06	0.8862	0.9881	0.8447	0.9901	0.9878	0.9929
Ser07	0.8807	0.9880	0.9036	0.9896	0.9794	0.9928
Ser08	0.8243	0.9847	0.9580	0.9895	0.9837	0.9924
Ser09	0.8084	0.9844	0.9172	0.9895	0.9766	0.9914
Ser10	0.7043	0.9832	0.8607	0.9892	0.9679	0.9903
Ser11	0.6555	0.9824	0.7374	0.9848	0.9673	0.9884
Ser12	0.7369	0.9822	0.7196	0.9846	0.9588	0.9861
Ser13	0.8373	0.9822	0.8252	0.9834	0.9577	0.9843
Ser14	0.8710	0.9823	0.7658	0.9815	0.9493	0.9829
Ser15	0.9333	0.9824	0.8445	0.9792	0.9399	0.9828
Ser16	0.9074	0.9824	0.9138	0.9744	0.9200	0.9827
Ser17	0.8665	0.9825	0.8621	0.9718	0.9088	0.9826
Ser18	0.9125	0.9827	0.7046	0.9715	0.9138	0.9825
Ser19	0.7175	0.9825	0.4590	0.9644	0.8826	0.9823
Ser20	0.7862	0.9820	0.7044	0.9632	0.8750	0.9812
Ser21	0.7803	0.9795	0.8934	0.9616	0.8367	0.9769
Ser22	0.8120	0.9774	0.8140	0.9602	0.5555	0.9716
Ser23	0.8316	0.9712	0.8922	0.9586	0.7074	0.9660
Ser24	0.8410	0.9707	0.8842	0.9569	0.7865	0.9610

TABLE 7.4.(c) Model Validation Statistic (Local Inflow Forecasting for Yeo Ju, Pal Dang and In Do Gyo)

Model	YJLI		PDLI		IDGLI	
Method	M-1	M-2	M-1	M-2	M-1	M-2
Ser01	0.9743	0.9985	0.9724	0.9928	0.9765	0.9857
Ser02	0.9700	0.9978	0.9422	0.9919	0.9690	0.9823
Ser03	0.9645	0.9961	0.8764	0.9903	0.8923	0.9829
Ser04	0.9561	0.9948	0.8180	0.9903	0.9345	0.9801
Ser05	0.9523	0.9952	0.8806	0.9892	0.7200	0.9750
Ser06	0.9514	0.9955	0.7725	0.9878	0.6586	0.9693
Ser07	0.9498	0.9957	0.8998	0.9876	0.6080	0.9415
Ser08	0.9664	0.9943	0.9775	0.9876	0.6100	0.9409
Ser09	0.9724	0.9883	0.9800	0.9877	0.6488	0.9403
Ser10	0.9762	0.9794	0.9610	0.9877	0.6683	0.9404
Ser11	0.9762	0.9703	0.9423	0.9872	0.7305	0.9386
Ser12	0.9705	0.9637	0.8293	0.9833	0.7670	0.9374
Ser13	0.9545	0.9567	0.9354	0.9826	0.5396	0.9350
Ser14	0.9228	0.9483	0.9514	0.9818	0.3946	0.9351
Ser15	0.8566	0.9420	0.9314	0.9818	0.4928	0.9344
Ser16	0.7959	0.9394	0.9593	0.9818	0.6998	0.9274
Ser17	0.7488	0.9381	0.9780	0.9812	0.7163	0.9201
Ser18	0.8105	0.9365	0.9780	0.9809	0.5620	0.9186
Ser19	0.8170	0.9350	0.9814	0.9801	0.6179	0.9186
Ser20	0.7914	0.9329	0.9682	0.9794	0.5657	0.9178
Ser21	0.7407	0.9295	0.9730	0.9779	0.5434	0.9175
Ser22	0.6765	0.9232	0.9800	0.9771	0.4632	0.9127
Ser23	0.6009	0.9182	0.9685	0.9772	0.5495	0.9120
Ser24	0.5368	0.9188	0.9594	0.9772	0.5526	0.9065

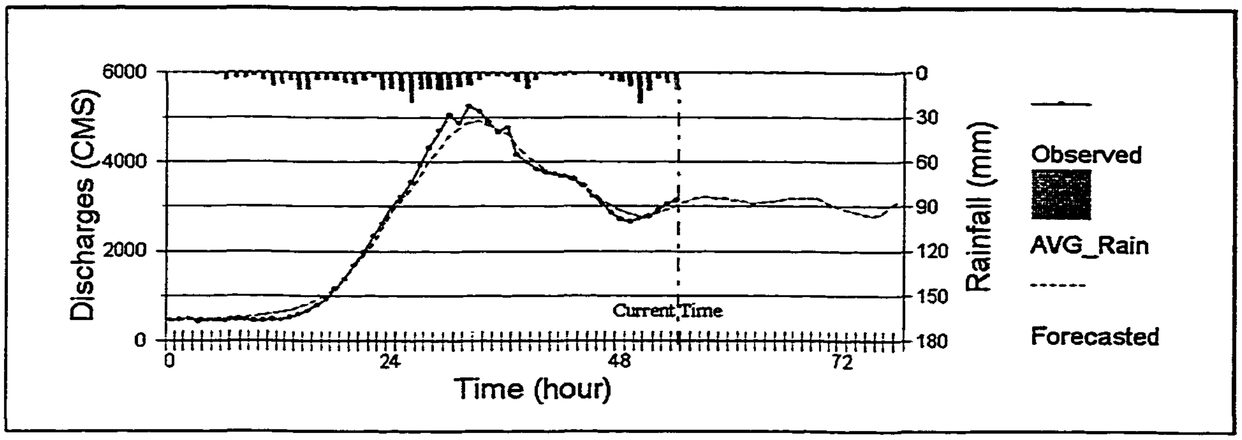


Fig 7.9 24-Step-Ahead Forecasting Hydrograph for Hwa Cheon Reservoir Inflow.

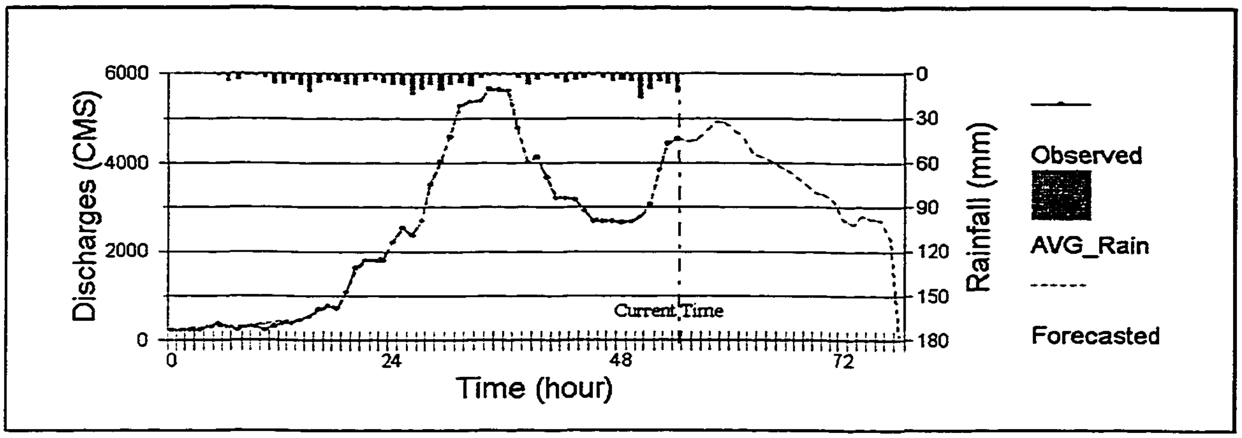


Fig 7.10 24-Step-Ahead Forecasting Hydrograph for So Yang Gang Reservoir Inflow.

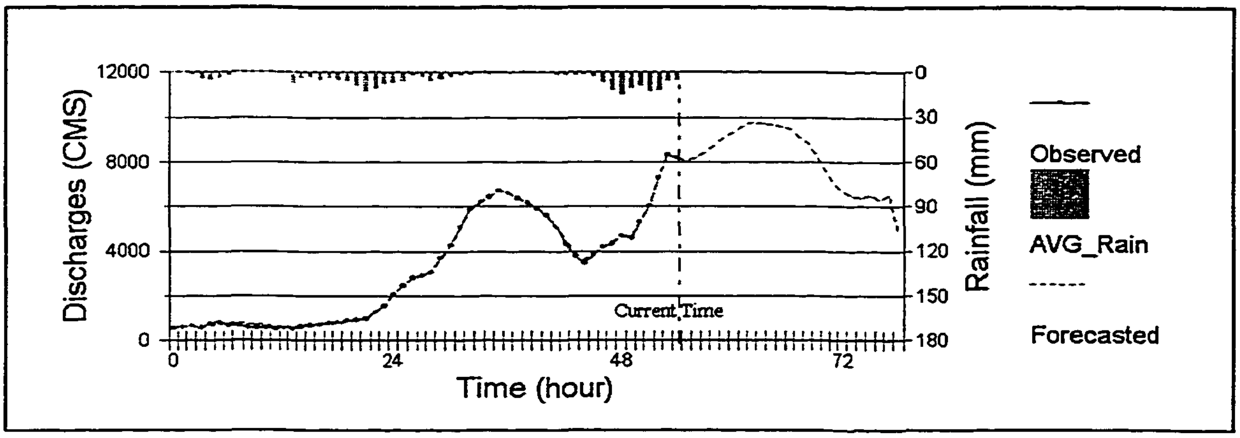


Fig 7.11 24-Step-Ahead Forecasting Hydrograph for Chung Ju Reservoir Inflow.

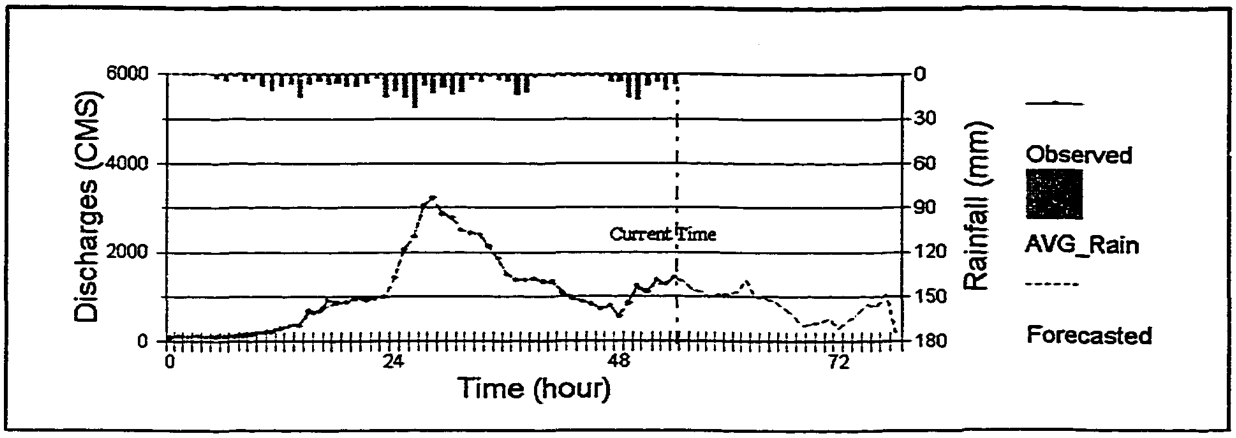


Fig 7.12 24-Step-Ahead Forecasting Hydrograph for the Local Inflow of Chun Cheon Reservoir.

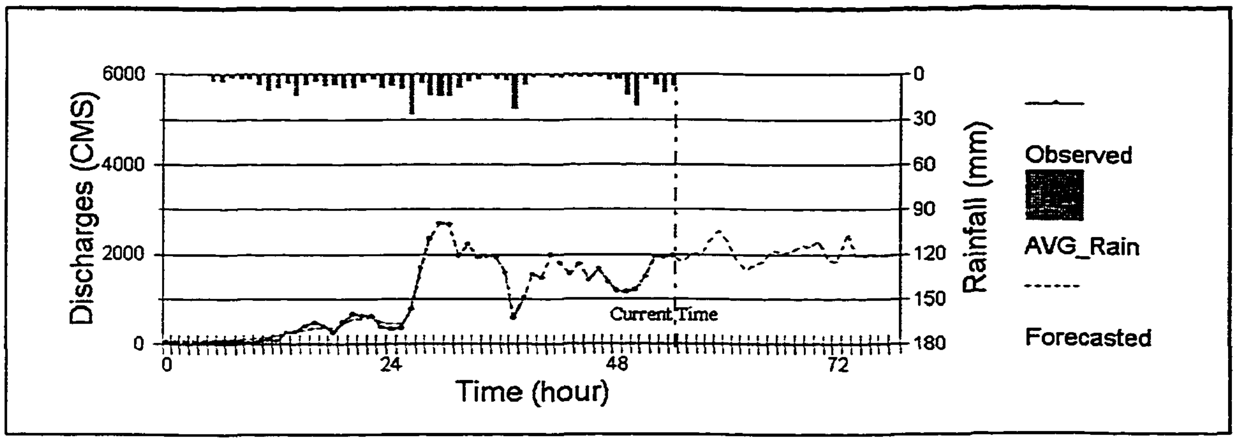


Fig 7.13 24-Step-Ahead Forecasting Hydrograph for the Local Inflow of Ui Am Reservoir.

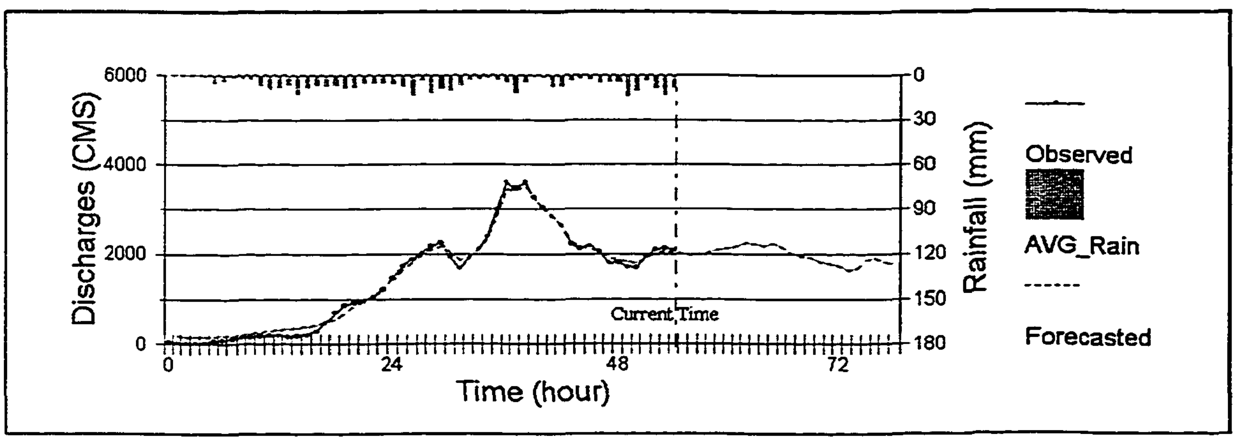


Fig 7.14 24-Step-Ahead Forecasting Hydrograph for the Local Inflow of Cheong Pyeong Reservoir.

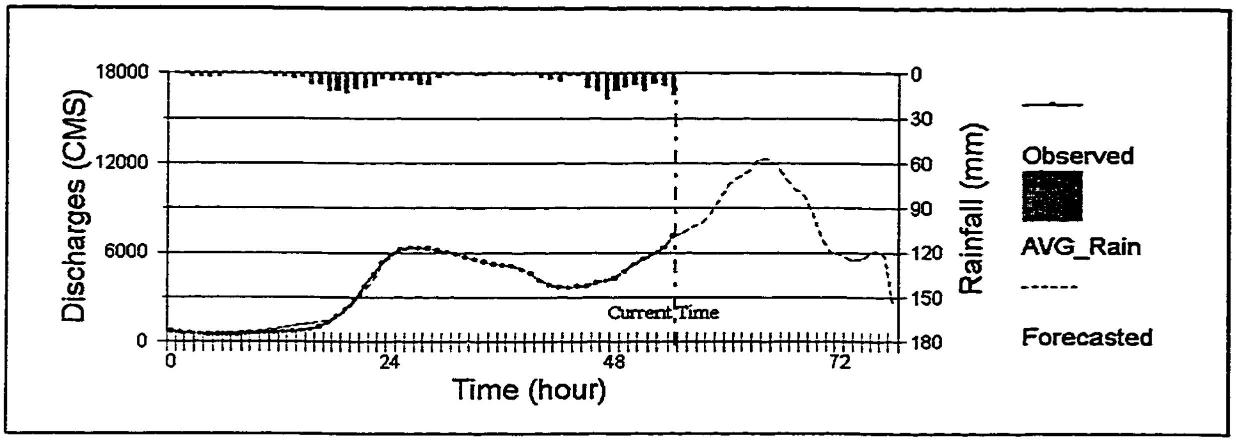


Fig 7.15 24-Step-Ahead Forecasting Hydrograph for the Local Inflow of Yeo Ju Flood Control Point.

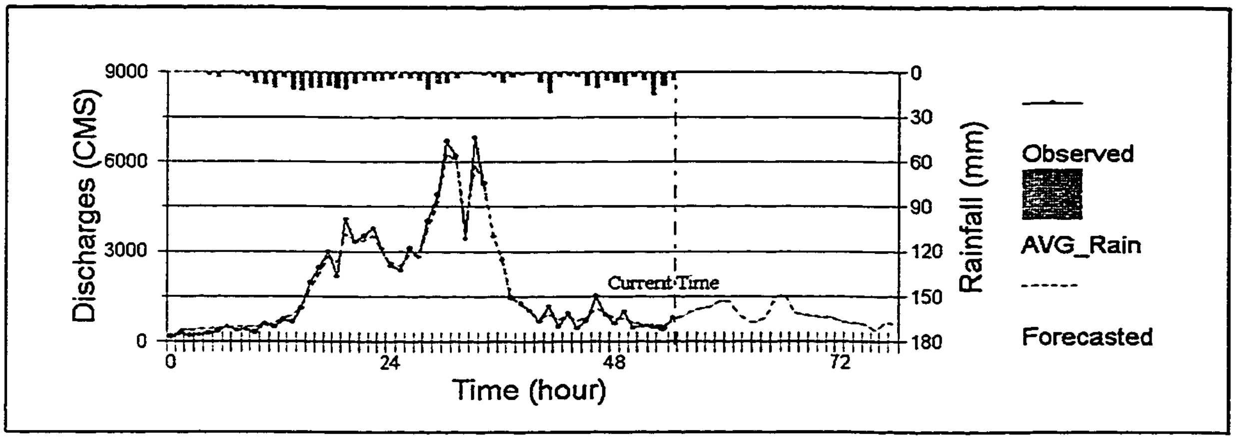


Fig 7.16 24-Step-Ahead Forecasting Hydrograph for the Local Inflow of Pal Dang Reservoir.

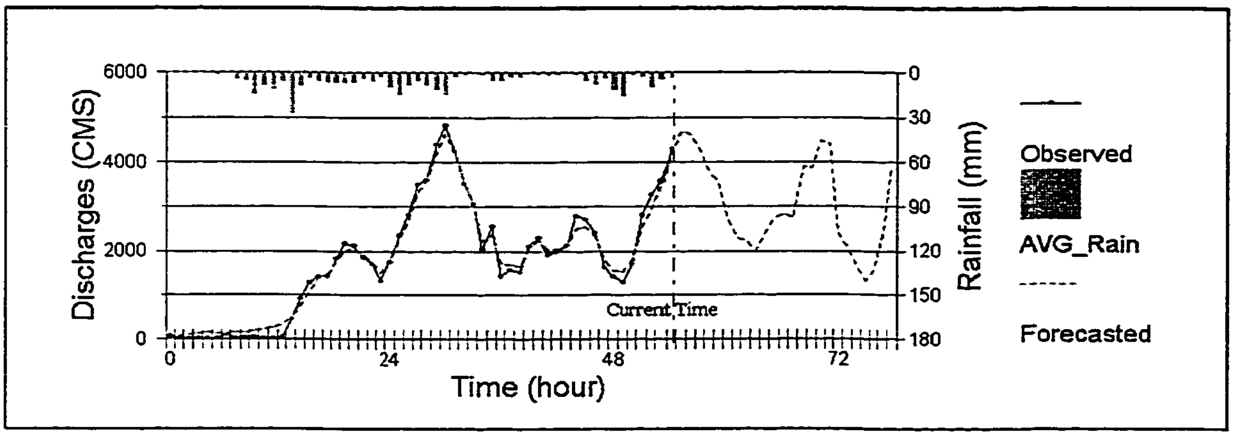


Fig 7.17 24-Step-Ahead Forecasting Hydrograph for the Local Inflow of In Do Gyo Flood Control Point.

7.4 The Operation of Multireservoir Systems for Flood Control

7.4.1 Selection of DPSA Control Data

Table 7.5 shows the flood control capacity, minimum and maximum storages and releases for the proposed nodes. Physically, the flood control capacity of the downstream reservoirs is more than 0.0. However, these flood control capacities were set to no capacity since the reservoirs just open their control gate during the flood. For the upstream reservoir, the limitation storage during the summer season and the total storage capacity were set as the minimum and maximum storage respectively. However, for the downstream reservoirs, the limitation storage during summer season was set the minimum as same as the maximum storage. The current operational records were used to select for minimum and maximum storage for initial stage. Table 7.6 shows the final storages for upstream reservoirs (Hwa Cheon, So Yang Gang and Chung Ju reservoir). The top and 1 m above the top of the full effective storage were set as the minimum and maximum storage for the final stage.

Table 7.5 The Characteristics for Flood Control in the Han River Basin

(Unit: MCM)

Node	Flood Control Capacity	Min Storage	Max Storage	Min Release	Max Release
HW	215.0	740.93	1018.40	0.0	34.20
SO	500.0	2345.00	2872.00	0.0	37.80
CH	616.0	2134.00	2750.00	0.0	74.13
CC	0.0	136.00	136.00	0.0	45.36
UA	0.0	64.00	64.00	0.0	57.60
CP	0.0	167.00	167.00	0.0	72.00
YJ	0.0	0.00	0.00	0.0	47.53
PD	0.0	226.00	226.00	0.0	136.80
IDG	0.0	0.00	0.00	0.0	133.20

Table 7.6 The Minimum and Maximum Storage of Final Stage for Upstream Reservoirs

(Unit: MCM)

Node	Min Storage For Final Stage	Max Storage For Final Stage
HW	803.30	900.00
SO	2543.00	2640.00
CH	2385.00	2655.00

Selection of DELX in CSUDP is extremely important because it affects execution time, computer storage requirements, and solution accuracy. Current dimensioning of CSUDP requires that the value of $(x_{i\max} - x_{i\min})/\text{DELX}$ must be less than the 101 (Labadie, 1990). Based on the criterion above, the DELX (DELXI and DELXF) was selected as shown in Table. 7.7. The splicing factor was incorporated to reduce the execution time. In this study, the value of the splicing factor was 2.

Table 7.7 The Discretization of State and Decision Variables

Node	DELXI	DELXF	DELU
HW	7.0	0.0007	0.0007
SO	22.0	0.0022	0.0022
CH	22.0	0.0022	0.0022
CC	1.0	0.001	0.001
UA	1.0	0.001	0.001
CP	1.0	0.001	0.001
YJ	1.0	0.001	0.001
PD	1.0	0.001	0.001
IDG	1.0	0.001	0.001

The median value between the minimum and maximum storage used to set of the initial trajectory for the first execution only, as shown in Table 7.8. The optimal solution or trajectory of the first execution was used to the initial trajectory in the next execution, which was described in Section 5.3.5.

Table 7.8. The Initial Trajectory for Multireservoir Operation at Aug. /25/10 in 1995.

(Unit: MCM)

Stage	HW	SO	CH	CC	UA	CP	YJ	PD	IDG
1	935.47	2508.68	2253.14	136.00	64.00	167.00	0.00	226.00	0.00
2	880.93	2609.00	2442.00	136.00	64.00	167.00	0.00	226.00	0.00
3	880.93	2609.00	2442.00	136.00	64.00	167.00	0.00	226.00	0.00
4	880.93	2609.00	2442.00	136.00	64.00	167.00	0.00	226.00	0.00
5	880.93	2609.00	2442.00	136.00	64.00	167.00	0.00	226.00	0.00
6	880.93	2609.00	2442.00	136.00	64.00	167.00	0.00	226.00	0.00
7	880.93	2609.00	2442.00	136.00	64.00	167.00	0.00	226.00	0.00
8	880.93	2609.00	2442.00	136.00	64.00	167.00	0.00	226.00	0.00
9	880.93	2609.00	2442.00	136.00	64.00	167.00	0.00	226.00	0.00
10	880.93	2609.00	2442.00	136.00	64.00	167.00	0.00	226.00	0.00
11	880.93	2609.00	2442.00	136.00	64.00	167.00	0.00	226.00	0.00
12	880.93	2609.00	2442.00	136.00	64.00	167.00	0.00	226.00	0.00
13	880.93	2609.00	2442.00	136.00	64.00	167.00	0.00	226.00	0.00
14	880.93	2609.00	2442.00	136.00	64.00	167.00	0.00	226.00	0.00
15	880.93	2609.00	2442.00	136.00	64.00	167.00	0.00	226.00	0.00
16	880.93	2609.00	2442.00	136.00	64.00	167.00	0.00	226.00	0.00
17	880.93	2609.00	2442.00	136.00	64.00	167.00	0.00	226.00	0.00
18	880.93	2609.00	2442.00	136.00	64.00	167.00	0.00	226.00	0.00
19	880.93	2609.00	2442.00	136.00	64.00	167.00	0.00	226.00	0.00
20	880.93	2609.00	2442.00	136.00	64.00	167.00	0.00	226.00	0.00
21	880.93	2609.00	2442.00	136.00	64.00	167.00	0.00	226.00	0.00
22	880.93	2609.00	2442.00	136.00	64.00	167.00	0.00	226.00	0.00
23	880.93	2609.00	2442.00	136.00	64.00	167.00	0.00	226.00	0.00
24	880.93	2609.00	2442.00	136.00	64.00	167.00	0.00	226.00	0.00
25	852.30	2587.00	2517.00	136.00	64.00	167.00	0.00	226.00	0.00

7.4.2 User-Customized Input Data

For executing the HRBSDP, the user-customized input file, HRBS.ADD was required. This file consisted of the Inflow and Local Inflow data that were forecasted by the flood forecasting module, weighting factors and other necessary parameters, which was described in Section 5.3.5. Figure 7.9 through Fig. 7.17 shows forecasted inflow and local inflows by the flood forecasting module. Table 7.9 shows the weighting factor of related objectives.

Table 7.9 The Weighting Factors for the Han River Basin Flood Control Project

Node Name	Objective 1 (W1)	Objective 2 (W2)	Objective 4 (W4)	Objective 5 (W5)	Objective 6 (W6)
HW	0	0	0	10^9	10
SO	0	0	0	10^9	10
CH	0	0	0	10^9	100
CC	0	0	0	0	0
UA	0	0	0	0	0
CP	0	0	0	0	0
YJ	10^9	0	0	0	0
PD	0	0	10^9	0	0
IDG	10^9	0	0	0	0

In the selection of weighting factors, for avoiding the flooding at downstream flood control point, objective 1, relatively large values were selected. For satisfied water demand for the Seoul Metropolitan Area, the weighting factor of objective 4 was also selected as a relatively large value. In addition, the weighting factors for objective 5 were also selected as relatively large values since it is physical constraint. However, weighting factors for avoiding the unacceptable gate control, objective 6 were selected as the relatively small values because those related objectives always violate their restrictions.

For the weighting factor of maintain the water for next hydrologic period water use, the value were selected 0 since storages of upstream reservoirs were already over the their full buffer zone capacity. The weighting factors of objective 3 and 7 should be ignored since objective 3 can be controlled by DPSA method as an boundary condition and objective 7 can be managed by DPSA method as an boundary condition of final stages respectively.

Table 7.10 shows the values of the other parameters required in the HRBSDP run. For the design flood at the downstream flood control points, the values that were already defined by Han River Basin Flood Control Office were used. For the Yeo Ju flood and the In Do Gyo control point, the 100-year and 200-year flood were used for the design flood respectively. For the water demand for the Seoul Metropolitan Area, 80.4 MCM was used at node 8 only. For avoiding unacceptable gate control, the current release amounts were used for the previous release for the first stage only.

Table 7.10 The defined parameter values for the Han River Basin Flood Control Project

Node Name	DFLOOD (CMS)	QPLAN (MCM)	UPRE (CMS)
HW	0.0	0.0	3166.00
SO	0.0	0.0	1151.00
CH	0.0	0.0	5784.00
CC	0.0	0.0	4877.00
UA	0.0	0.0	7925.00
CP	0.0	0.0	9743.00
YJ	13203.0	0.0	10359.28
PD	0.0	80.4	16375.00
IDG	37000.0	0.0	19400.42

7.4.3 The Results and Discussion

The HRBSDP Program was initially run assuming nominal values of 1.0 for routing coefficients. These were subsequently updating by running Program ROUT for the initial controlled release trajectories by Program HRBSDP, followed by repeated solution of HRBSDP with the updated routing coefficients. Convergence of the routing coefficients required about seven iterations. Figure 7.18 shows the sum of squared errors between the routing coefficients. After seven executions of HRBSDP, the sum square error was 0.118514. This amount implies that the mean variation of the routing coefficient was 0.000617 (= 0.118514 / (24*8)). That is, if the simulated flood flow was 1000 CMS then ± 6.17 CMS is the mean error of the simulated flood flow. Therefore, this convergence criterion used to terminate the HRBSDP run.

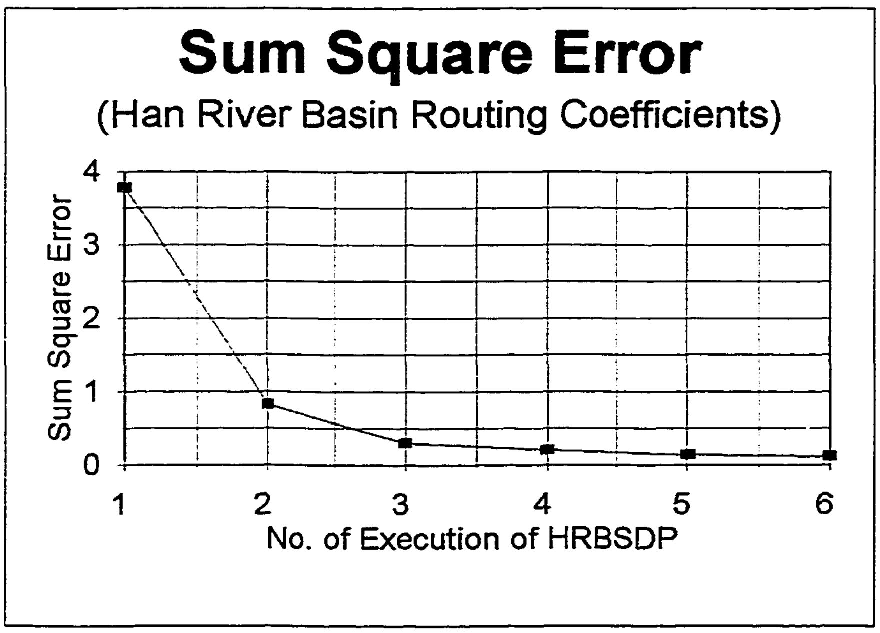


Fig. 7.18 The Sum Square Error for Han River Basin Routing Coefficients

Table 7.11 shows the comparison of peak storages of upstream reservoirs (Hwa Cheon, So Yang Gang and Chung Ju reservoir) between the observed operational data and the simulated data by the HRBSDP. Figure 7.19 through Fig. 7.21 shows the complete comparison of storages of the upstream reservoir during the operational time span. Based on the two comparisons, the results of the HRBSDP maintained more water than the observed operational data. This gives more benefits for water use for the next hydrologic period. However, it can also have more risk in the next flood control project since there is less room to control the following flood events.

Table 7.11 The Comparison of Peak Storages

Classified		Hwa Cheon	So Yang Gang	Chung Ju
Peak Storages	Observed	936.55	2638.07	2468.76
	Simulated	949.34	2643.16	2655.00
Maximum		1018.40	2872.00	2750.00

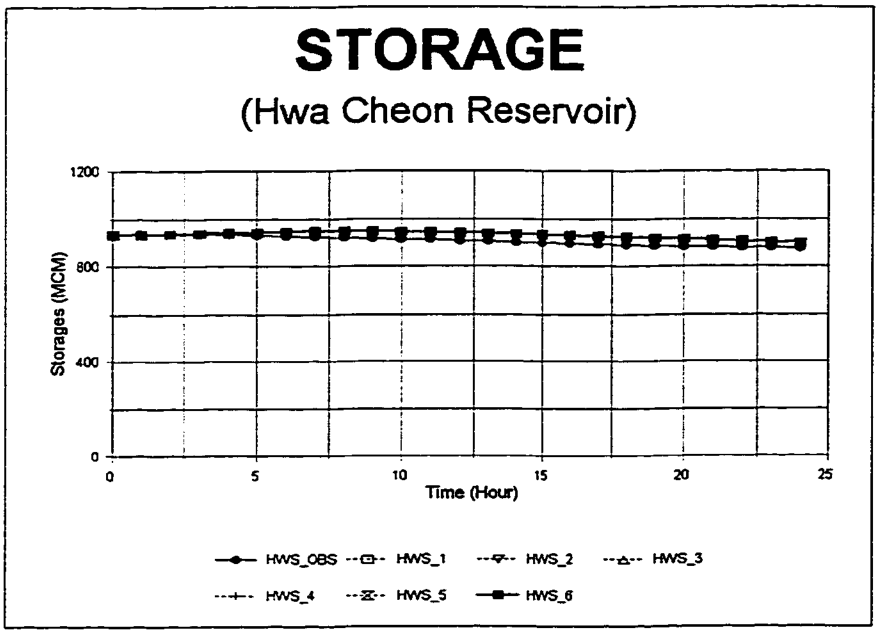


Fig. 7.19 The Storages of Hwa Cheon Reservoir

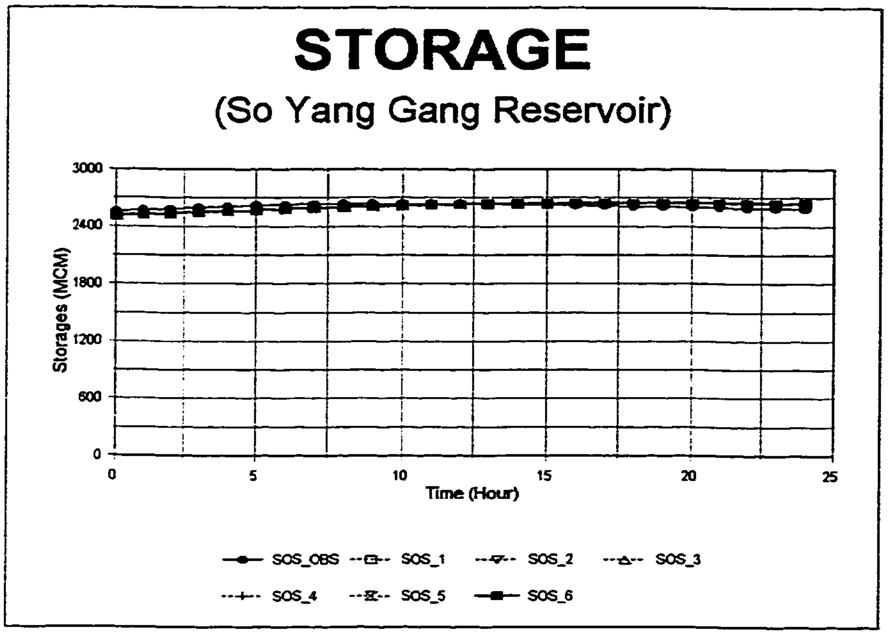


Fig. 7.20 The Storages of So Yang Gang Reservoir

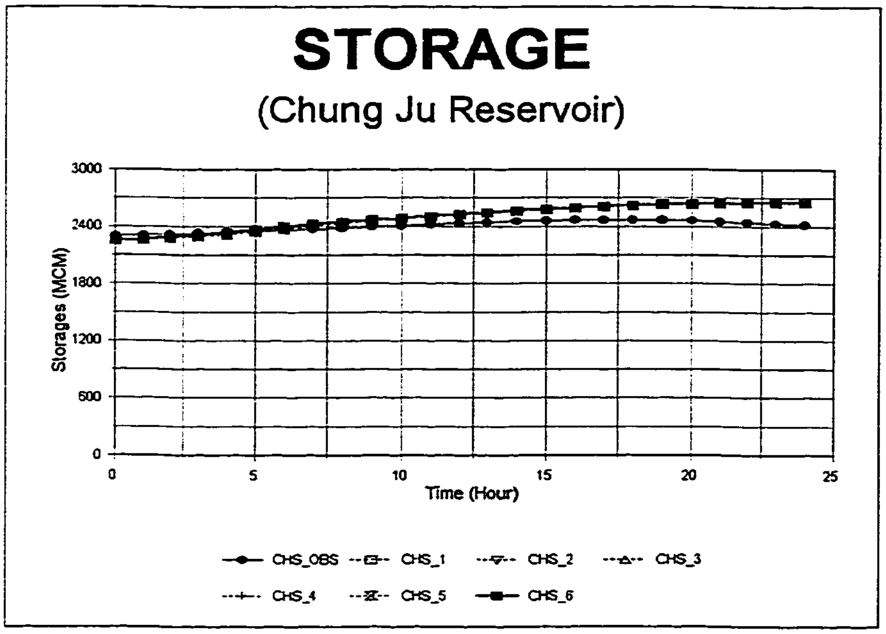


Fig. 7.21 The Storages of Chung Ju Reservoir

Table 7.12 shows the comparison of peak discharges between the observed operational data and simulated data by HRBSDP. Figure 7.22 through Fig. 7.30 show the comparison of release policies between the observed operational data and the simulated data by the HRBSDP. Most of simulated peak discharges by HRBSDP were less than the observed ones. The observed data at Yeo Ju flood control point overflowed its capacity up to a 200-year flood level. However, the peak discharges at Yeo Ju flood control were reduced a lot by the HRBSDP and never overflowed at all, as seen in Fig. 7.28.

Table 7.12 The Comparison of Peak Discharges

NODE	PEAK Discharges (CMS)		
	Observed	Simulated	Difference
HWR	3166.00	3187.58	21.58
SOR	3532.00	2058.83	-1473.17
CHR	8675.00	5832.00	-2843.00
CCR	5279.00	4828.61	-450.39
UAR	9886.00	8613.33	-1272.67
CPR	12308.00	10638.10	-1669.90
YJF	17145.36	13202.50	-3942.86
PDR	24956.00	25345.60	389.60
IDGF	27122.60	29080.60	1958.00

Therefore, the overall results showed that the decision by HRBSDP could minimize the downstream flood impacts while maintaining water for the next hydrologic use.

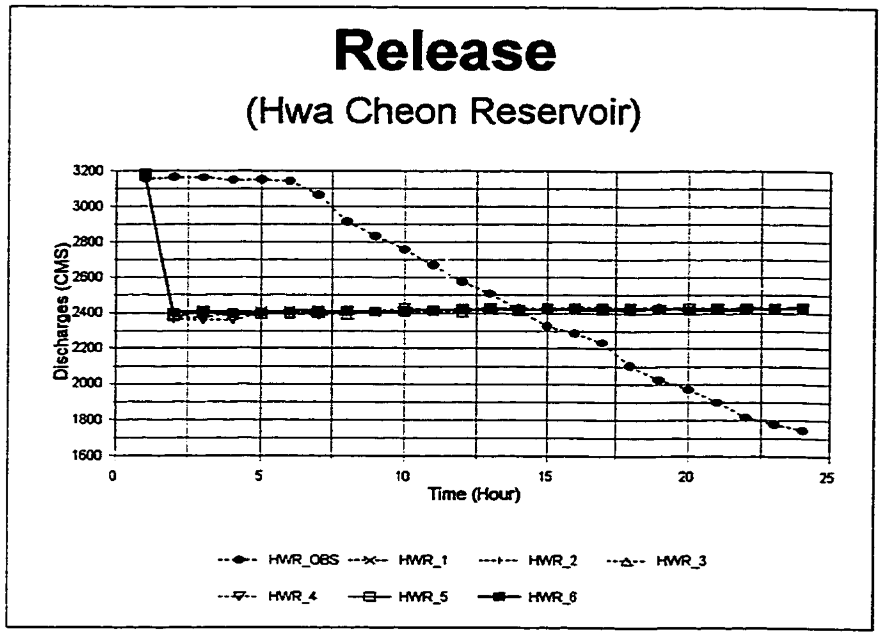


Fig. 7.22 The Release of Hwa Cheon Reservoir

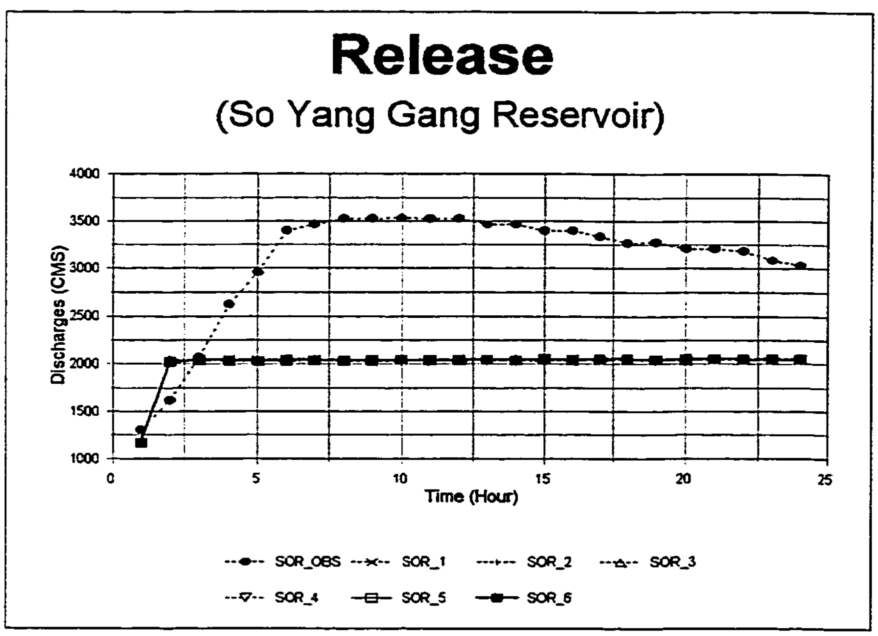


Fig. 7.23 The Release of So Yang Gang Reservoir

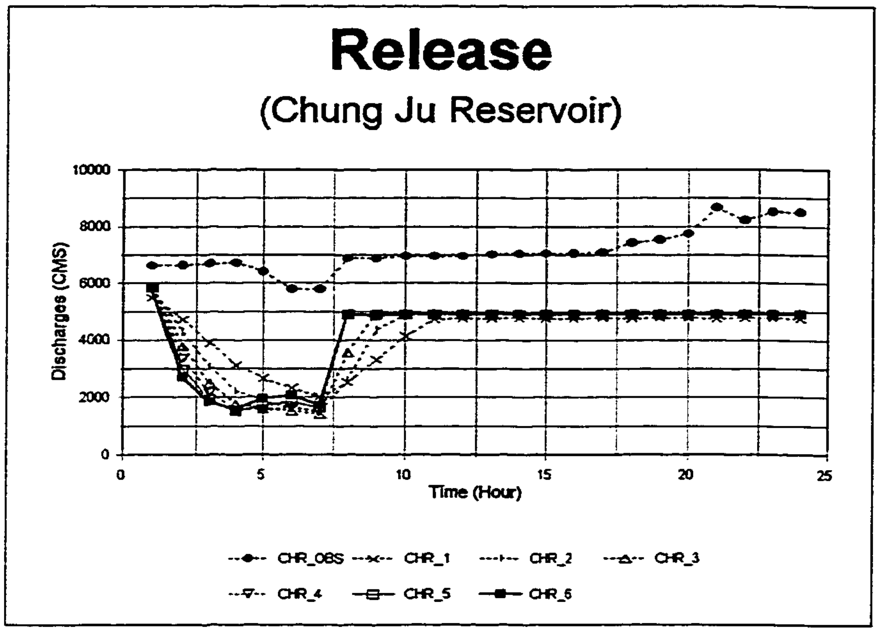


Fig. 7.24 The Release of Chung Ju Reservoir

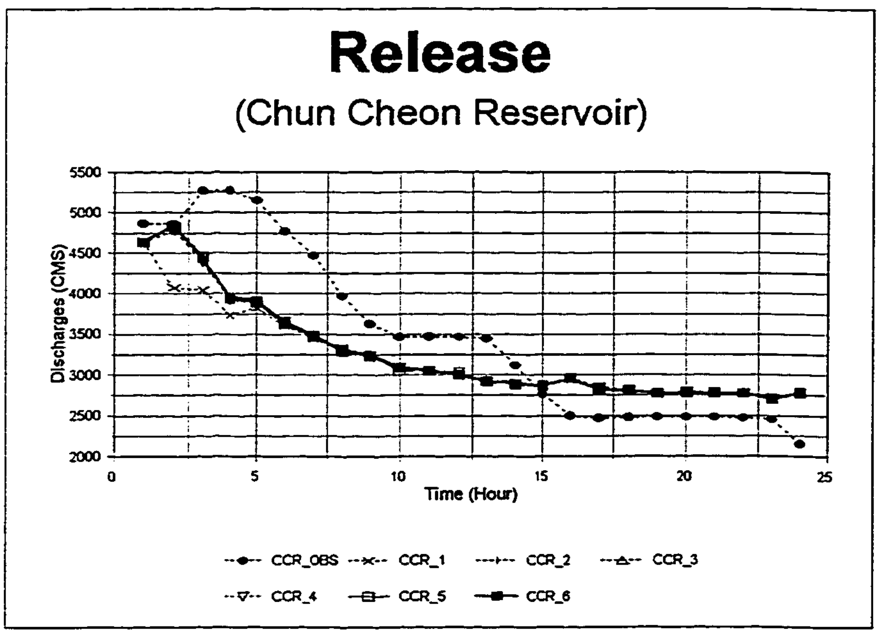


Fig. 7.25 The Release of Chun Cheon Reservoir

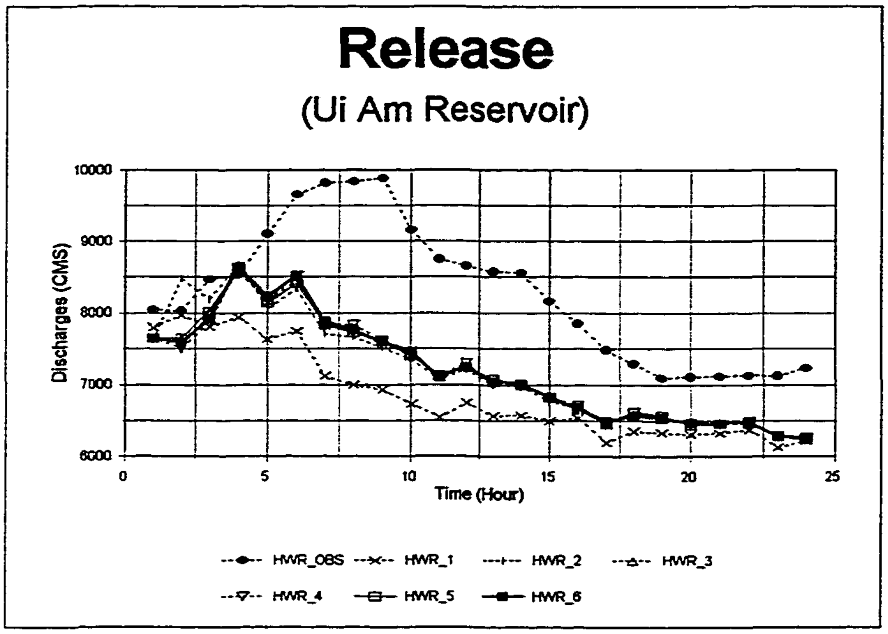


Fig. 7.26 The Release of Ui Am Reservoir

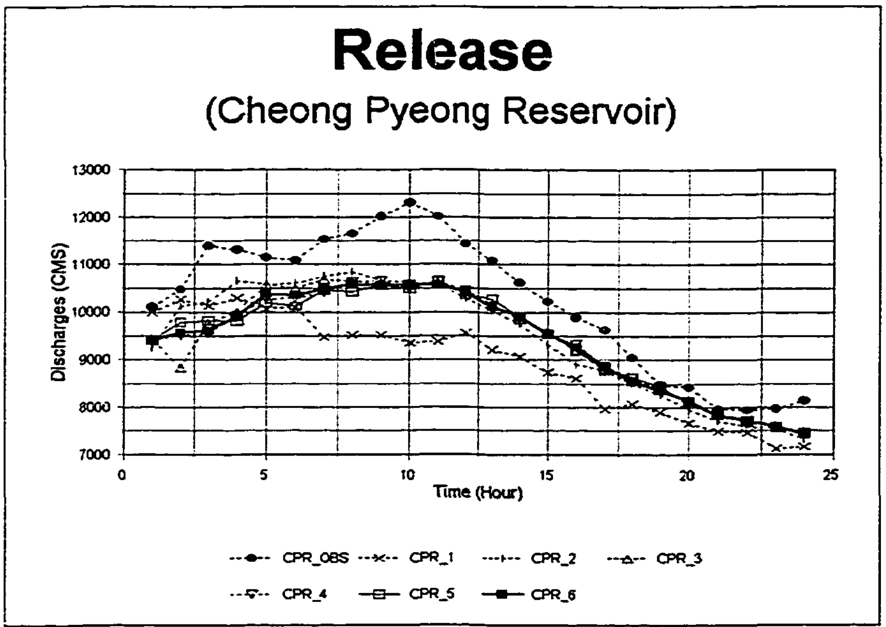


Fig. 7.27 The Release of Cheong Pyeong Reservoir

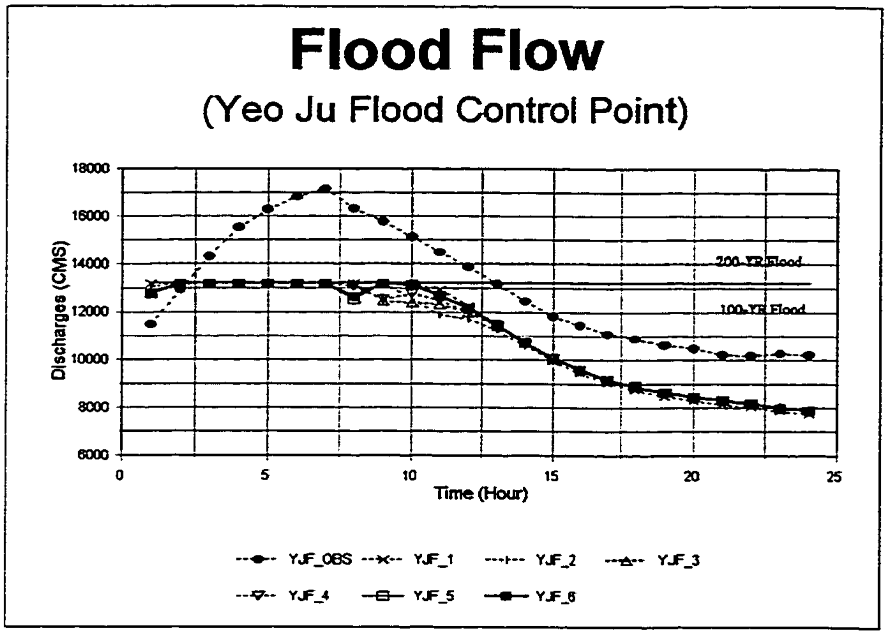


Fig. 7.28 The Flood Flow at Yeo Ju Flood Control Point

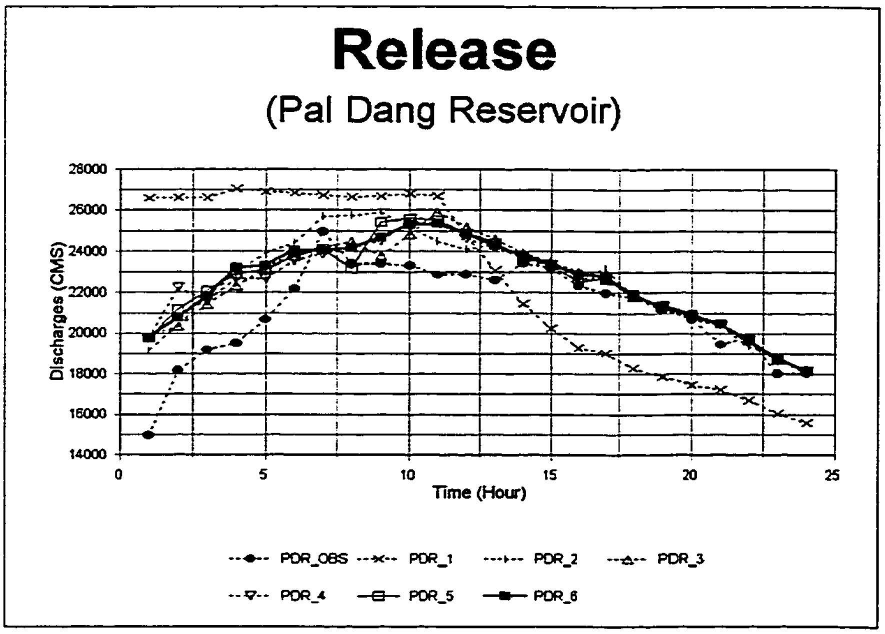


Fig. 7.29 The Release of Pal Dang Reservoir

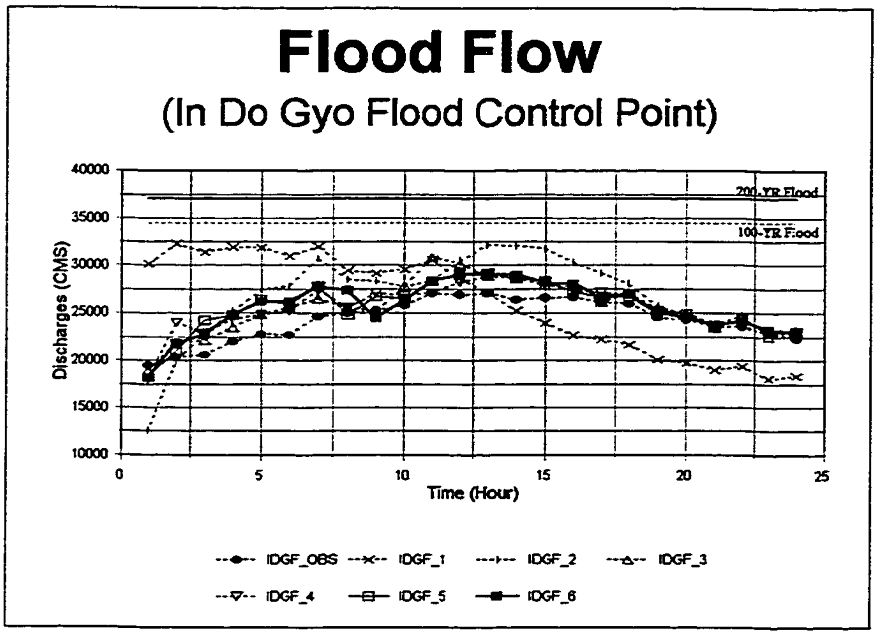


Fig. 7.30 The Flood Flow at In Do Gyo Flood Control Point

CHAPTER VIII

SUMMARY AND CONCLUSIONS

8.1 SUMMARY

During the real-time flood events, the operation of water surface system is important and crucial to minimize the impacts of flood. In order to improve the current approaches of flood forecasting and control systems, a comprehensive methodology has been developed using enhanced technologies, such as neural network algorithms and multidimensional dynamic programming. The developed methodology has been embedded in a PC based Spatial Decision Support System for integrated river basin flood control. For implementing the prototype of SDSS, several submodules have been developed, which consists of: 1) Relational Database Management System, 2) Spatial Analysis Module, 3) Flood Forecasting Module 4) Real-Time Operation of Multireservoir System, and 5) Dialog Module with Graphical User Interface and Graphic Display Systems.

For developing a Relational Database Management System (RDBMS), first, original textural files from the Flood Control Office of the Han River Basin were extracted as raw data. These textural files consisted of the rainfall data of 82 telemetry gages, water level data of 28 telemetry gages and operational data of 7 reservoirs for 10 years (1987 – 1996). The original data files for rainfall, stream flow and operational data files were indexed by two fields, date and gage number (ID) in a single file for all 10 years. Therefore, seeking time for searching the 1-hour record of each gage or reservoir requires significant time. In the newly constructed database, the seeking time for searching the related record was reduced by segmenting the data files into the each table as described in the section 6.2.1 and indexing just a single field (i.e. date), for each table. To reformulate the data file into suited tables for the hanbasin database system simple FORTRAN programs and the QuattroPro for Windows spreadsheet were used. The developed RDBMS serves the as center of the SDSS by updating the real-time hydrologic data throughout the basin and generating the necessary data files for various modules in the system.

For the spatial analysis module, first base maps were collected and generated. The base maps consisted of DEM and thematic maps. The DEM for this study was extracted from the Global 30-Arc-Second Elevation Data Set (GTOPO_30). For the thematic maps, the Korea boundary, streams, water bodies, railroads maps were extracted from the Digital Chart of the World, which is made by Environmental System Research Institute Inc. Those geographic, attribute, and textual data that were accessed, queried, displayed and modified with ARC/INFO software. In addition, other thematic maps including the boundary, reservoirs, rainfall gauging stations, flow gauging stations of the Han River Basin, were created based on the map from Korea National Geographic. The coordinate reference system (Map units) of the base maps was decimal degree, which had been projected on to the Traverse Mercator.

The spatial analysis module was used to generate the isohyets for the Han River Basin for every hour. Then, the one-hour isohyet is used to calculate the areal estimates of rainfall of each subbasin using the spatial analysis tool. Finally, these areal estimates of rainfall were uploaded into a dynamic database table. This dynamic database table was used to generate necessary data files for other modules.

Inflow forecasting models of the upstream reservoirs (HwaCheon, SoYangGang, ChungJu reservoir) and local inflow forecasting models of downstream reservoirs (ChunCheon, UiAm, CheongPyeong and PalDang reservoir) and flood control points (YeoJu, InDoGyo Station) in the Han River Basin were developed using a Multi-layer Feed Forward Neuron Network (MFFNN) Algorithm. In this study, the lag-time was used to make a relationship between the rainfall and runoff.

For the dynamic flood forecasting, it is important to minimize the training time since ANN models can train their weights again after fresh observations of input data become available. To minimize the training time, each model was divided in 24 different segment models with 1 output node each. In addition, initial weights for the next segment module were set by the optimal weights for current segment module. This schema provides significant time saving for training each model. Two experiments were performed to find the best range of parameters for training the models: 1) Number of Hidden Node Testing, 2) Desired Sum of Squared Errors Goal Test. These experiments proved useful to determine best parameters for training the models while minimizing the training time required.

The real-time operation of multireservoir module has been developed to minimize the downstream impacts of floods, while maintaining the water for the next hydrologic period. CSUDP, a generalized dynamic programming model (Labadie, 1988), was selected to develop the Han River Basin System Dynamic Programming (HRBSDP) based on the Dynamic Programming with Successive Approximation (DPSA) algorithm. The HRBSDP consists of user-supplied subroutines (i.e. READIN, STATE, OBJECT and RESULTS), program ROUT and the main CSUDP program. ROUT was externally incorporated to calculate routing coefficients utilized the Muskingum method. Program ROUT was developed using Visual Basic Software.

The Han River Basin Flood Control Project that has 9 state variables was solved using the developed HRBSDP. This project was modeled with has 7 objectives and required constraints. The weighting factors of objective and state variable were involved to flexibly implement under given hydrologic conditions throughout the basin.

For providing the hydrologic information of the preceding 24 hour period to the decision-maker, a Hydrologic Data Monitoring System was developed with a Graphical User Interface (GUI). A spatial and temporal analysis rainfall tool has been developed to give the user or decision-maker a lot of information about the results of the spatial analysis. For creating input files, execution, and displaying the results of various modules, Graphical User Interfaces (GUI) and Graphical Display System (GDS) have been developed and integrated to a Spatial Decision Support System.

Finally, 1995 flood event was used as a case study to demonstrate the developed methodology for integrated river basin flood control for the Han River Basin in Korea. Utilizing this flood event, spatial analysis, flood forecasting and real-time operation of the multireservoir system were evaluated. The results of the case study show the potential implementation and practical use of the developed methodology.

8.2 CONCLUSIONS

The prototype system is intended to demonstrate the potential value of a SDSS to the water resources manager and engineer for operational flood management. The developed SDSS provides an automated process of alternative evaluation and selection within a flexible, fully integrated, interactive, centered relational database management system in a user-friendly computer environment. The river basin decision-maker for flood control should expect that he could manage flood events more effectively by fully grasping the hydrologic situation throughout the basin.

The detailed contribution of each module is as follows:

1. The database management system serves as the center of the spatial decision support system. To speed up access time for the database, various database tables were used instead of single large database table. This enables the developed SDSS to update quickly the real-time hydrologic data throughout the basin and generate the necessary data files for various modules in the system.

2. The GIS module contributes by minimizing the time required for spatial analysis. This module provides isohyets for each time period, as well as new information of the spatial characteristics of the basin. Given such a short time period, as an hour, it would not be possible to analyze the hydrologic process dynamically without the GIS module.

3. The rainfall-runoff models can be easily constructed beforehand without a lot of knowledge of the underlying process using a neural network algorithm. The weights involved can be updated when fresh observations are made available. The developed

rainfall-runoff models can effectively and accurately forecast the for the various control points as well as reservoir inflows throughout the basin.

4. Trial and error procedures can be very time consuming. However, the power of using dynamic programming for reservoir operation should give more assurance to the operational decision-maker, providing quantitative information rather than qualitative information. In addition, combining the optimization and simulation routing technique gives the user more reliable and realistic strategies for real-time operation of multireservoir systems for managing the flood control problem.

5. The graphical user interface should serve the great advantages of time saving, error checking and control, understanding the overall procedures for water resources management problems through guiding the user through the various tasks. In addition, the decision-maker should have more assurance of his decision using the graphical display system, which can show the graphical results of each module. The developed temporal and spatial analysis tool for the current rainfall can help the river basin manager better grasp the rainfall condition throughout the basin at a glance.

6. The case study provides motivation, ease of use, and understanding the overall operational flood management works for the system. The results of case study for 1995 flood event in the Han River Basin have shown that the developed methodology and computer based SDSS can operate water surface system to minimize downstream flood impacts, while maintaining water for next hydrologic period water use during real-time flood events.

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APPENDIXES

APPENDIX A

'1995 Rainfall Events

Table A.1.(a) Database File for Rainfall Gages (Gage 1 to 9 during 1995-8/23/05 – 25/05)

MDTIME	ST1	ST2	ST3	ST4	ST5	ST6	ST7	ST8	ST9
T82305	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82306	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82307	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82308	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
T82309	1.0	7.0	4.0	6.0	1.0	14.0	0.0	2.0	1.0
T82310	0.0	2.0	2.0	3.0	3.0	3.0	7.0	2.0	0.0
T82311	1.0	5.0	0.0	1.0	1.0	1.0	0.0	0.0	0.0
T82312	3.0	7.0	3.0	3.0	8.0	1.0	0.0	0.0	0.0
T82313	14.0	5.0	8.0	3.0	3.0	3.0	0.0	2.0	0.0
T82314	7.0	2.0	7.0	7.0	11.0	13.0	3.0	2.0	1.0
T82315	11.0	8.0	8.0	8.0	12.0	10.0	11.0	13.0	0.0
T82316	3.0	11.0	4.0	6.0	8.0	17.0	10.0	9.0	2.0
T82317	24.0	31.0	13.0	11.0	4.0	4.0	1.0	1.0	2.0
T82318	25.0	4.0	10.0	11.0	19.0	25.0	4.0	13.0	0.0
T82319	3.0	1.0	4.0	4.0	6.0	3.0	11.0	20.0	6.0
T82320	5.0	4.0	6.0	5.0	3.0	5.0	6.0	10.0	19.0
T82321	6.0	6.0	6.0	8.0	5.0	6.0	7.0	8.0	19.0
T82322	10.0	2.0	8.0	7.0	5.0	8.0	4.0	6.0	8.0
T82323	6.0	6.0	8.0	9.0	6.0	6.0	10.0	8.0	13.0
T82400	7.0	11.0	7.0	9.0	7.0	7.0	6.0	8.0	6.0
T82401	3.0	6.0	4.0	4.0	7.0	5.0	6.0	6.0	3.0
T82402	5.0	6.0	3.0	3.0	0.0	3.0	7.0	5.0	3.0
T82403	3.0	3.0	4.0	5.0	30.0	4.0	3.0	3.0	2.0
T82404	0.0	13.0	2.0	5.0	16.0	3.0	4.0	4.0	1.0
T82405	5.0	27.0	7.0	12.0	21.0	2.0	2.0	0.0	0.0
T82406	11.0	7.0	12.0	29.0	12.0	5.0	6.0	1.0	0.0
T82407	14.0	4.0	6.0	4.0	11.0	3.0	2.0	1.0	1.0
T82408	18.0	1.0	23.0	23.0	12.0	15.0	6.0	4.0	40.0
T82409	13.0	2.0	11.0	9.0	5.0	9.0	8.0	5.0	12.0
T82410	14.0	17.0	16.0	28.0	9.0	2.0	3.0	3.0	0.0
T82411	10.0	0.0	10.0	16.0	16.0	7.0	3.0	2.0	0.0
T82412	1.0	3.0	1.0	0.0	0.0	4.0	1.0	1.0	0.0
T82413	0.0	1.0	0.0	1.0	7.0	0.0	1.0	0.0	0.0
T82414	0.0	5.0	0.0	1.0	1.0	7.0	0.0	0.0	0.0
T82415	6.0	3.0	0.0	3.0	1.0	0.0	3.0	0.0	0.0
T82416	12.0	0.0	5.0	12.0	4.0	7.0	0.0	1.0	0.0
T82417	0.0	5.0	13.0	24.0	4.0	13.0	2.0	5.0	0.0
T82418	2.0	6.0	3.0	4.0	20.0	0.0	3.0	1.0	0.0
T82419	0.0	0.0	2.0	0.0	3.0	1.0	1.0	0.0	0.0
T82420	1.0	0.0	0.0	1.0	0.0	0.0	1.0	1.0	0.0
T82421	0.0	0.0	0.0	0.0	0.0	18.0	5.0	19.0	3.0
T82422	2.0	0.0	0.0	0.0	0.0	1.0	24.0	21.0	3.0
T82423	1.0	0.0	2.0	0.0	1.0	5.0	9.0	9.0	1.0
T82500	2.0	0.0	1.0	1.0	1.0	1.0	4.0	4.0	0.0
T82501	3.0	1.0	2.0	2.0	1.0	2.0	2.0	3.0	5.0
T82502	9.0	23.0	3.0	3.0	1.0	4.0	7.0	6.0	8.0
T82503	2.0	3.0	0.0	2.0	10.0	2.0	5.0	4.0	4.0
T82504	4.0	33.0	3.0	1.0	6.0	2.0	1.0	2.0	5.0
T82505	13.0	25.0	21.0	25.0	11.0	11.0	5.0	7.0	8.0

Table A.1.(b) Database File for Rainfall Gages (Gage 10 to 18 during 1995-8/23/05 – 25/05)

MDTIME	ST10	ST11	ST12	ST13	ST14	ST15	ST16	ST17	ST18
T82305	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82306	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82307	1.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0
T82308	3.0	0.0	2.0	2.0	5.0	14.0	0.0	0.0	0.0
T82309	2.0	1.0	9.0	0.0	2.0	0.0	0.0	4.0	0.0
T82310	0.0	1.0	0.0	0.0	0.0	0.0	0.0	3.0	1.0
T82311	0.0	0.0	1.0	0.0	1.0	4.0	3.0	2.0	9.0
T82312	0.0	1.0	3.0	1.0	3.0	5.0	5.0	2.0	11.0
T82313	1.0	1.0	6.0	0.0	4.0	18.0	27.0	2.0	11.0
T82314	0.0	2.0	13.0	1.0	12.0	5.0	12.0	4.0	14.0
T82315	2.0	1.0	23.0	8.0	8.0	15.0	19.0	9.0	17.0
T82316	3.0	1.0	1.0	5.0	1.0	2.0	7.0	9.0	4.0
T82317	8.0	3.0	8.0	5.0	6.0	9.0	45.0	5.0	23.0
T82318	1.0	1.0	19.0	2.0	11.0	24.0	12.0	11.0	11.0
T82319	5.0	27.0	16.0	2.0	13.0	20.0	5.0	5.0	2.0
T82320	8.0	12.0	14.0	7.0	9.0	8.0	5.0	4.0	5.0
T82321	17.0	15.0	6.0	26.0	9.0	5.0	8.0	7.0	6.0
T82322	21.0	26.0	8.0	11.0	10.0	5.0	6.0	7.0	6.0
T82323	34.0	26.0	8.0	17.0	14.0	9.0	7.0	9.0	6.0
T82400	12.0	8.0	9.0	23.0	5.0	7.0	7.0	9.0	7.0
T82401	9.0	5.0	7.0	12.0	6.0	4.0	4.0	5.0	3.0
T82402	7.0	5.0	8.0	5.0	7.0	8.0	7.0	2.0	9.0
T82403	3.0	5.0	10.0	2.0	7.0	11.0	1.0	6.0	4.0
T82404	1.0	4.0	9.0	0.0	4.0	4.0	1.0	6.0	10.0
T82405	0.0	0.0	1.0	0.0	0.0	0.0	7.0	5.0	31.0
T82406	1.0	1.0	0.0	0.0	0.0	0.0	2.0	26.0	6.0
T82407	2.0	2.0	6.0	3.0	2.0	9.0	3.0	7.0	1.0
T82408	4.0	9.0	20.0	2.0	5.0	6.0	12.0	15.0	1.0
T82409	0.0	2.0	11.0	0.0	4.0	5.0	9.0	21.0	2.0
T82410	1.0	1.0	6.0	0.0	1.0	2.0	16.0	14.0	20.0
T82411	0.0	0.0	2.0	2.0	1.0	1.0	5.0	7.0	0.0
T82412	1.0	0.0	0.0	0.0	0.0	2.0	1.0	5.0	1.0
T82413	2.0	1.0	2.0	2.0	1.0	0.0	0.0	0.0	2.0
T82414	3.0	1.0	0.0	1.0	1.0	1.0	0.0	0.0	0.0
T82415	1.0	2.0	0.0	1.0	3.0	6.0	16.0	0.0	7.0
T82416	0.0	0.0	15.0	0.0	3.0	10.0	11.0	2.0	2.0
T82417	0.0	2.0	1.0	0.0	1.0	2.0	2.0	30.0	10.0
T82418	0.0	0.0	1.0	1.0	0.0	0.0	2.0	3.0	6.0
T82419	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
T82420	0.0	4.0	10.0	1.0	10.0	45.0	0.0	0.0	0.0
T82421	5.0	4.0	56.0	3.0	19.0	2.0	0.0	0.0	0.0
T82422	1.0	1.0	4.0	0.0	0.0	2.0	4.0	1.0	0.0
T82423	1.0	1.0	1.0	2.0	3.0	1.0	0.0	1.0	1.0
T82500	1.0	1.0	1.0	1.0	8.0	3.0	3.0	1.0	0.0
T82501	20.0	14.0	7.0	26.0	14.0	22.0	11.0	2.0	1.0
T82502	15.0	13.0	11.0	16.0	16.0	29.0	10.0	1.0	4.0
T82503	8.0	8.0	9.0	6.0	8.0	6.0	1.0	4.0	4.0
T82504	7.0	8.0	10.0	13.0	8.0	3.0	7.0	1.0	22.0
T82505	8.0	9.0	8.0	8.0	3.0	2.0	1.0	10.0	33.0

Table A.1.(c) Database File for Rainfall Gages (Gage 19 to 27 during 1995-8/23/05 – 25/05)

MDTIME	ST19	ST20	ST21	ST22	ST23	ST24	ST25	ST26	ST27
T82305	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82306	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	1.0
T82307	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	4.0
T82308	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	1.0
T82309	0.0	0.0	0.0	1.0	1.0	5.0	11.0	0.0	0.0
T82310	0.0	0.0	0.0	0.0	0.0	5.0	1.0	0.0	0.0
T82311	6.0	2.0	3.0	2.0	1.0	2.0	0.0	1.0	0.0
T82312	4.0	4.0	9.0	5.0	2.0	6.0	1.0	1.0	0.0
T82313	21.0	18.0	7.0	7.0	7.0	3.0	3.0	2.0	0.0
T82314	13.0	5.0	8.0	16.0	5.0	9.0	15.0	0.0	0.0
T82315	9.0	9.0	5.0	11.0	7.0	10.0	7.0	3.0	1.0
T82316	2.0	7.0	9.0	8.0	2.0	8.0	12.0	1.0	4.0
T82317	28.0	29.0	22.0	21.0	13.0	10.0	6.0	8.0	7.0
T82318	7.0	6.0	2.0	1.0	9.0	16.0	12.0	2.0	1.0
T82319	3.0	4.0	4.0	3.0	3.0	4.0	16.0	8.0	2.0
T82320	8.0	5.0	8.0	8.0	3.0	4.0	18.0	21.0	6.0
T82321	6.0	8.0	8.0	7.0	3.0	9.0	4.0	37.0	17.0
T82322	8.0	7.0	6.0	4.0	4.0	6.0	5.0	35.0	19.0
T82323	7.0	7.0	7.0	10.0	4.0	10.0	8.0	24.0	16.0
T82400	5.0	5.0	4.0	3.0	3.0	10.0	8.0	7.0	17.0
T82401	2.0	3.0	3.0	1.0	2.0	6.0	7.0	6.0	11.0
T82402	6.0	4.0	5.0	4.0	3.0	5.0	5.0	6.0	6.0
T82403	1.0	1.0	3.0	1.0	2.0	15.0	4.0	5.0	2.0
T82404	19.0	0.0	1.0	36.0	1.0	12.0	6.0	0.0	0.0
T82405	19.0	4.0	16.0	17.0	2.0	24.0	1.0	0.0	0.0
T82406	3.0	24.0	3.0	0.0	2.0	44.0	3.0	0.0	1.0
T82407	7.0	2.0	6.0	6.0	3.0	4.0	2.0	5.0	1.0
T82408	6.0	13.0	2.0	1.0	7.0	10.0	4.0	11.0	4.0
T82409	20.0	18.0	16.0	3.0	5.0	3.0	5.0	0.0	0.0
T82410	15.0	11.0	11.0	11.0	5.0	20.0	4.0	0.0	1.0
T82411	3.0	2.0	1.0	0.0	3.0	13.0	2.0	1.0	1.0
T82412	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0
T82413	0.0	0.0	0.0	0.0	0.0	10.0	0.0	2.0	1.0
T82414	2.0	0.0	0.0	0.0	0.0	1.0	1.0	4.0	3.0
T82415	0.0	10.0	0.0	1.0	4.0	13.0	1.0	1.0	1.0
T82416	6.0	6.0	1.0	1.0	5.0	6.0	9.0	0.0	0.0
T82417	1.0	0.0	1.0	1.0	0.0	32.0	4.0	0.0	0.0
T82418	2.0	2.0	1.0	2.0	1.0	18.0	1.0	0.0	0.0
T82419	2.0	1.0	1.0	1.0	0.0	1.0	0.0	0.0	0.0
T82420	0.0	0.0	0.0	0.0	1.0	1.0	3.0	3.0	3.0
T82421	0.0	0.0	0.0	0.0	5.0	0.0	18.0	5.0	0.0
T82422	0.0	2.0	1.0	0.0	1.0	0.0	11.0	0.0	0.0
T82423	1.0	0.0	1.0	1.0	0.0	0.0	5.0	2.0	2.0
T82500	1.0	2.0	3.0	6.0	1.0	1.0	1.0	2.0	1.0
T82501	3.0	5.0	7.0	11.0	4.0	1.0	4.0	28.0	11.0
T82502	3.0	6.0	0.0	1.0	5.0	1.0	8.0	6.0	14.0
T82503	6.0	2.0	5.0	4.0	2.0	4.0	6.0	5.0	9.0
T82504	5.0	4.0	8.0	6.0	3.0	7.0	4.0	8.0	8.0
T82505	27.0	2.0	0.0	3.0	3.0	36.0	9.0	8.0	8.0

Table A.1.(d) Database File for Rainfall Gages (Gage 28 to 36 during 1995-8/23/05 – 25/05)

MDTIME	ST28	ST29	ST30	ST31	ST32	ST33	ST34	ST35	ST36
T82305	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82306	0.0	4.0	0.0	0.0	0.0	0.0	1.0	0.0	16.0
T82307	1.0	1.0	3.0	19.0	1.0	0.0	2.0	2.0	12.0
T82308	2.0	3.0	16.0	9.0	10.0	2.0	0.0	7.0	1.0
T82309	1.0	0.0	4.0	0.0	4.0	3.0	0.0	12.0	0.0
T82310	0.0	0.0	0.0	0.0	1.0	6.0	0.0	0.0	0.0
T82311	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82312	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82313	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82314	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
T82315	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	9.0
T82316	2.0	0.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0
T82317	1.0	0.0	0.0	29.0	5.0	3.0	0.0	29.0	16.0
T82318	5.0	0.0	18.0	0.0	1.0	4.0	0.0	5.0	0.0
T82319	4.0	0.0	3.0	0.0	0.0	1.0	0.0	2.0	0.0
T82320	37.0	0.0	1.0	0.0	1.0	11.0	0.0	5.0	1.0
T82321	31.0	1.0	0.0	0.0	8.0	12.0	0.0	0.0	0.0
T82322	38.0	0.0	8.0	0.0	1.0	9.0	0.0	3.0	0.0
T82323	29.0	5.0	2.0	0.0	1.0	11.0	1.0	18.0	0.0
T82400	6.0	3.0	19.0	2.0	2.0	15.0	0.0	20.0	1.0
T82401	8.0	29.0	33.0	1.0	6.0	8.0	1.0	29.0	0.0
T82402	9.0	23.0	14.0	2.0	12.0	7.0	17.0	16.0	6.0
T82403	4.0	5.0	3.0	15.0	9.0	5.0	4.0	4.0	16.0
T82404	2.0	10.0	1.0	34.0	2.0	2.0	4.0	2.0	41.0
T82405	0.0	3.0	1.0	14.0	4.0	1.0	3.0	2.0	6.0
T82406	1.0	2.0	0.0	2.0	1.0	1.0	6.0	2.0	1.0
T82407	7.0	36.0	1.0	1.0	1.0	1.0	6.0	0.0	2.0
T82408	1.0	4.0	16.0	5.0	2.0	5.0	9.0	10.0	10.0
T82409	0.0	3.0	0.0	11.0	6.0	6.0	2.0	1.0	6.0
T82410	0.0	6.0	0.0	1.0	0.0	0.0	1.0	1.0	1.0
T82411	1.0	3.0	2.0	1.0	1.0	1.0	3.0	1.0	3.0
T82412	0.0	2.0	1.0	3.0	1.0	0.0	0.0	1.0	1.0
T82413	2.0	3.0	0.0	1.0	0.0	0.0	1.0	0.0	1.0
T82414	7.0	1.0	2.0	1.0	1.0	1.0	2.0	2.0	2.0
T82415	0.0	0.0	1.0	0.0	1.0	1.0	0.0	2.0	0.0
T82416	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
T82417	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82418	0.0	3.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
T82419	2.0	3.0	1.0	1.0	0.0	0.0	1.0	0.0	3.0
T82420	12.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0
T82421	0.0	0.0	2.0	1.0	0.0	2.0	0.0	2.0	1.0
T82422	1.0	0.0	0.0	3.0	0.0	12.0	0.0	0.0	0.0
T82423	1.0	0.0	1.0	0.0	0.0	7.0	0.0	2.0	1.0
T82500	9.0	1.0	1.0	0.0	0.0	2.0	1.0	0.0	0.0
T82501	12.0	8.0	7.0	1.0	7.0	2.0	2.0	5.0	0.0
T82502	6.0	18.0	12.0	2.0	4.0	7.0	5.0	7.0	3.0
T82503	5.0	93.0	15.0	18.0	6.0	12.0	5.0	12.0	11.0
T82504	11.0	32.0	9.0	5.0	20.0	9.0	10.0	22.0	15.0
T82505	7.0	11.0	8.0	22.0	8.0	8.0	14.0	7.0	11.0

Table A.1.(e) Database File for Rainfall Gages (Gage 37 to 45 during 1995-8/23/05 – 25/05)

MDTIME	ST37	ST38	ST39	ST40	ST41	ST42	ST43	ST44	ST45
T82305	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82306	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82307	1.0	6.0	11.0	0.0	0.0	1.0	0.0	0.0	8.0
T82308	6.0	4.0	7.0	6.0	2.0	6.0	6.0	1.0	3.0
T82309	8.0	0.0	0.0	12.0	3.0	10.0	16.0	6.0	1.0
T82310	1.0	0.0	0.0	1.0	13.0	1.0	7.0	10.0	0.0
T82311	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82312	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
T82313	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82314	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82315	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
T82316	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0
T82317	1.0	1.0	12.0	7.0	4.0	17.0	9.0	0.0	14.0
T82318	1.0	0.0	0.0	1.0	26.0	16.0	1.0	2.0	10.0
T82319	1.0	0.0	1.0	3.0	3.0	3.0	2.0	2.0	0.0
T82320	4.0	8.0	0.0	9.0	7.0	12.0	11.0	8.0	0.0
T82321	8.0	0.0	0.0	0.0	1.0	11.0	1.0	1.0	0.0
T82322	0.0	0.0	0.0	8.0	13.0	21.0	18.0	9.0	0.0
T82323	1.0	0.0	0.0	15.0	9.0	26.0	35.0	12.0	1.0
T82400	1.0	1.0	0.0	10.0	17.0	39.0	20.0	9.0	0.0
T82401	3.0	8.0	0.0	29.0	11.0	15.0	37.0	19.0	6.0
T82402	13.0	16.0	2.0	13.0	7.0	7.0	17.0	6.0	20.0
T82403	6.0	7.0	14.0	5.0	4.0	5.0	6.0	5.0	12.0
T82404	2.0	1.0	41.0	1.0	2.0	2.0	3.0	1.0	3.0
T82405	4.0	5.0	12.0	4.0	1.0	0.0	3.0	1.0	15.0
T82406	1.0	2.0	1.0	0.0	0.0	1.0	0.0	0.0	2.0
T82407	1.0	1.0	1.0	3.0	0.0	0.0	3.0	3.0	1.0
T82408	1.0	7.0	7.0	10.0	2.0	8.0	10.0	1.0	2.0
T82409	6.0	3.0	8.0	2.0	7.0	2.0	5.0	4.0	7.0
T82410	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	9.0
T82411	0.0	2.0	2.0	1.0	0.0	1.0	0.0	0.0	0.0
T82412	1.0	2.0	2.0	1.0	0.0	0.0	0.0	0.0	3.0
T82413	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82414	0.0	1.0	2.0	2.0	0.0	0.0	1.0	0.0	1.0
T82415	1.0	0.0	0.0	2.0	0.0	2.0	1.0	0.0	1.0
T82416	0.0	0.0	0.0	1.0	1.0	1.0	1.0	0.0	0.0
T82417	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82418	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82419	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
T82420	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
T82421	0.0	0.0	0.0	1.0	1.0	1.0	2.0	0.0	0.0
T82422	0.0	0.0	1.0	0.0	5.0	8.0	1.0	1.0	0.0
T82423	0.0	0.0	0.0	1.0	5.0	4.0	7.0	1.0	8.0
T82500	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	0.0
T82501	0.0	4.0	1.0	2.0	1.0	2.0	1.0	0.0	1.0
T82502	11.0	5.0	3.0	10.0	5.0	10.0	13.0	4.0	4.0
T82503	6.0	8.0	13.0	8.0	12.0	46.0	15.0	7.0	15.0
T82504	17.0	11.0	13.0	21.0	10.0	8.0	43.0	15.0	12.0
T82505	10.0	5.0	8.0	7.0	9.0	8.0	9.0	8.0	12.0

Table A.1.(f) Database File for Rainfall Gages (Gage 46 to 54 during 1995-8/23/05 – 25/05)

MDTIME	ST46	ST47	ST48	ST49	ST50	ST51	ST52	ST53	ST54
T82305	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82306	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82307	6.0	2.0	2.0	3.0	4.0	0.0	0.0	0.0	0.0
T82308	4.0	5.0	4.0	4.0	1.0	2.0	2.0	1.0	1.0
T82309	1.0	7.0	1.0	4.0	7.0	4.0	2.0	2.0	3.0
T82310	0.0	0.0	0.0	0.0	0.0	3.0	0.0	1.0	4.0
T82311	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
T82312	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82313	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0
T82314	0.0	0.0	0.0	0.0	0.0	0.0	2.0	2.0	1.0
T82315	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0
T82316	2.0	0.0	0.0	0.0	0.0	0.0	2.0	2.0	2.0
T82317	0.0	16.0	3.0	1.0	8.0	4.0	4.0	1.0	1.0
T82318	0.0	14.0	0.0	1.0	10.0	1.0	1.0	2.0	3.0
T82319	3.0	15.0	0.0	7.0	0.0	3.0	11.0	18.0	13.0
T82320	0.0	15.0	3.0	10.0	0.0	7.0	12.0	6.0	9.0
T82321	0.0	36.0	0.0	3.0	0.0	4.0	20.0	21.0	16.0
T82322	0.0	24.0	0.0	2.0	0.0	7.0	17.0	12.0	12.0
T82323	4.0	14.0	1.0	0.0	0.0	14.0	31.0	19.0	13.0
T82400	21.0	29.0	2.0	3.0	0.0	9.0	12.0	11.0	14.0
T82401	9.0	13.0	18.0	22.0	0.0	23.0	7.0	6.0	6.0
T82402	23.0	7.0	17.0	11.0	35.0	9.0	6.0	7.0	8.0
T82403	1.0	4.0	3.0	8.0	14.0	7.0	5.0	5.0	4.0
T82404	7.0	1.0	4.0	2.0	4.0	1.0	2.0	6.0	5.0
T82405	2.0	0.0	1.0	7.0	12.0	4.0	0.0	2.0	4.0
T82406	2.0	0.0	1.0	7.0	2.0	2.0	0.0	5.0	3.0
T82407	2.0	1.0	1.0	1.0	0.0	5.0	2.0	3.0	3.0
T82408	5.0	5.0	5.0	8.0	2.0	0.0	11.0	7.0	5.0
T82409	6.0	1.0	1.0	3.0	3.0	5.0	1.0	10.0	9.0
T82410	0.0	0.0	32.0	0.0	4.0	0.0	0.0	1.0	1.0
T82411	1.0	1.0	1.0	2.0	0.0	0.0	0.0	0.0	0.0
T82412	0.0	1.0	1.0	2.0	2.0	0.0	1.0	1.0	1.0
T82413	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
T82414	1.0	2.0	2.0	1.0	0.0	0.0	1.0	1.0	1.0
T82415	0.0	3.0	0.0	2.0	0.0	0.0	1.0	1.0	1.0
T82416	0.0	1.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0
T82417	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	6.0
T82418	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82419	4.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
T82420	2.0	0.0	0.0	0.0	0.0	0.0	1.0	3.0	8.0
T82421	0.0	2.0	0.0	0.0	0.0	1.0	7.0	7.0	3.0
T82422	0.0	6.0	0.0	0.0	1.0	0.0	5.0	13.0	16.0
T82423	0.0	0.0	0.0	1.0	1.0	0.0	3.0	2.0	2.0
T82500	1.0	1.0	1.0	1.0	0.0	0.0	0.0	1.0	1.0
T82501	5.0	6.0	3.0	6.0	1.0	1.0	12.0	10.0	5.0
T82502	9.0	13.0	6.0	6.0	4.0	8.0	17.0	15.0	7.0
T82503	19.0	20.0	9.0	8.0	13.0	8.0	8.0	10.0	12.0
T82504	8.0	10.0	8.0	14.0	16.0	31.0	9.0	17.0	15.0
T82505	5.0	9.0	6.0	8.0	20.0	9.0	8.0	8.0	8.0

Table A.1.(g) Database File for Rainfall Gages (Gage 55 to 63 during 1995-3/23/05 – 25/05)

MDTIME	ST55	ST56	ST57	ST58	ST59	ST60	ST61	ST62	ST63
T82305	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82306	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82307	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82308	3.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
T82309	0.0	0.0	0.0	0.0	2.0	0.0	2.0	0.0	0.0
T82310	0.0	5.0	3.0	1.0	9.0	5.0	11.0	3.0	4.0
T82311	0.0	6.0	6.0	1.0	3.0	9.0	1.0	4.0	8.0
T82312	0.0	6.0	2.0	1.0	0.0	0.0	2.0	1.0	1.0
T82313	0.0	2.0	2.0	0.0	0.0	2.0	2.0	2.0	1.0
T82314	0.0	2.0	2.0	0.0	0.0	3.0	8.0	1.0	2.0
T82315	2.0	7.0	4.0	1.0	1.0	6.0	22.0	3.0	5.0
T82316	1.0	6.0	7.0	1.0	2.0	8.0	11.0	5.0	8.0
T82317	0.0	4.0	4.0	1.0	1.0	5.0	2.0	5.0	3.0
T82318	0.0	8.0	6.0	0.0	4.0	9.0	21.0	5.0	6.0
T82319	0.0	11.0	16.0	1.0	1.0	18.0	9.0	20.0	23.0
T82320	0.0	5.0	4.0	0.0	14.0	5.0	4.0	4.0	6.0
T82321	0.0	2.0	3.0	0.0	7.0	4.0	6.0	2.0	3.0
T82322	1.0	3.0	6.0	0.0	7.0	5.0	5.0	5.0	6.0
T82323	2.0	4.0	5.0	0.0	7.0	8.0	10.0	6.0	8.0
T82400	23.0	6.0	7.0	1.0	13.0	7.0	8.0	4.0	9.0
T82401	29.0	4.0	4.0	0.0	9.0	5.0	5.0	4.0	5.0
T82402	13.0	2.0	4.0	0.0	7.0	5.0	2.0	3.0	6.0
T82403	2.0	18.0	2.0	0.0	5.0	1.0	11.0	2.0	2.0
T82404	3.0	11.0	16.0	0.0	1.0	9.0	7.0	15.0	11.0
T82405	4.0	12.0	12.0	0.0	4.0	8.0	7.0	13.0	9.0
T82406	0.0	28.0	18.0	1.0	4.0	16.0	34.0	18.0	10.0
T82407	6.0	23.0	13.0	0.0	16.0	7.0	3.0	21.0	7.0
T82408	2.0	6.0	8.0	2.0	5.0	10.0	12.0	8.0	6.0
T82409	0.0	6.0	21.0	0.0	9.0	21.0	13.0	19.0	9.0
T82410	0.0	7.0	9.0	0.0	3.0	8.0	12.0	8.0	10.0
T82411	0.0	5.0	8.0	0.0	1.0	18.0	6.0	5.0	7.0
T82412	0.0	7.0	14.0	1.0	0.0	24.0	4.0	9.0	15.0
T82413	2.0	1.0	7.0	0.0	0.0	13.0	2.0	5.0	2.0
T82414	0.0	5.0	5.0	0.0	0.0	1.0	0.0	2.0	1.0
T82415	0.0	1.0	2.0	0.0	1.0	1.0	0.0	2.0	1.0
T82416	0.0	1.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0
T82417	0.0	2.0	0.0	0.0	14.0	5.0	0.0	0.0	1.0
T82418	0.0	7.0	19.0	0.0	6.0	14.0	0.0	10.0	9.0
T82419	1.0	12.0	7.0	1.0	0.0	2.0	0.0	10.0	4.0
T82420	1.0	1.0	1.0	0.0	18.0	0.0	0.0	1.0	0.0
T82421	0.0	0.0	0.0	0.0	6.0	4.0	0.0	0.0	1.0
T82422	0.0	0.0	0.0	0.0	9.0	3.0	0.0	1.0	2.0
T82423	0.0	1.0	1.0	2.0	11.0	0.0	0.0	0.0	2.0
T82500	0.0	0.0	1.0	0.0	9.0	1.0	0.0	1.0	0.0
T82501	6.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	1.0
T82502	10.0	1.0	2.0	0.0	9.0	3.0	0.0	1.0	2.0
T82503	31.0	10.0	2.0	0.0	9.0	3.0	0.0	1.0	3.0
T82504	13.0	22.0	2.0	0.0	6.0	1.0	0.0	2.0	4.0
T82505	12.0	1.0	17.0	0.0	7.0	1.0	0.0	17.0	1.0

Table A.1.(h) Database File for Rainfall Gages (Gage 64 to 72 during 1995-8/23/05 – 25/05)

MDTIME	ST64	ST65	ST66	ST67	ST68	ST69	ST70	ST71	ST72
T82305	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
T82306	0.0	0.0	3.0	2.0	4.0	0.0	0.0	3.0	0.0
T82307	0.0	0.0	4.0	1.0	6.0	0.0	0.0	5.0	4.0
T82308	0.0	0.0	3.0	1.0	4.0	0.0	0.0	1.0	2.0
T82309	1.0	2.0	0.0	0.0	0.0	0.0	1.0	0.0	2.0
T82310	6.0	9.0	0.0	0.0	0.0	4.0	5.0	0.0	0.0
T82311	1.0	2.0	0.0	0.0	0.0	2.0	8.0	0.0	0.0
T82312	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0
T82313	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82314	3.0	6.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
T82315	10.0	8.0	0.0	0.0	0.0	2.0	1.0	0.0	0.0
T82316	5.0	8.0	1.0	0.0	1.0	17.0	3.0	1.0	1.0
T82317	4.0	6.0	0.0	0.0	7.0	5.0	10.0	3.0	7.0
T82318	3.0	13.0	0.0	0.0	1.0	2.0	2.0	0.0	0.0
T82319	12.0	11.0	2.0	0.0	18.0	18.0	4.0	0.0	0.0
T82320	7.0	3.0	0.0	0.0	0.0	8.0	11.0	0.0	5.0
T82321	8.0	5.0	0.0	0.0	2.0	5.0	4.0	0.0	0.0
T82322	5.0	5.0	0.0	0.0	6.0	6.0	7.0	0.0	0.0
T82323	8.0	8.0	2.0	0.0	8.0	6.0	5.0	0.0	1.0
T82400	6.0	8.0	9.0	0.0	44.0	9.0	14.0	0.0	7.0
T82401	7.0	4.0	6.0	4.0	22.0	5.0	8.0	0.0	19.0
T82402	8.0	4.0	9.0	24.0	9.0	6.0	7.0	16.0	13.0
T82403	4.0	2.0	1.0	5.0	1.0	3.0	4.0	5.0	5.0
T82404	4.0	6.0	2.0	6.0	2.0	3.0	1.0	6.0	3.0
T82405	4.0	8.0	1.0	4.0	0.0	2.0	3.0	4.0	6.0
T82406	3.0	12.0	1.0	3.0	0.0	3.0	3.0	2.0	7.0
T82407	5.0	6.0	2.0	2.0	5.0	5.0	11.0	3.0	3.0
T82408	9.0	17.0	2.0	1.0	3.0	11.0	1.0	6.0	9.0
T82409	9.0	11.0	1.0	1.0	0.0	7.0	9.0	2.0	1.0
T82410	5.0	9.0	0.0	0.0	1.0	6.0	3.0	3.0	0.0
T82411	4.0	7.0	1.0	0.0	2.0	2.0	1.0	3.0	2.0
T82412	2.0	21.0	0.0	0.0	0.0	2.0	2.0	1.0	0.0
T82413	1.0	2.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0
T82414	0.0	0.0	0.0	0.0	1.0	0.0	1.0	2.0	1.0
T82415	4.0	1.0	0.0	0.0	0.0	1.0	2.0	0.0	0.0
T82416	1.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82417	4.0	5.0	0.0	0.0	0.0	1.0	2.0	0.0	0.0
T82418	5.0	5.0	0.0	0.0	1.0	4.0	13.0	0.0	0.0
T82419	1.0	0.0	1.0	1.0	0.0	0.0	0.0	1.0	1.0
T82420	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0
T82421	7.0	7.0	0.0	0.0	0.0	1.0	9.0	0.0	0.0
T82422	24.0	2.0	3.0	25.0	0.0	25.0	5.0	0.0	0.0
T82423	7.0	1.0	0.0	0.0	1.0	9.0	18.0	0.0	0.0
T82500	6.0	0.0	0.0	0.0	1.0	2.0	16.0	0.0	2.0
T82501	2.0	1.0	3.0	3.0	11.0	0.0	3.0	2.0	4.0
T82502	6.0	4.0	6.0	6.0	28.0	4.0	6.0	4.0	6.0
T82503	5.0	4.0	8.0	12.0	10.0	6.0	8.0	3.0	18.0
T82504	1.0	1.0	5.0	5.0	8.0	1.0	2.0	24.0	6.0
T82505	5.0	2.0	8.0	10.0	9.0	1.0	5.0	15.0	6.0

Table A.1.(i) Database File for Rainfall Gages (Gage 73 to 82 during 1995-8/23/05 – 25/05)

MDTIME	ST73	ST74	ST75	ST76	ST77	ST78	ST79	ST80	ST81	ST82
T82305	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82306	2.0	0.0	0.0	14.0	0.0	0.0	0.0	0.0	0.0	0.0
T82307	24.0	2.0	3.0	9.0	5.0	1.0	0.0	10.0	0.0	1.0
T82308	0.0	3.0	4.0	1.0	8.0	7.0	4.0	26.0	4.0	10.0
T82309	0.0	8.0	3.0	0.0	8.0	7.0	14.0	1.0	5.0	2.0
T82310	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.0	1.0	0.0
T82311	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82312	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
T82313	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82314	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82315	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82316	0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
T82317	5.0	12.0	1.0	3.0	4.0	3.0	3.0	9.0	10.0	4.0
T82318	0.0	15.0	0.0	2.0	5.0	1.0	2.0	0.0	1.0	1.0
T82319	0.0	5.0	9.0	0.0	2.0	11.0	1.0	0.0	8.0	0.0
T82320	0.0	20.0	16.0	0.0	1.0	10.0	11.0	0.0	4.0	0.0
T82321	0.0	30.0	0.0	0.0	0.0	4.0	1.0	0.0	9.0	2.0
T82322	0.0	24.0	2.0	0.0	18.0	5.0	13.0	0.0	1.0	0.0
T82323	0.0	20.0	1.0	0.0	4.0	4.0	16.0	0.0	1.0	1.0
T82400	1.0	28.0	2.0	0.0	25.0	5.0	14.0	3.0	5.0	2.0
T82401	8.0	9.0	28.0	10.0	25.0	28.0	25.0	0.0	22.0	0.0
T82402	8.0	6.0	14.0	2.0	9.0	10.0	10.0	4.0	14.0	2.0
T82403	5.0	3.0	6.0	7.0	3.0	5.0	5.0	15.0	8.0	28.0
T82404	8.0	2.0	2.0	4.0	3.0	2.0	2.0	10.0	2.0	4.0
T82405	12.0	0.0	5.0	20.0	0.0	7.0	2.0	9.0	6.0	10.0
T82406	1.0	0.0	10.0	2.0	1.0	10.0	0.0	1.0	2.0	1.0
T82407	4.0	2.0	1.0	1.0	0.0	6.0	6.0	1.0	7.0	0.0
T82408	8.0	7.0	8.0	3.0	13.0	6.0	4.0	5.0	5.0	1.0
T82409	3.0	1.0	3.0	19.0	0.0	4.0	0.0	7.0	5.0	2.0
T82410	1.0	0.0	0.0	12.0	0.0	0.0	5.0	1.0	0.0	1.0
T82411	0.0	0.0	2.0	3.0	2.0	2.0	0.0	0.0	1.0	1.0
T82412	4.0	1.0	1.0	2.0	1.0	1.0	0.0	4.0	1.0	2.0
T82413	1.0	1.0	0.0	1.0	1.0	1.0	0.0	0.0	0.0	1.0
T82414	2.0	1.0	1.0	1.0	3.0	3.0	0.0	1.0	1.0	0.0
T82415	0.0	2.0	2.0	0.0	2.0	2.0	1.0	0.0	1.0	0.0
T82416	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	1.0	0.0
T82417	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82418	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82419	1.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0
T82420	0.0	0.0	0.0	1.0	2.0	0.0	0.0	1.0	0.0	0.0
T82421	0.0	2.0	0.0	1.0	4.0	1.0	1.0	0.0	0.0	0.0
T82422	0.0	6.0	0.0	2.0	1.0	0.0	0.0	0.0	0.0	1.0
T82423	0.0	2.0	0.0	15.0	1.0	2.0	4.0	0.0	0.0	0.0
T82500	0.0	0.0	2.0	0.0	1.0	1.0	1.0	2.0	1.0	0.0
T82501	2.0	4.0	5.0	0.0	6.0	3.0	0.0	2.0	6.0	3.0
T82502	5.0	11.0	6.0	5.0	10.0	16.0	6.0	3.0	13.0	1.0
T82503	10.0	28.0	8.0	14.0	16.0	9.0	9.0	19.0	6.0	0.0
T82504	17.0	8.0	9.0	5.0	9.0	23.0	30.0	13.0	19.0	14.0
T82505	11.0	8.0	7.0	20.0	7.0	9.0	7.0	15.0	10.0	13.0

Table A.1.(j) Database File for Rainfall Gages (Gage 1 to 9 during 1995-8/25/06 – 27/06)

MDTIME	ST1	ST2	ST3	ST4	ST5	ST6	ST7	ST8	ST9
T82506	0.0	3.0	10.0	16.0	19.0	13.0	8.0	1.0	4.0
T82507	0.0	1.0	1.0	4.0	14.0	2.0	3.0	3.0	3.0
T82508	9.0	4.0	7.0	8.0	1.0	9.0	7.0	8.0	4.0
T82509	3.0	4.0	8.0	12.0	7.0	16.0	15.0	17.0	44.0
T82510	3.0	2.0	2.0	3.0	5.0	3.0	11.0	7.0	20.0
T82511	5.0	4.0	5.0	8.0	18.0	7.0	10.0	7.0	6.0
T82512	2.0	6.0	3.0	3.0	4.0	3.0	7.0	5.0	5.0
T82513	2.0	0.0	0.0	0.0	1.0	1.0	3.0	2.0	5.0
T82514	6.0	2.0	8.0	6.0	2.0	6.0	7.0	6.0	4.0
T82515	5.0	3.0	5.0	3.0	0.0	3.0	3.0	2.0	3.0
T82516	2.0	0.0	2.0	2.0	0.0	2.0	2.0	2.0	1.0
T82517	1.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0
T82518	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0
T82519	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
T82520	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
T82521	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
T82522	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82523	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	1.0
T82600	0.0	0.0	0.0	1.0	0.0	0.0	1.0	1.0	1.0
T82601	1.0	1.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0
T82602	5.0	1.0	1.0	2.0	1.0	3.0	2.0	3.0	1.0
T82603	7.0	3.0	6.0	4.0	1.0	8.0	6.0	8.0	4.0
T82604	1.0	8.0	2.0	3.0	2.0	2.0	9.0	3.0	0.0
T82605	5.0	5.0	5.0	7.0	5.0	1.0	1.0	1.0	3.0
T82606	11.0	3.0	9.0	11.0	5.0	6.0	2.0	2.0	14.0
T82607	1.0	2.0	4.0	2.0	3.0	3.0	13.0	14.0	0.0
T82608	8.0	1.0	2.0	1.0	7.0	1.0	3.0	1.0	0.0
T82609	8.0	1.0	4.0	4.0	1.0	8.0	1.0	1.0	1.0
T82610	2.0	1.0	1.0	1.0	2.0	0.0	1.0	0.0	0.0
T82611	0.0	1.0	1.0	2.0	0.0	3.0	0.0	0.0	0.0
T82612	0.0	2.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
T82613	3.0	2.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0
T82614	1.0	2.0	3.0	1.0	0.0	1.0	0.0	2.0	0.0
T82615	1.0	1.0	3.0	3.0	1.0	2.0	1.0	1.0	0.0
T82616	3.0	1.0	1.0	1.0	3.0	2.0	2.0	2.0	0.0
T82617	2.0	3.0	3.0	1.0	1.0	2.0	1.0	0.0	0.0
T82618	4.0	6.0	7.0	7.0	2.0	9.0	2.0	5.0	2.0
T82619	5.0	7.0	9.0	8.0	3.0	12.0	5.0	7.0	1.0
T82620	0.0	0.0	0.0	4.0	3.0	4.0	3.0	4.0	0.0
T82621	0.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0
T82622	0.0	3.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0
T82623	1.0	12.0	11.0	4.0	0.0	0.0	1.0	0.0	0.0
T82700	0.0	22.0	2.0	0.0	2.0	1.0	0.0	0.0	0.0
T82701	7.0	26.0	6.0	6.0	3.0	7.0	1.0	3.0	0.0
T82702	1.0	7.0	7.0	0.0	12.0	4.0	3.0	3.0	0.0
T82703	0.0	3.0	3.0	0.0	8.0	1.0	7.0	4.0	0.0
T82704	0.0	2.0	1.0	0.0	6.0	0.0	4.0	0.0	0.0
T82705	1.0	2.0	3.0	0.0	4.0	3.0	3.0	6.0	0.0
T82706	1.0	0.0	0.0	0.0	1.0	0.0	3.0	3.0	0.0

Table A.1.(k) Database File for Rainfall Gages (Gage 10 to 18 during 1995-8/25/06 – 27/06)

MDTIME	ST10	ST11	ST12	ST13	ST14	ST15	ST16	ST17	ST18
T82506	11.0	2.0	1.0	5.0	2.0	3.0	0.0	29.0	4.0
T82507	14.0	5.0	7.0	11.0	7.0	9.0	3.0	2.0	1.0
T82508	6.0	8.0	47.0	6.0	7.0	10.0	15.0	6.0	6.0
T82509	6.0	15.0	10.0	5.0	11.0	3.0	2.0	11.0	7.0
T82510	10.0	7.0	5.0	17.0	5.0	7.0	6.0	9.0	2.0
T82511	11.0	5.0	8.0	10.0	6.0	5.0	4.0	8.0	5.0
T82512	4.0	5.0	4.0	4.0	3.0	3.0	2.0	4.0	6.0
T82513	6.0	6.0	6.0	3.0	7.0	7.0	9.0	2.0	5.0
T82514	3.0	5.0	8.0	2.0	5.0	4.0	6.0	2.0	4.0
T82515	2.0	3.0	5.0	1.0	4.0	4.0	5.0	4.0	8.0
T82516	1.0	1.0	2.0	0.0	2.0	0.0	1.0	2.0	1.0
T82517	0.0	0.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0
T82518	0.0	1.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0
T82519	1.0	1.0	0.0	2.0	1.0	0.0	1.0	0.0	0.0
T82520	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82521	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82522	0.0	0.0	0.0	3.0	0.0	0.0	1.0	0.0	1.0
T82523	3.0	1.0	3.0	2.0	1.0	2.0	0.0	0.0	0.0
T82600	1.0	1.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0
T82601	1.0	0.0	2.0	1.0	0.0	2.0	1.0	0.0	1.0
T82602	1.0	6.0	3.0	5.0	4.0	5.0	10.0	1.0	0.0
T82603	6.0	7.0	9.0	3.0	3.0	1.0	2.0	3.0	3.0
T82604	2.0	1.0	2.0	1.0	0.0	2.0	2.0	6.0	4.0
T82605	4.0	2.0	2.0	2.0	2.0	2.0	5.0	4.0	11.0
T82606	1.0	3.0	0.0	1.0	6.0	2.0	5.0	9.0	3.0
T82607	1.0	2.0	0.0	0.0	1.0	1.0	1.0	4.0	1.0
T82608	0.0	0.0	0.0	0.0	1.0	1.0	11.0	2.0	1.0
T82609	7.0	0.0	0.0	0.0	1.0	2.0	2.0	4.0	2.0
T82610	0.0	0.0	0.0	0.0	0.0	0.0	2.0	3.0	1.0
T82611	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	2.0
T82612	0.0	0.0	0.0	0.0	0.0	0.0	6.0	1.0	1.0
T82613	0.0	0.0	0.0	0.0	0.0	1.0	2.0	0.0	1.0
T82614	0.0	0.0	0.0	0.0	0.0	0.0	2.0	1.0	3.0
T82615	0.0	0.0	0.0	1.0	1.0	1.0	0.0	2.0	1.0
T82616	0.0	1.0	0.0	1.0	2.0	4.0	4.0	1.0	1.0
T82617	3.0	3.0	0.0	2.0	6.0	3.0	5.0	1.0	2.0
T82618	7.0	8.0	0.0	5.0	10.0	3.0	7.0	3.0	6.0
T82619	2.0	0.0	1.0	0.0	5.0	1.0	2.0	6.0	3.0
T82620	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0
T82621	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82622	0.0	0.0	0.0	0.0	0.0	1.0	2.0	0.0	0.0
T82623	0.0	0.0	0.0	0.0	0.0	1.0	4.0	0.0	10.0
T82700	0.0	1.0	0.0	1.0	1.0	5.0	2.0	0.0	9.0
T82701	0.0	0.0	0.0	0.0	1.0	1.0	2.0	1.0	11.0
T82702	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0	18.0
T82703	1.0	0.0	0.0	0.0	0.0	1.0	1.0	15.0	1.0
T82704	0.0	0.0	0.0	0.0	0.0	1.0	0.0	8.0	0.0
T82705	0.0	0.0	0.0	0.0	0.0	1.0	0.0	3.0	13.0
T82706	0.0	0.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0

Table A.1.(l) Database File for Rainfall Gages (Gage 19 to 27 during 1995-8/25/06 – 27/06)

MDTIME	ST19	ST20	ST21	ST22	ST23	ST24	ST25	ST26	ST27
T82506	0.0	0.0	2.0	0.0	0.0	20.0	0.0	4.0	6.0
T82507	3.0	4.0	6.0	6.0	1.0	1.0	3.0	12.0	8.0
T82508	9.0	14.0	4.0	8.0	8.0	9.0	19.0	6.0	6.0
T82509	6.0	2.0	2.0	2.0	2.0	20.0	21.0	7.0	4.0
T82510	3.0	4.0	4.0	5.0	2.0	7.0	4.0	10.0	10.0
T82511	5.0	6.0	5.0	3.0	2.0	7.0	7.0	5.0	21.0
T82512	0.0	1.0	0.0	2.0	1.0	2.0	4.0	5.0	3.0
T82513	4.0	2.0	2.0	1.0	3.0	6.0	4.0	4.0	3.0
T82514	2.0	5.0	6.0	3.0	3.0	3.0	6.0	3.0	3.0
T82515	2.0	5.0	3.0	2.0	2.0	5.0	2.0	3.0	2.0
T82516	1.0	1.0	0.0	1.0	1.0	1.0	2.0	1.0	0.0
T82517	0.0	1.0	1.0	3.0	0.0	0.0	0.0	0.0	0.0
T82518	2.0	0.0	5.0	2.0	0.0	1.0	0.0	0.0	0.0
T82519	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	1.0
T82520	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
T82521	0.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0
T82522	1.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0
T82523	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	1.0
T82600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
T82601	1.0	1.0	2.0	1.0	0.0	1.0	0.0	0.0	0.0
T82602	1.0	7.0	7.0	5.0	3.0	1.0	0.0	9.0	2.0
T82603	5.0	3.0	2.0	2.0	2.0	3.0	0.0	1.0	2.0
T82604	5.0	2.0	5.0	11.0	0.0	3.0	0.0	0.0	1.0
T82605	21.0	8.0	7.0	14.0	2.0	11.0	0.0	2.0	1.0
T82606	5.0	6.0	4.0	2.0	3.0	9.0	0.0	1.0	0.0
T82607	1.0	0.0	0.0	1.0	0.0	2.0	0.0	1.0	0.0
T82608	3.0	12.0	8.0	4.0	3.0	2.0	0.0	0.0	0.0
T82609	2.0	6.0	3.0	3.0	2.0	5.0	0.0	0.0	0.0
T82610	2.0	1.0	4.0	2.0	0.0	2.0	0.0	0.0	0.0
T82611	1.0	2.0	1.0	2.0	0.0	1.0	0.0	0.0	0.0
T82612	1.0	2.0	7.0	3.0	1.0	0.0	0.0	0.0	0.0
T82613	3.0	2.0	3.0	4.0	1.0	1.0	0.0	0.0	0.0
T82614	1.0	3.0	1.0	2.0	0.0	2.0	0.0	0.0	0.0
T82615	3.0	0.0	1.0	1.0	0.0	2.0	0.0	1.0	1.0
T82616	2.0	2.0	3.0	4.0	1.0	3.0	0.0	1.0	1.0
T82617	3.0	5.0	6.0	6.0	1.0	1.0	0.0	4.0	3.0
T82618	5.0	5.0	4.0	5.0	2.0	5.0	0.0	6.0	9.0
T82619	5.0	3.0	2.0	3.0	1.0	6.0	0.0	4.0	3.0
T82620	0.0	1.0	1.0	0.0	0.0	4.0	0.0	0.0	0.0
T82621	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82622	1.0	0.0	2.0	2.0	0.0	0.0	0.0	0.0	0.0
T82623	2.0	5.0	4.0	8.0	1.0	3.0	0.0	0.0	0.0
T82700	1.0	2.0	3.0	1.0	0.0	3.0	0.0	0.0	1.0
T82701	13.0	3.0	1.0	1.0	1.0	9.0	0.0	1.0	0.0
T82702	2.0	0.0	0.0	0.0	0.0	18.0	0.0	0.0	1.0
T82703	2.0	0.0	0.0	0.0	0.0	9.0	0.0	0.0	0.0
T82704	1.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0
T82705	0.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0
T82706	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0

Table A.1.(m) Database File for Rainfall Gages (Gage 28 to 36 during 1995-8/25/06 – 27/06)

MDTIME	ST28	ST29	ST30	ST31	ST32	ST33	ST34	ST35	ST36
T82506	4.0	10.0	4.0	19.0	5.0	8.0	10.0	5.0	23.0
T82507	9.0	3.0	17.0	15.0	4.0	5.0	13.0	6.0	29.0
T82508	9.0	3.0	5.0	16.0	15.0	8.0	21.0	7.0	15.0
T82509	10.0	1.0	2.0	7.0	6.0	9.0	12.0	4.0	2.0
T82510	14.0	4.0	6.0	4.0	1.0	15.0	3.0	3.0	2.0
T82511	4.0	12.0	21.0	4.0	3.0	10.0	8.0	6.0	3.0
T82512	5.0	35.0	4.0	5.0	15.0	8.0	6.0	22.0	4.0
T82513	4.0	4.0	3.0	7.0	9.0	7.0	3.0	5.0	5.0
T82514	3.0	12.0	3.0	0.0	1.0	5.0	0.0	2.0	0.0
T82515	3.0	9.0	3.0	1.0	0.0	1.0	2.0	3.0	3.0
T82516	0.0	1.0	1.0	3.0	1.0	0.0	2.0	1.0	4.0
T82517	0.0	1.0	0.0	2.0	1.0	0.0	1.0	1.0	2.0
T82518	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
T82519	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82520	0.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0
T82521	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82522	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82523	1.0	1.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0
T82600	1.0	4.0	0.0	1.0	1.0	0.0	2.0	1.0	2.0
T82601	1.0	7.0	2.0	1.0	0.0	1.0	1.0	1.0	0.0
T82602	8.0	16.0	1.0	3.0	0.0	0.0	2.0	2.0	0.0
T82603	2.0	4.0	3.0	0.0	1.0	1.0	6.0	2.0	0.0
T82604	1.0	1.0	1.0	11.0	4.0	5.0	1.0	2.0	0.0
T82605	2.0	0.0	1.0	0.0	1.0	2.0	0.0	0.0	0.0
T82606	4.0	0.0	0.0	0.0	0.0	9.0	0.0	0.0	0.0
T82607	1.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
T82608	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82609	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
T82610	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0
T82611	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0
T82612	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82613	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82614	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82615	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82616	0.0	2.0	1.0	1.0	7.0	1.0	1.0	1.0	0.0
T82617	0.0	3.0	0.0	1.0	2.0	0.0	0.0	1.0	0.0
T82618	0.0	4.0	5.0	1.0	2.0	1.0	2.0	3.0	0.0
T82619	0.0	1.0	3.0	1.0	1.0	3.0	1.0	4.0	0.0
T82620	0.0	0.0	1.0	4.0	3.0	2.0	0.0	2.0	0.0
T82621	0.0	0.0	0.0	1.0	1.0	2.0	1.0	4.0	0.0
T82622	0.0	0.0	0.0	1.0	2.0	3.0	0.0	0.0	0.0
T82623	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
T82700	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0
T82701	1.0	2.0	1.0	2.0	0.0	2.0	0.0	0.0	0.0
T82702	0.0	1.0	1.0	0.0	1.0	1.0	0.0	3.0	0.0
T82703	0.0	1.0	2.0	1.0	2.0	2.0	0.0	2.0	0.0
T82704	0.0	0.0	0.0	0.0	1.0	5.0	0.0	0.0	0.0
T82705	1.0	0.0	0.0	1.0	2.0	2.0	0.0	0.0	0.0
T82706	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0

Table A.1.(n) Database File for Rainfall Gages (Gage 37 to 45 during 1995-8/25/06 – 27/06)

MDTIME	ST37	ST38	ST39	ST40	ST41	ST42	ST43	ST44	ST45
T82506	4.0	7.0	17.0	5.0	5.0	6.0	8.0	4.0	10.0
T82507	4.0	16.0	25.0	4.0	9.0	8.0	6.0	8.0	10.0
T82508	11.0	11.0	11.0	7.0	7.0	12.0	14.0	5.0	11.0
T82509	7.0	3.0	5.0	4.0	5.0	3.0	5.0	5.0	7.0
T82510	2.0	2.0	2.0	3.0	18.0	4.0	7.0	8.0	2.0
T82511	3.0	3.0	5.0	9.0	29.0	16.0	19.0	13.0	4.0
T82512	21.0	17.0	3.0	21.0	7.0	8.0	10.0	13.0	4.0
T82513	8.0	5.0	6.0	5.0	5.0	6.0	6.0	5.0	6.0
T82514	1.0	1.0	0.0	3.0	4.0	3.0	2.0	2.0	2.0
T82515	0.0	0.0	0.0	2.0	1.0	2.0	2.0	0.0	0.0
T82516	1.0	2.0	3.0	1.0	0.0	1.0	1.0	0.0	1.0
T82517	0.0	0.0	2.0	1.0	0.0	1.0	1.0	0.0	1.0
T82518	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
T82519	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82520	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
T82521	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82522	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82523	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
T82600	0.0	1.0	0.0	1.0	1.0	0.0	2.0	1.0	0.0
T82601	1.0	2.0	1.0	0.0	0.0	1.0	0.0	0.0	1.0
T82602	0.0	1.0	3.0	1.0	1.0	0.0	1.0	0.0	0.0
T82603	0.0	2.0	0.0	1.0	0.0	2.0	0.0	0.0	0.0
T82604	5.0	5.0	12.0	2.0	7.0	2.0	4.0	3.0	7.0
T82605	1.0	0.0	0.0	0.0	2.0	2.0	2.0	2.0	0.0
T82606	1.0	1.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0
T82607	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0
T82608	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0
T82609	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
T82610	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82611	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0
T82612	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82613	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82614	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82615	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82616	8.0	0.0	1.0	0.0	1.0	1.0	0.0	0.0	7.0
T82617	1.0	0.0	0.0	1.0	2.0	0.0	1.0	3.0	1.0
T82618	7.0	3.0	1.0	1.0	2.0	3.0	1.0	1.0	1.0
T82619	1.0	1.0	2.0	2.0	2.0	8.0	2.0	3.0	1.0
T82620	5.0	2.0	2.0	2.0	2.0	3.0	1.0	5.0	3.0
T82621	1.0	3.0	2.0	4.0	0.0	5.0	2.0	3.0	1.0
T82622	1.0	0.0	0.0	0.0	3.0	0.0	1.0	3.0	1.0
T82623	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
T82700	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82701	0.0	0.0	0.0	1.0	1.0	3.0	0.0	1.0	0.0
T82702	1.0	0.0	0.0	1.0	1.0	3.0	3.0	1.0	1.0
T82703	1.0	0.0	0.0	1.0	1.0	4.0	3.0	1.0	1.0
T82704	1.0	0.0	0.0	2.0	1.0	2.0	3.0	0.0	0.0
T82705	0.0	1.0	0.0	1.0	3.0	1.0	1.0	1.0	2.0
T82706	1.0	0.0	0.0	1.0	1.0	1.0	2.0	1.0	1.0

Table A.1.(o) Database File for Rainfall Gages (Gage 46 to 54 during 1995-8/25/06 – 27/06)

MDTIME	ST46	ST47	ST48	ST49	ST50	ST51	ST52	ST53	ST54
T82506	10.0	8.0	6.0	7.0	5.0	5.0	9.0	4.0	6.0
T82507	31.0	11.0	20.0	9.0	7.0	5.0	7.0	5.0	4.0
T82508	10.0	9.0	9.0	11.0	11.0	11.0	9.0	7.0	10.0
T82509	3.0	5.0	5.0	3.0	6.0	6.0	9.0	13.0	7.0
T82510	3.0	6.0	3.0	2.0	2.0	2.0	16.0	43.0	35.0
T82511	11.0	26.0	5.0	3.0	4.0	6.0	6.0	7.0	12.0
T82512	6.0	5.0	10.0	27.0	2.0	13.0	4.0	7.0	9.0
T82513	4.0	5.0	2.0	6.0	12.0	5.0	6.0	5.0	7.0
T82514	4.0	5.0	0.0	1.0	4.0	3.0	2.0	6.0	5.0
T82515	6.0	2.0	1.0	1.0	0.0	0.0	4.0	3.0	2.0
T82516	1.0	2.0	1.0	3.0	1.0	0.0	0.0	0.0	1.0
T82517	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
T82518	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82519	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
T82520	1.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0
T82521	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82522	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0
T82523	0.0	2.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0
T82600	1.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0
T82601	3.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	2.0
T82602	2.0	0.0	0.0	1.0	0.0	0.0	5.0	0.0	0.0
T82603	4.0	2.0	1.0	2.0	0.0	0.0	10.0	10.0	5.0
T82604	2.0	2.0	0.0	4.0	5.0	5.0	1.0	1.0	3.0
T82605	0.0	4.0	0.0	1.0	2.0	1.0	8.0	3.0	2.0
T82606	0.0	0.0	0.0	0.0	0.0	0.0	1.0	4.0	4.0
T82607	0.0	1.0	0.0	0.0	0.0	0.0	0.0	2.0	1.0
T82608	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	1.0
T82609	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82610	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	4.0
T82611	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82612	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0
T82613	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82614	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82615	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
T82616	1.0	1.0	1.0	0.0	2.0	3.0	0.0	2.0	2.0
T82617	1.0	1.0	0.0	1.0	2.0	1.0	1.0	2.0	0.0
T82618	6.0	6.0	1.0	4.0	4.0	2.0	4.0	3.0	2.0
T82619	3.0	6.0	2.0	3.0	0.0	3.0	2.0	7.0	4.0
T82620	1.0	5.0	0.0	4.0	2.0	4.0	0.0	1.0	1.0
T82621	0.0	2.0	0.0	3.0	2.0	1.0	0.0	0.0	1.0
T82622	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	1.0
T82623	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
T82700	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
T82701	0.0	5.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
T82702	0.0	4.0	0.0	1.0	0.0	2.0	0.0	0.0	0.0
T82703	0.0	2.0	0.0	1.0	0.0	3.0	0.0	2.0	2.0
T82704	0.0	0.0	4.0	2.0	0.0	1.0	0.0	0.0	1.0
T82705	0.0	1.0	0.0	1.0	0.0	1.0	0.0	0.0	1.0
T82706	0.0	1.0	1.0	2.0	0.0	0.0	1.0	1.0	2.0

Table A.1.(p) Database File for Rainfall Gages (Gage 55 to 63 during 1995-8/25/06 – 27/06)

MDTIME	ST55	ST56	ST57	ST58	ST59	ST60	ST61	ST62	ST63
T82506	8.0	34.0	42.0	0.0	8.0	16.0	0.0	33.0	13.0
T82507	31.0	16.0	16.0	0.0	3.0	19.0	0.0	24.0	18.0
T82508	5.0	4.0	4.0	0.0	9.0	5.0	0.0	5.0	4.0
T82509	0.0	2.0	3.0	0.0	15.0	6.0	0.0	2.0	6.0
T82510	7.0	12.0	22.0	2.0	17.0	19.0	0.0	8.0	19.0
T82511	21.0	2.0	6.0	0.0	10.0	11.0	0.0	4.0	13.0
T82512	8.0	5.0	6.0	0.0	9.0	18.0	0.0	6.0	8.0
T82513	1.0	1.0	2.0	0.0	6.0	2.0	0.0	2.0	2.0
T82514	2.0	0.0	0.0	0.0	4.0	0.0	0.0	1.0	0.0
T82515	2.0	0.0	1.0	0.0	2.0	3.0	0.0	0.0	2.0
T82516	3.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	2.0
T82517	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82518	0.0	0.0	1.0	0.0	0.0	1.0	2.0	1.0	1.0
T82519	0.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0
T82520	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82521	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82522	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
T82523	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82600	0.0	1.0	1.0	0.0	1.0	1.0	1.0	0.0	0.0
T82601	0.0	0.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0
T82602	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
T82603	0.0	1.0	2.0	0.0	1.0	2.0	2.0	2.0	2.0
T82604	0.0	2.0	2.0	1.0	7.0	5.0	5.0	1.0	7.0
T82605	0.0	2.0	4.0	0.0	2.0	5.0	3.0	2.0	4.0
T82606	0.0	4.0	2.0	0.0	4.0	2.0	8.0	2.0	2.0
T82607	0.0	3.0	10.0	0.0	2.0	17.0	5.0	9.0	15.0
T82608	0.0	1.0	2.0	0.0	0.0	1.0	2.0	2.0	4.0
T82609	0.0	6.0	3.0	0.0	1.0	6.0	4.0	3.0	2.0
T82610	0.0	2.0	8.0	0.0	1.0	3.0	9.0	6.0	2.0
T82611	0.0	1.0	0.0	0.0	2.0	0.0	1.0	1.0	0.0
T82612	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0
T82613	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
T82614	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
T82615	0.0	1.0	1.0	2.0	0.0	3.0	3.0	1.0	2.0
T82616	0.0	3.0	3.0	5.0	2.0	1.0	2.0	3.0	1.0
T82617	0.0	1.0	2.0	4.0	1.0	1.0	1.0	1.0	3.0
T82618	0.0	1.0	1.0	1.0	3.0	2.0	2.0	1.0	2.0
T82619	0.0	4.0	3.0	1.0	2.0	4.0	4.0	4.0	5.0
T82620	0.0	5.0	3.0	1.0	1.0	2.0	4.0	8.0	3.0
T82621	0.0	5.0	5.0	2.0	2.0	3.0	0.0	9.0	6.0
T82622	0.0	3.0	5.0	1.0	2.0	3.0	0.0	4.0	2.0
T82623	0.0	3.0	2.0	1.0	1.0	1.0	0.0	5.0	2.0
T82700	0.0	2.0	0.0	0.0	0.0	0.0	0.0	13.0	0.0
T82701	0.0	0.0	0.0	0.0	1.0	1.0	1.0	0.0	0.0
T82702	0.0	24.0	14.0	6.0	6.0	13.0	18.0	21.0	12.0
T82703	0.0	10.0	15.0	15.0	3.0	21.0	9.0	16.0	17.0
T82704	0.0	7.0	9.0	13.0	2.0	8.0	4.0	11.0	11.0
T82705	0.0	5.0	4.0	3.0	1.0	6.0	2.0	4.0	2.0
T82706	0.0	1.0	2.0	3.0	3.0	2.0	1.0	1.0	3.0

Table A.1.(q) Database File for Rainfall Gages (Gage 64 to 72 during 1995-8/25/06 – 27/06)

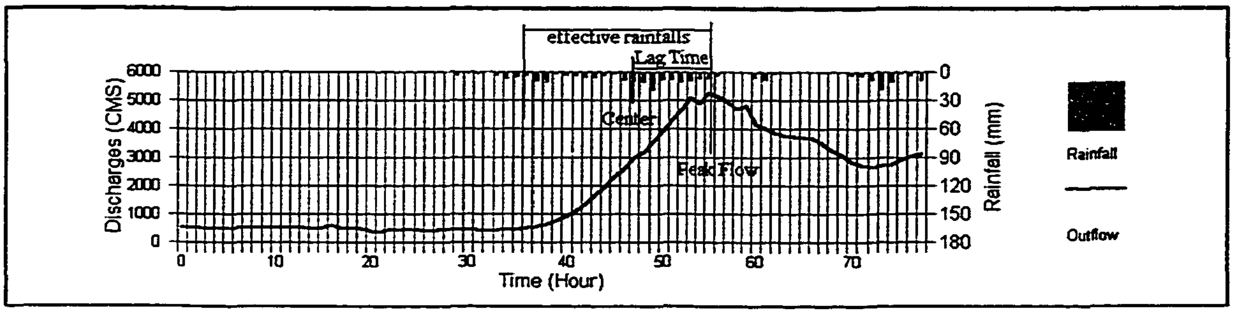
MDTIME	ST64	ST65	ST66	ST67	ST68	ST69	ST70	ST71	ST72
T82506	8.0	13.0	8.0	6.0	26.0	6.0	7.0	28.0	5.0
T82507	5.0	9.0	14.0	15.0	27.0	11.0	4.0	14.0	23.0
T82508	8.0	6.0	4.0	3.0	4.0	6.0	5.0	13.0	6.0
T82509	11.0	11.0	1.0	0.0	3.0	13.0	8.0	2.0	4.0
T82510	13.0	18.0	7.0	39.0	8.0	15.0	11.0	2.0	3.0
T82511	10.0	7.0	7.0	17.0	14.0	28.0	12.0	10.0	5.0
T82512	13.0	6.0	4.0	12.0	3.0	19.0	8.0	5.0	5.0
T82513	2.0	2.0	1.0	2.0	4.0	2.0	6.0	2.0	3.0
T82514	4.0	3.0	2.0	2.0	4.0	1.0	2.0	1.0	2.0
T82515	3.0	5.0	2.0	5.0	3.0	2.0	3.0	1.0	4.0
T82516	1.0	1.0	0.0	1.0	1.0	1.0	0.0	2.0	1.0
T82517	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
T82518	1.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
T82519	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
T82520	0.0	0.0	0.0	1.0	1.0	0.0	0.0	1.0	0.0
T82521	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82522	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82523	0.0	0.0	0.0	1.0	1.0	0.0	1.0	1.0	0.0
T82600	1.0	1.0	0.0	1.0	3.0	0.0	0.0	2.0	1.0
T82601	0.0	1.0	1.0	4.0	2.0	1.0	0.0	2.0	2.0
T82602	3.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	2.0
T82603	4.0	3.0	2.0	10.0	2.0	3.0	1.0	8.0	3.0
T82604	8.0	7.0	0.0	0.0	0.0	7.0	5.0	2.0	3.0
T82605	2.0	6.0	0.0	0.0	1.0	4.0	2.0	0.0	0.0
T82606	3.0	3.0	0.0	0.0	0.0	2.0	2.0	0.0	0.0
T82607	21.0	16.0	0.0	0.0	0.0	12.0	3.0	0.0	0.0
T82608	5.0	4.0	0.0	0.0	0.0	14.0	2.0	0.0	0.0
T82609	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82610	1.0	4.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
T82611	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
T82612	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82613	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82614	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82615	1.0	3.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0
T82616	3.0	1.0	0.0	0.0	1.0	1.0	2.0	1.0	1.0
T82617	1.0	1.0	0.0	0.0	1.0	2.0	3.0	1.0	0.0
T82618	3.0	2.0	2.0	1.0	4.0	2.0	2.0	5.0	3.0
T82619	4.0	6.0	1.0	0.0	1.0	5.0	5.0	2.0	3.0
T82620	3.0	3.0	0.0	0.0	0.0	0.0	1.0	2.0	3.0
T82621	4.0	0.0	0.0	0.0	0.0	4.0	4.0	1.0	1.0
T82622	3.0	3.0	0.0	0.0	0.0	2.0	3.0	0.0	0.0
T82623	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
T82700	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
T82701	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0
T82702	9.0	14.0	0.0	0.0	0.0	3.0	5.0	0.0	0.0
T82703	16.0	23.0	0.0	0.0	0.0	12.0	3.0	0.0	0.0
T82704	16.0	12.0	0.0	0.0	0.0	11.0	2.0	0.0	0.0
T82705	7.0	6.0	0.0	0.0	1.0	4.0	4.0	1.0	0.0
T82706	4.0	2.0	0.0	0.0	0.0	1.0	3.0	0.0	2.0

Table A.1.(r) Database File for Rainfall Gages (Gage 73 to 82 during 1995-8/25/06 – 27/06)

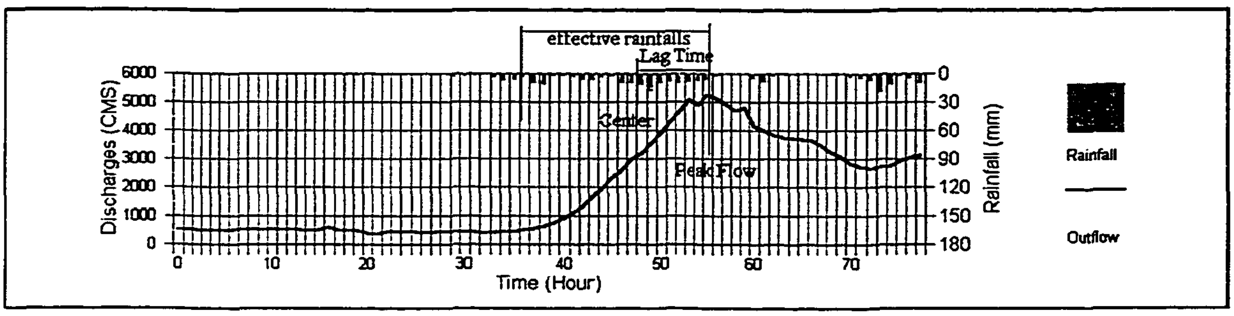
MDTIME	ST73	ST74	ST75	ST76	ST77	ST78	ST79	ST80	ST81	ST82
T82506	13.0	5.0	6.0	12.0	5.0	6.0	6.0	8.0	6.0	7.0
T82507	23.0	9.0	12.0	38.0	6.0	8.0	9.0	14.0	4.0	6.0
T82508	21.0	8.0	8.0	41.0	7.0	8.0	10.0	15.0	12.0	14.0
T82509	8.0	4.0	2.0	12.0	3.0	5.0	4.0	7.0	6.0	5.0
T82510	3.0	5.0	2.0	3.0	5.0	3.0	7.0	4.0	3.0	2.0
T82511	4.0	18.0	3.0	2.0	28.0	5.0	11.0	4.0	4.0	3.0
T82512	6.0	5.0	27.0	3.0	7.0	29.0	0.0	11.0	18.0	8.0
T82513	5.0	5.0	6.0	6.0	3.0	6.0	0.0	10.0	6.0	14.0
T82514	0.0	4.0	1.0	1.0	4.0	3.0	16.0	1.0	2.0	2.0
T82515	1.0	2.0	2.0	0.0	2.0	1.0	0.0	0.0	0.0	0.0
T82516	3.0	1.0	2.0	2.0	2.0	2.0	0.0	2.0	1.0	1.0
T82517	2.0	1.0	0.0	2.0	0.0	2.0	1.0	1.0	0.0	0.0
T82518	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
T82519	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82520	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0
T82521	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
T82522	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82523	0.0	2.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
T82600	1.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0
T82601	0.0	1.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
T82602	2.0	0.0	1.0	0.0	0.0	1.0	0.0	1.0	1.0	0.0
T82603	1.0	2.0	5.0	2.0	3.0	2.0	0.0	0.0	0.0	0.0
T82604	11.0	2.0	3.0	3.0	2.0	3.0	3.0	6.0	6.0	3.0
T82605	0.0	1.0	1.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0
T82606	0.0	1.0	0.0	0.0	0.0	1.0	1.0	0.0	1.0	0.0
T82607	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
T82608	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82609	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
T82610	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82611	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82612	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82613	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82614	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82615	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T82616	0.0	2.0	0.0	4.0	2.0	0.0	3.0	5.0	3.0	2.0
T82617	0.0	0.0	1.0	1.0	0.0	0.0	2.0	1.0	2.0	1.0
T82618	1.0	2.0	1.0	2.0	4.0	1.0	2.0	2.0	3.0	1.0
T82619	0.0	5.0	3.0	6.0	4.0	1.0	2.0	2.0	2.0	0.0
T82620	1.0	2.0	2.0	7.0	3.0	1.0	3.0	2.0	3.0	2.0
T82621	2.0	3.0	2.0	3.0	4.0	2.0	3.0	1.0	2.0	1.0
T82622	0.0	0.0	1.0	1.0	0.0	0.0	2.0	0.0	1.0	1.0
T82623	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0
T82700	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0
T82701	0.0	2.0	0.0	0.0	2.0	1.0	1.0	1.0	0.0	0.0
T82702	0.0	1.0	0.0	1.0	3.0	4.0	1.0	0.0	3.0	0.0
T82703	0.0	2.0	1.0	1.0	3.0	4.0	2.0	0.0	1.0	0.0
T82704	0.0	1.0	0.0	1.0	1.0	3.0	2.0	1.0	3.0	0.0
T82705	0.0	1.0	0.0	0.0	0.0	1.0	2.0	0.0	4.0	1.0
T82706	0.0	1.0	1.0	0.0	1.0	3.0	2.0	1.0	1.0	1.0

APENDIX B

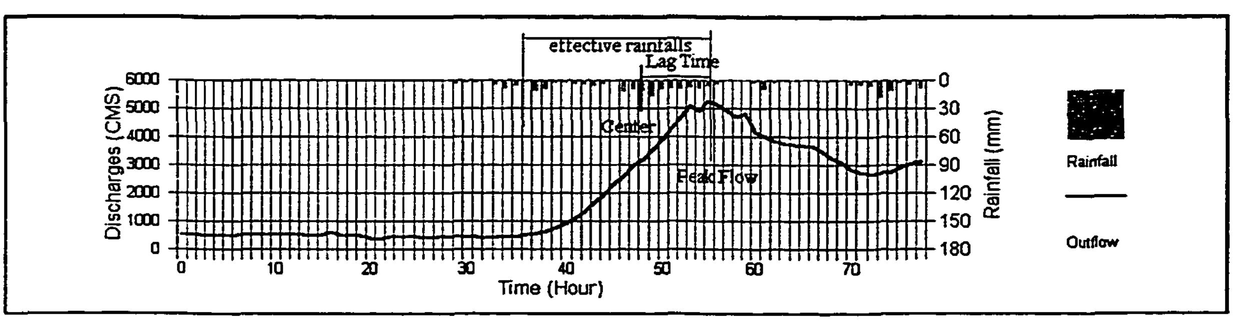
Lag-Time Calculations



(Subbasin 1)

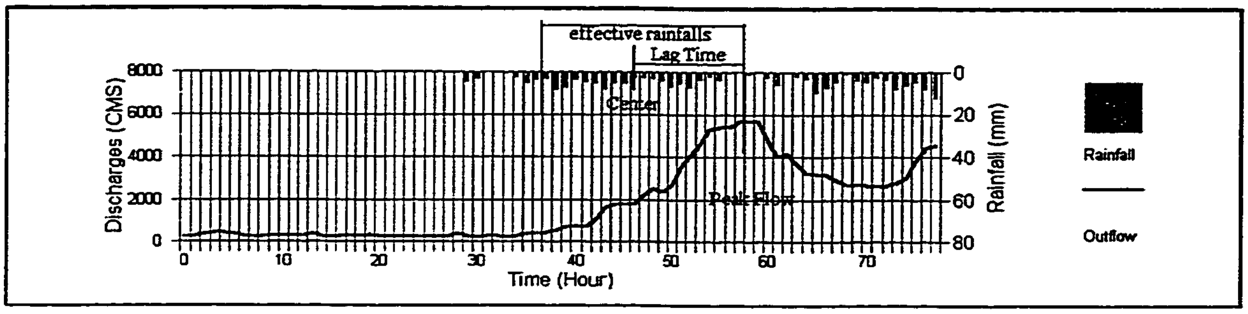


(Subbasin 2)

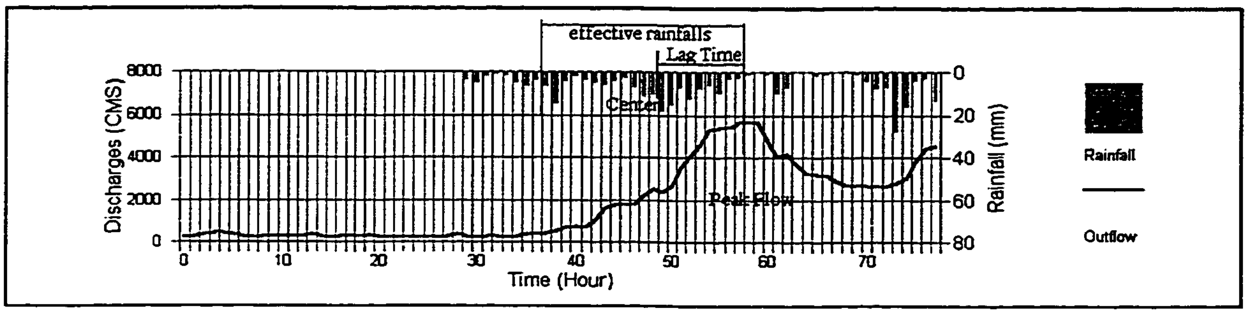


(Subbasin 3)

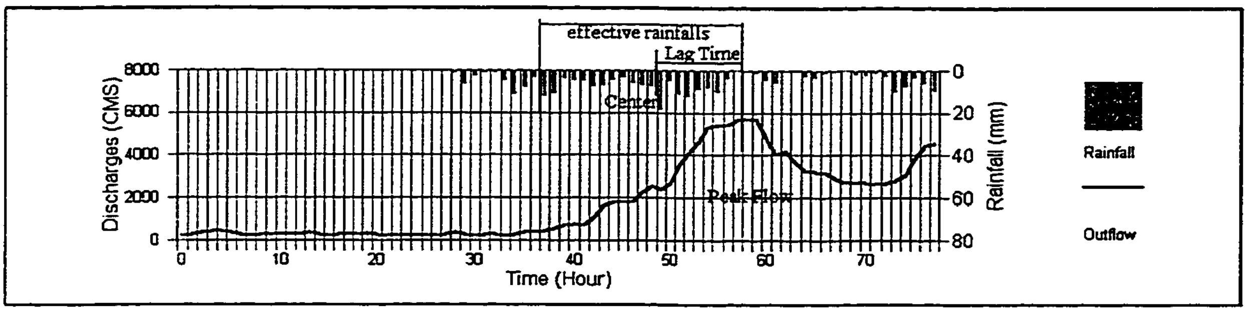
Fig. B.1 The Lag-Time Calculations at HwaCheon Reservoir



(Subbasin 5)

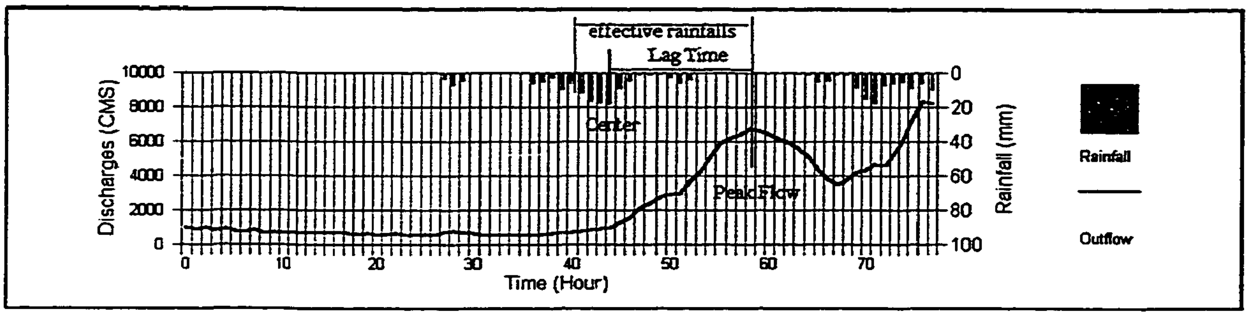


(Subbasin 6)

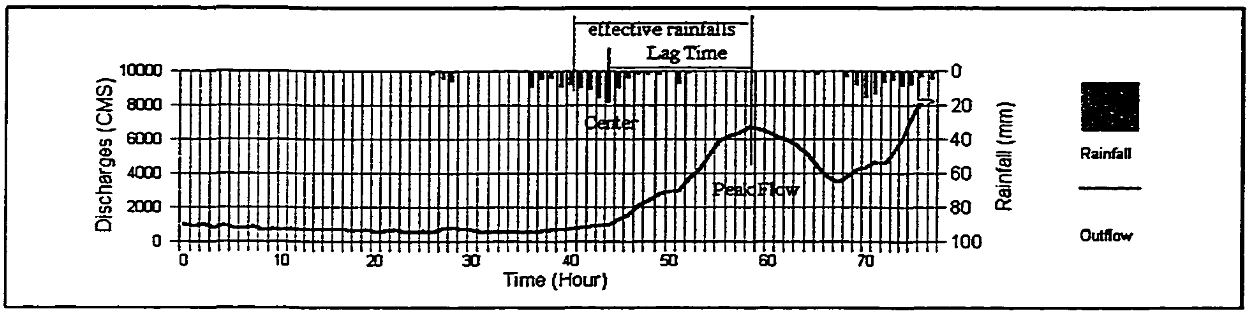


(Subbasin 7)

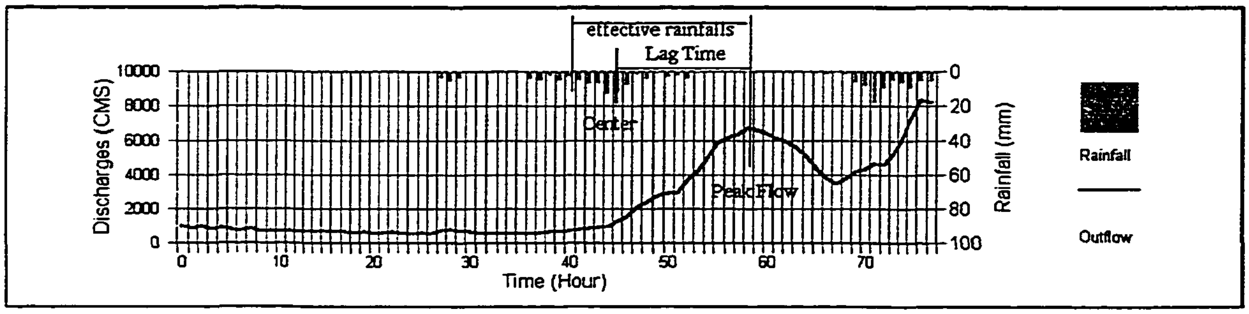
Fig. B.2 The Lag-Time Calculations at SoYangGang Reservoir



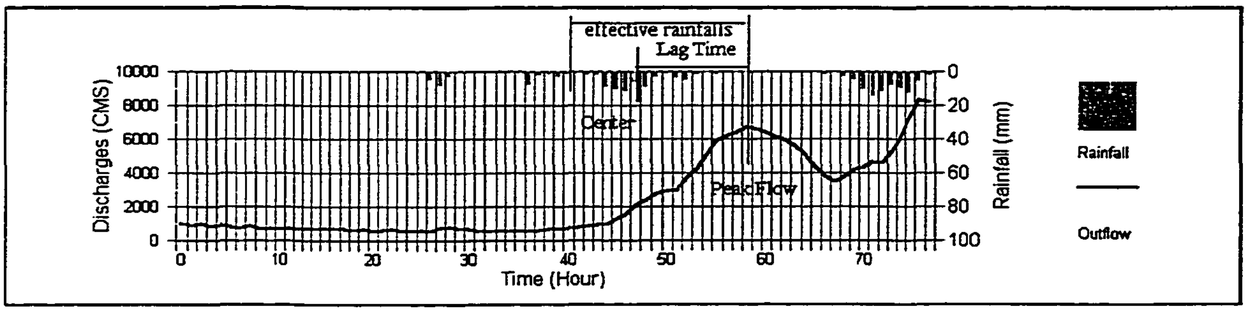
(Subbasin 13)



(Subbasin 14)

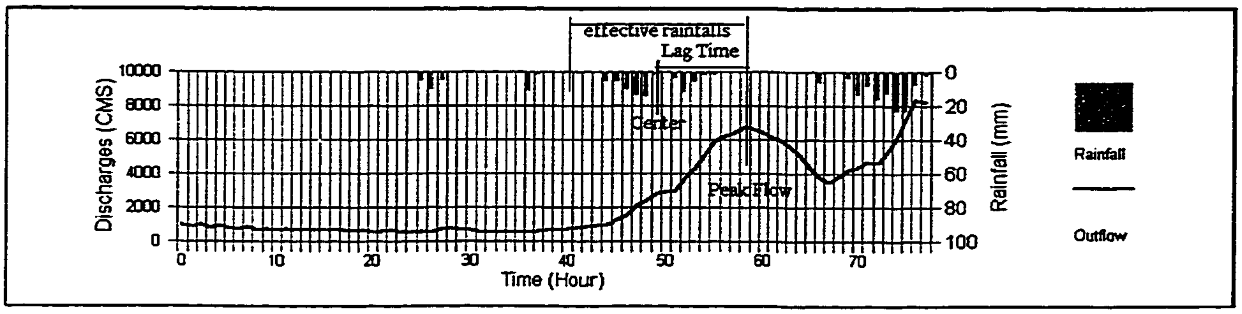


(Subbasin 15)

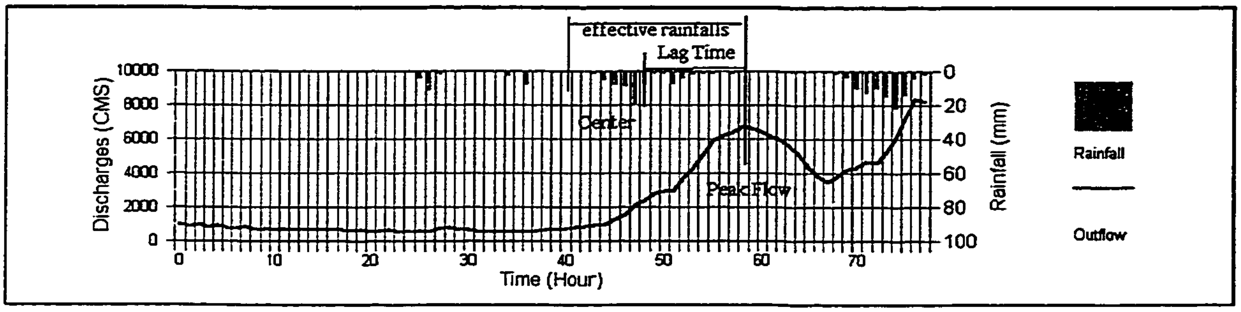


(Subbasin 16)

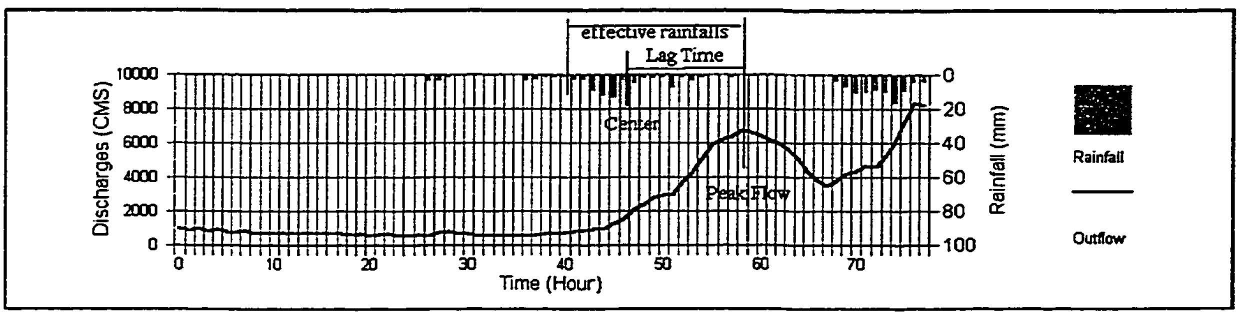
Fig. B.3.(a) The Lag-Time Calculations at ChungJu Reservoir



(Subbasin 17)



(Subbasin 18)



(Subbasin 19)

Fig. B.3.(b) The Lag-Time Calculations at ChungJu Reservoir

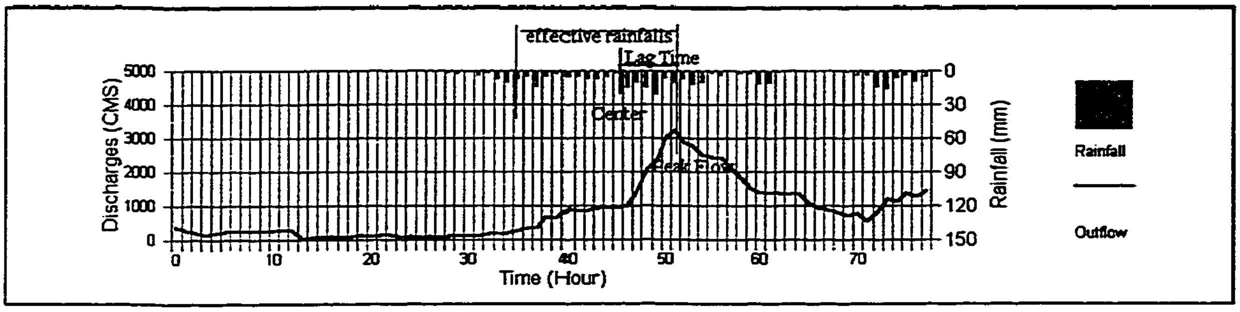


Fig. B.4 The Lag-Time Calculations at ChunCheon Reservoir

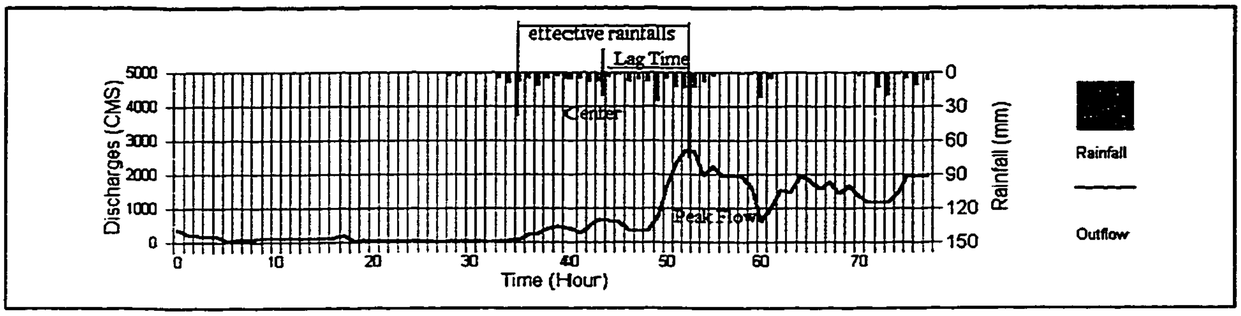


Fig. B.5 The Lag-Time Calculations at UiAm Reservoir

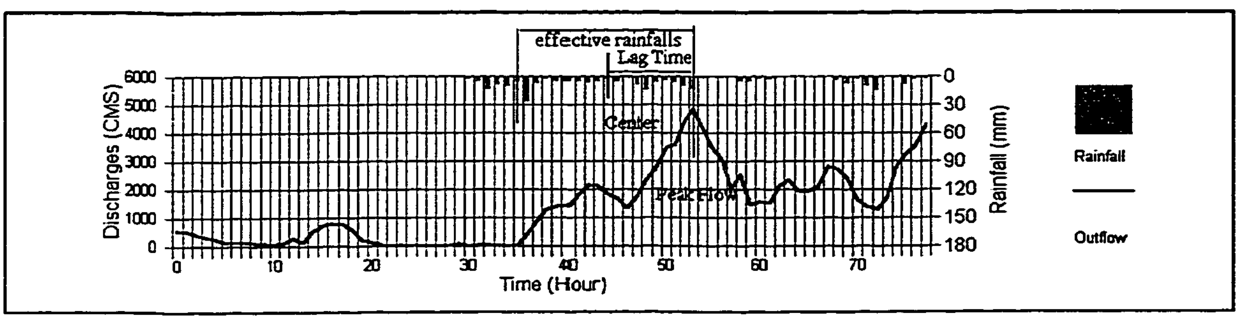
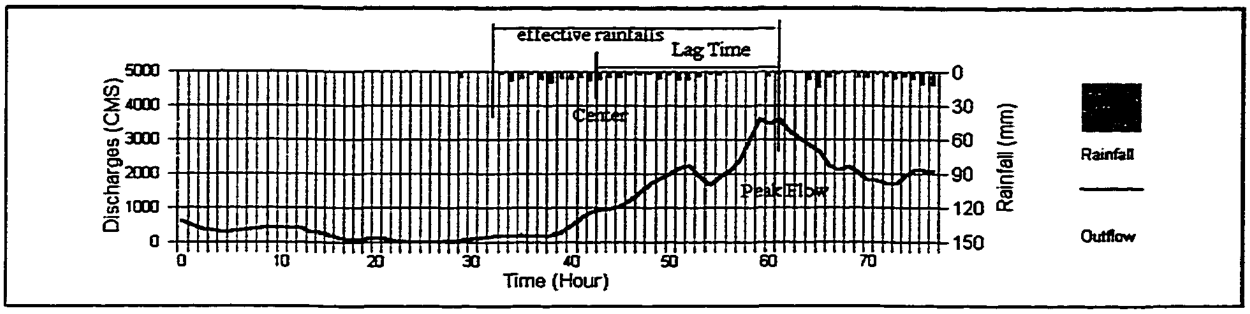
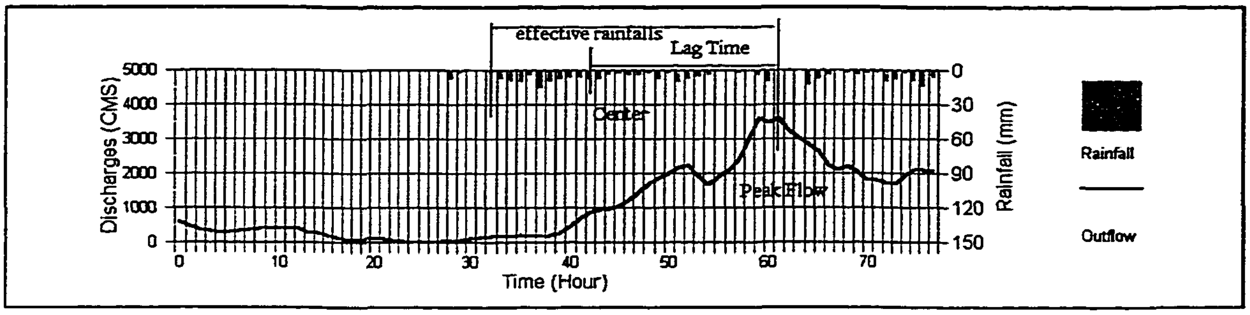


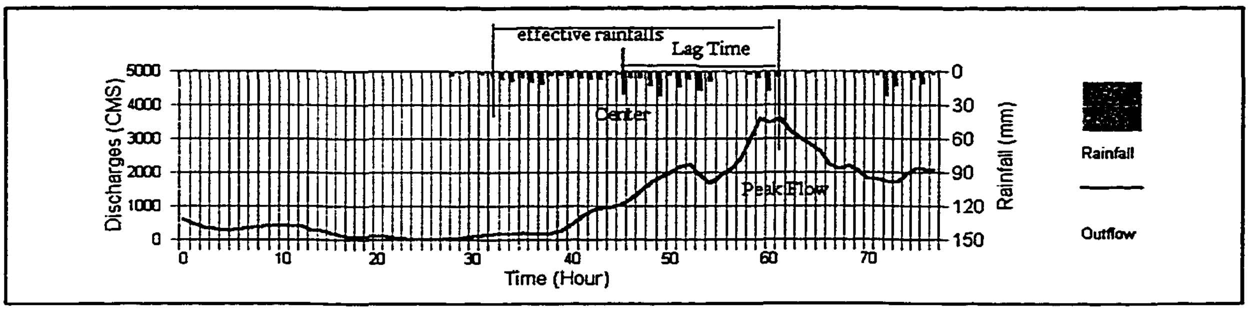
Fig. B.6 The Lag-Time Calculations at InDoGyo Flood Control Point



(Subbasin 9)

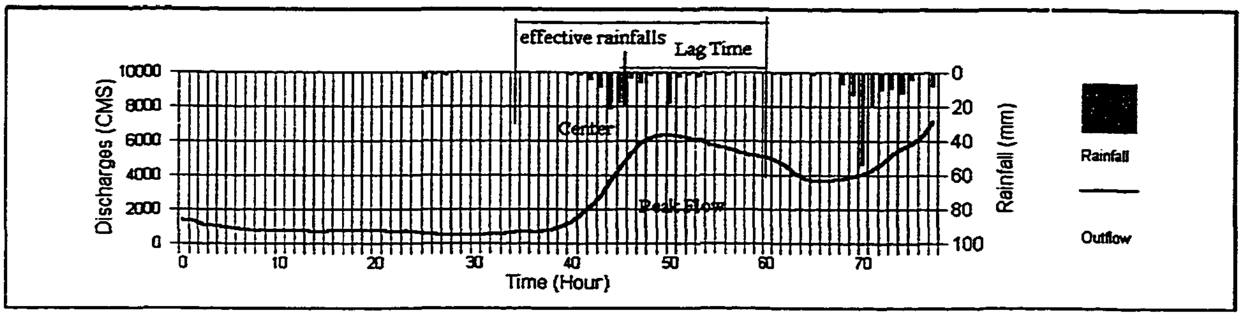


(Subbasin 10)

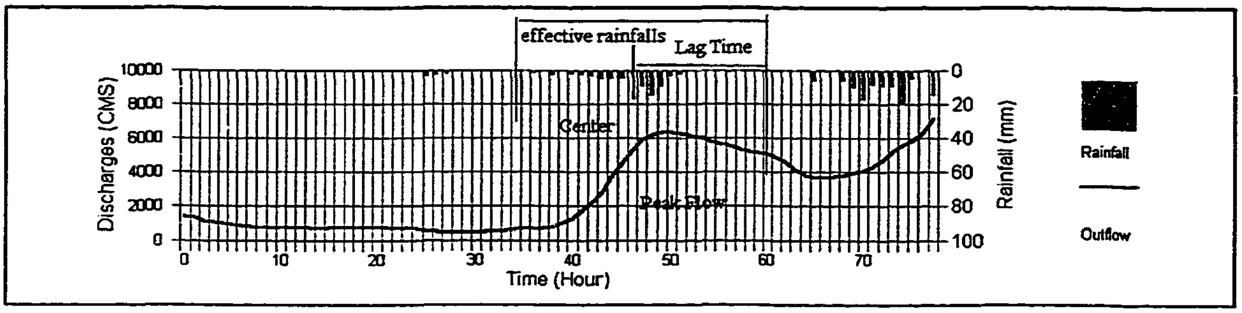


(Subbasin 11)

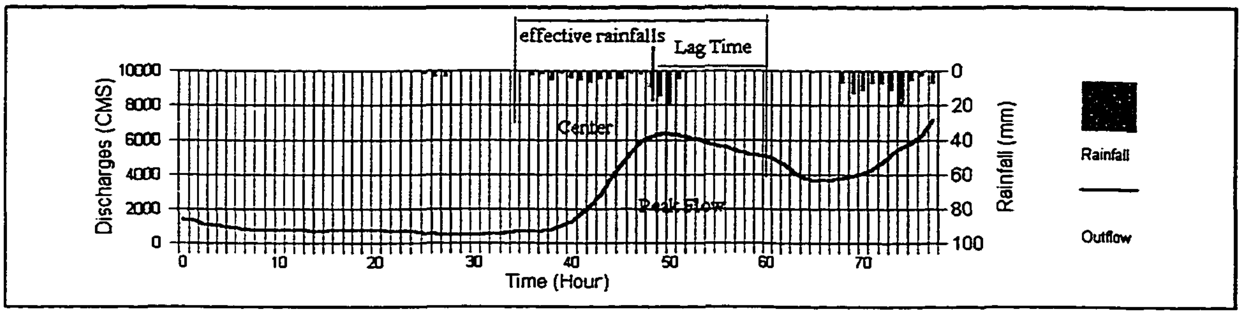
Fig. B.7 The Lag-Time Calculations at CheongPyeong Reservoir



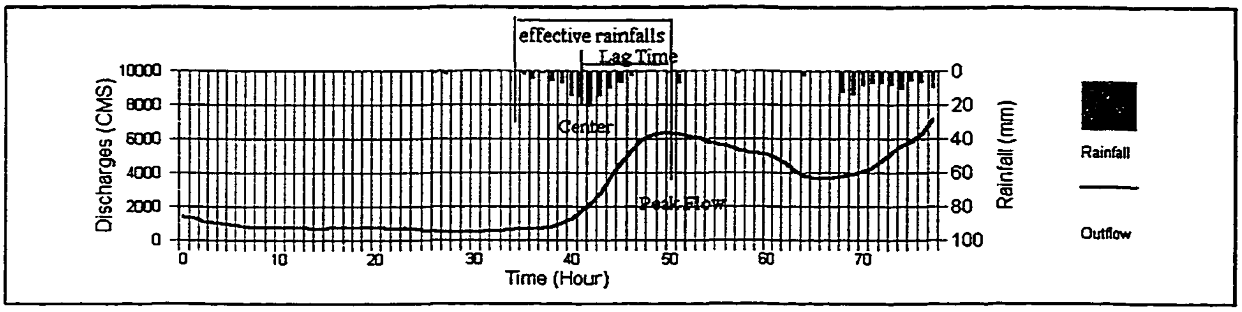
(Subbasin 20)



(Subbasin 21)

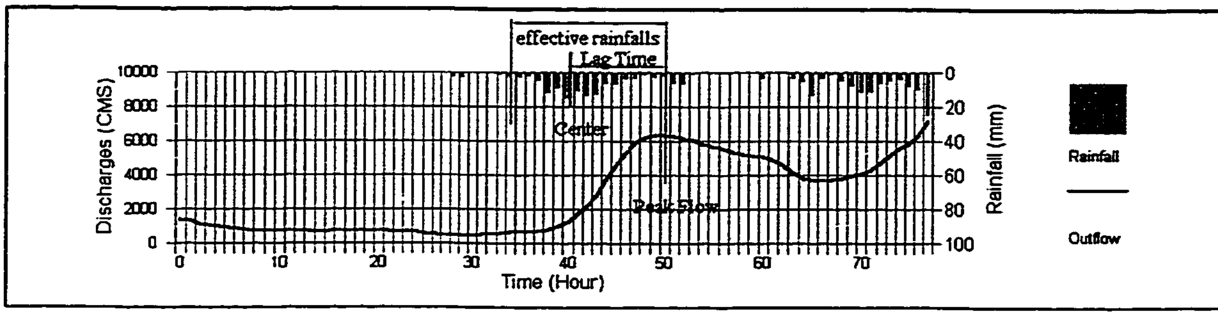


(Subbasin 22)

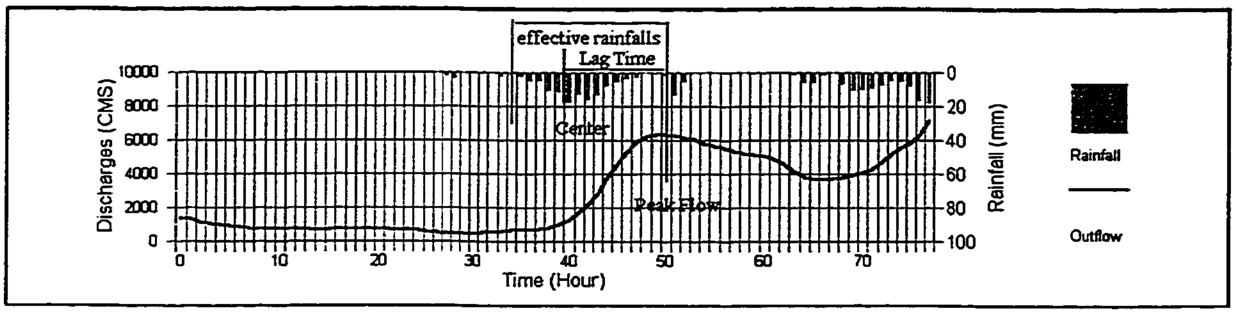


(Subbasin 23)

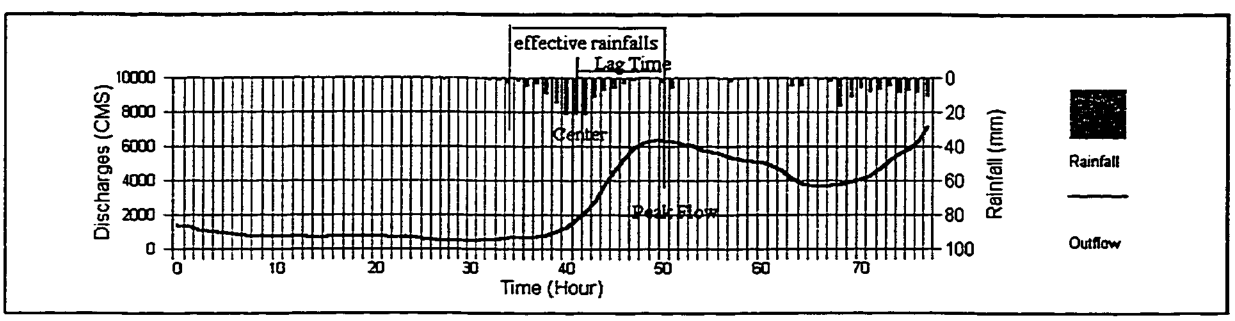
Fig. B.8.(a) The Lag-Time Calculations at YeoJu Flood Control Point



(Subbasin 24)

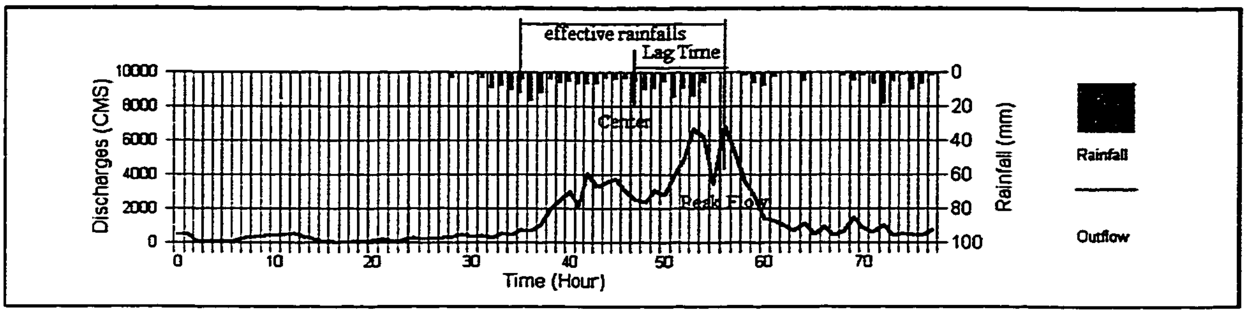


(Subbasin 25)

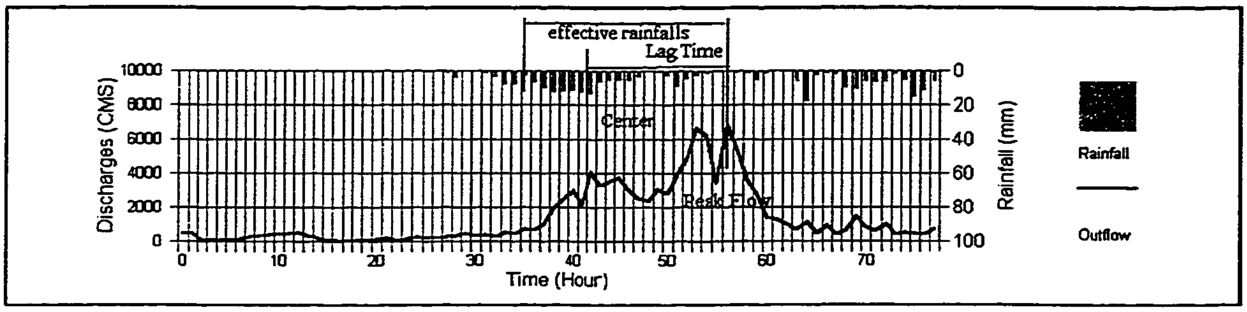


(Subbasin 26)

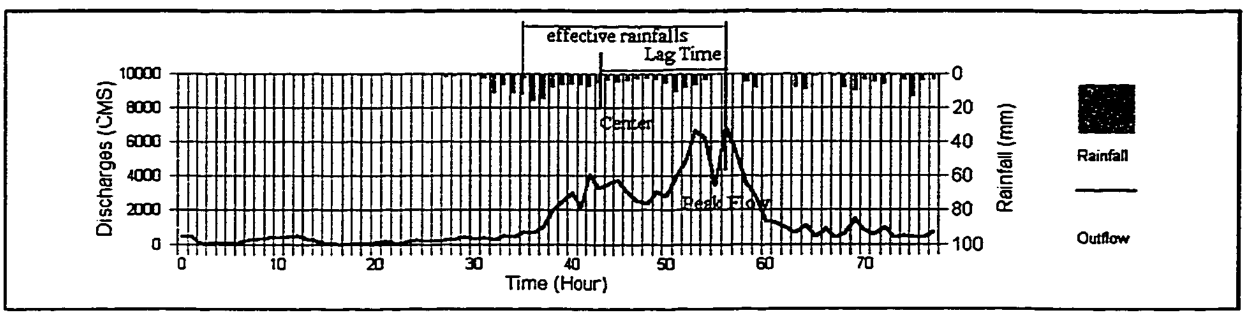
Fig. B.8.(b) The Lag-Time Calculations at YeoJu Flood Control Point



(Subbasin 12)



(Subbasin 27)



(Subbasin 28)

Fig. B.9. The Lag-Time Calculations at PalDang Reservoir

APPENDIX C

Training Statistics for Flood Forecasting Models

Table C.1 Statistical Representation for FLOOD FORECASTING Models Training for Inflow of the Hwa Cheon Reservoir (Data Set;1995 08/22/05 – 08/25/10)

SN	NHL	MNEP	DEG	CEP	TT	SSE
Ser01	6	2000	0.05	5	2.69	0.0085605226
Ser02	6	2000	0.05	0	0.11	0.028332701
Ser03	6	2000	0.05	1	0.55	0.020055855
Ser04	6	2000	0.05	0	0.16	0.039399909
Ser05	6	2000	0.05	1	0.55	0.02974854
Ser06	6	2000	0.05	1	0.55	0.021143132
Ser07	6	2000	0.05	0	0.11	0.04517512
Ser08	6	2000	0.05	1	0.61	0.015534967
Ser09	6	2000	0.05	0	0.16	0.041546628
Ser10	6	2000	0.05	1	0.55	0.0181658
Ser11	6	2000	0.05	0	0.17	0.043474466
Ser12	6	2000	0.05	1	0.55	0.020319698
Ser13	6	2000	0.05	0	0.11	0.047041817
Ser14	6	2000	0.05	1	0.55	0.033324901
Ser15	6	2000	0.05	1	0.49	0.037647917
Ser16	6	2000	0.05	1	0.49	0.032530363
Ser17	6	2000	0.05	1	0.49	0.035606217
Ser18	6	2000	0.05	1	0.44	0.037467712
Ser19	6	2000	0.05	1	0.44	0.037967147
Ser20	6	2000	0.05	1	0.50	0.03724111
Ser21	6	2000	0.05	1	0.38	0.036890556
Ser22	6	2000	0.05	1	0.49	0.041158208
Ser23	6	2000	0.05	1	0.50	0.045398279
Ser24	6	2000	0.05	1	0.49	0.043245264
Total					12.13	

SN; Series Number
NHN; No. of Hidden Layer
MNEP; Maximum No. of Epoch
DEG; Desired Error Goal
CEP; Converged Epoch
TT; Training Time (Seconds)
SSE; Sum Square Error between the given and predicted values

Table C.2 Statistical Representation for FLOOD FORECASTING Models Training for Inflow of the So Yang Gang Reservoir (Data Set;1995 08/22/05 – 08/25/10)

SN	NHN	MNEP	DEG	CEP	TT	SSE
Ser01	6	2000	0.005	6	3.02	0.0012261915
Ser02	6	2000	0.005	4	1.43	0.00089299523
Ser03	6	2000	0.005	4	1.71	0.0019413186
Ser04	6	2000	0.005	3	1.10	0.00094064711
Ser05	6	2000	0.005	3	1.10	0.0037785091
Ser06	6	2000	0.005	3	1.21	0.0021029594
Ser07	6	2000	0.005	2	0.82	0.0038428862
Ser08	6	2000	0.005	6	2.26	0.0039300443
Ser09	6	2000	0.005	2	0.77	0.0044341296
Ser10	6	2000	0.005	3	1.15	0.0048048606
Ser11	6	2000	0.005	9	3.41	0.0044564296
Ser12	6	2000	0.005	4	1.43	0.004058691
Ser13	6	2000	0.005	4	1.43	0.0043013188
Ser14	6	2000	0.005	2	0.77	0.0046651564
Ser15	6	2000	0.005	3	1.26	0.0032419531
Ser16	6	2000	0.005	3	1.10	0.0042979095
Ser17	6	2000	0.005	6	2.09	0.0049069257
Ser18	6	2000	0.005	15	5.22	0.0048956448
Ser19	6	2000	0.005	5	1.70	0.003965184
Ser20	6	2000	0.005	2	0.71	0.0036446677
Ser21	6	2000	0.005	3	1.15	0.0030681105
Ser22	6	2000	0.005	2	0.77	0.0046279605
Ser23	6	2000	0.005	4	1.54	0.0024393341
Ser24	6	2000	0.005	2	0.71	0.001772149
Total					37.86	

SN; Series Number
NHN; No. of Hidden Layer
MNEP; Maximum No. of Epoch
DEG; Desired Error Goal
CEP; Converged Epoch
TT; Training Time (Seconds)
SSE; Sum Square Error between the given and predicted values

Table C.3 Statistical Representation for FLOOD FORECASTING Models Training for Inflow of the Chung Ju Reservoir (Data Set;1995 08/22/05 – 08/25/10)

SN	NHN	MNEP	DEG	CEP	TT	SSE
Ser01	6	2000	0.005	4	32.24	3.1664875E-05
Ser02	6	2000	0.005	1	10.00	0.0005314092
Ser03	6	2000	0.005	1	6.43	0.00067550951
Ser04	6	2000	0.005	1	10.10	0.00083094058
Ser05	6	2000	0.005	1	10.05	0.00072441742
Ser06	6	2000	0.005	1	6.42	0.00092211584
Ser07	6	2000	0.005	1	6.38	0.0011445707
Ser08	6	2000	0.005	1	9.77	0.00092139315
Ser09	6	2000	0.005	1	6.26	0.00077107822
Ser10	6	2000	0.005	1	6.21	0.0010362713
Ser11	6	2000	0.005	1	9.44	0.0010333016
Ser12	6	2000	0.005	1	6.09	0.00074562371
Ser13	6	2000	0.005	1	6.05	0.00066084567
Ser14	6	2000	0.005	1	9.23	0.0011661176
Ser15	6	2000	0.005	1	9.17	0.0021333669
Ser16	6	2000	0.005	1	9.00	0.00054193148
Ser17	6	2000	0.005	1	8.95	0.00025128904
Ser18	6	2000	0.005	1	9.06	0.0002697075
Ser19	6	2000	0.005	1	8.95	0.00035098856
Ser20	6	2000	0.005	1	8.90	0.00057059091
Ser21	6	2000	0.005	1	8.84	0.0014508925
Ser22	6	2000	0.005	1	8.79	0.0020143926
Ser23	6	2000	0.005	1	8.73	0.0024545541
Ser24	6	2000	0.005	1	8.68	0.0019138674
Total					223.74	

SN; Series Number
NHN; No. of Hidden Layer
MNEP; Maximum No. of Epoch
DEG; Desired Error Goal
CEP; Converged Epoch
TT; Training Time (Seconds)
SSE; Sum Square Error between the given and predicted values

Table C.4 Statistical Representation for FLOOD FORECASTING Models Training for Local Inflow of the Chun Cheon Reservoir (Data Set;1995 08/22/05 – 08/25/10)

SN	NHN	MNEP	DEG	CEP	TT	SSE
Ser01	5	2000	0.01	39	4.95	0.0070
Ser02	5	2000	0.01	12	1.48	0.0084
Ser03	5	2000	0.01	6	0.77	0.0072
Ser04	5	2000	0.01	10	1.16	0.0073
Ser05	5	2000	0.01	11	1.38	0.0079
Ser06	5	2000	0.01	7	0.88	0.0094
Ser07	5	2000	0.01	2	0.38	0.0068
Ser08	5	2000	0.01	5	0.61	0.0066
Ser09	5	2000	0.01	4	0.49	0.0093
Ser10	5	2000	0.01	7	0.82	0.0094
Ser11	5	2000	0.01	6	0.82	0.0100
Ser12	5	2000	0.01	10	1.10	0.0092
Ser13	5	2000	0.01	11	1.27	0.0095
Ser14	5	2000	0.01	4	0.49	0.0086
Ser15	5	2000	0.01	16	1.59	0.0092
Ser16	5	2000	0.01	5	0.55	0.0070
Ser17	5	2000	0.01	3	0.44	0.0099
Ser18	5	2000	0.01	5	0.55	0.0095
Ser19	5	2000	0.01	35	3.57	0.0098
Ser20	5	2000	0.01	55	4.94	0.0099
Ser21	5	2000	0.01	379	35.65	0.0095
Ser22	5	2000	0.01	131	12.19	0.0032
Ser23	5	2000	0.01	3	0.39	0.0058
Ser24	5	2000	0.01	5	0.50	0.0089
Total					76.97	

SN; Series Number
NHN; No. of Hidden Layer
MNEP; Maximum No. of Epoch
DEG; Desired Error Goal
CEP; Converged Epoch
TT; Training Time (Seconds)
SSE; Sum Square Error between the given and predicted values

Table C.5 Statistical Representation for FLOOD FORECASTING Models Training for Local Inflow of the Ui Am Reservoir (Data Set;1995 08/22/05 – 08/25/10)

SN	NHN	MNEP	DEG	CEP	TT	SSE
Ser01	5	2000	0.02	19	2.69	0.019886027
Ser02	5	2000	0.02	8	1.04	0.017987721
Ser03	5	2000	0.02	8	0.99	0.019513937
Ser04	5	2000	0.02	31	3.52	0.016574311
Ser05	5	2000	0.02	4	0.54	0.019391434
Ser06	5	2000	0.02	15	1.65	0.019119968
Ser07	5	2000	0.02	5	0.66	0.018638586
Ser08	5	2000	0.02	7	0.88	0.019336144
Ser09	5	2000	0.02	4	0.49	0.014892138
Ser10	5	2000	0.02	11	1.21	0.019081301
Ser11	5	2000	0.02	17	1.82	0.019695547
Ser12	5	2000	0.02	21	2.25	0.019872143
Ser13	5	2000	0.02	20	2.03	0.019035144
Ser14	5	2000	0.02	12	1.32	0.019150586
Ser15	5	2000	0.02	7	0.77	0.019824264
Ser16	5	2000	0.02	13	1.37	0.012477474
Ser17	5	2000	0.02	3	0.39	0.018951237
Ser18	5	2000	0.02	3	0.44	0.018377696
Ser19	5	2000	0.02	37	3.3	0.019393893
Ser20	5	2000	0.02	46	4.56	0.019602574
Ser21	5	2000	0.02	5	0.55	0.019405782
Ser22	5	2000	0.02	4	0.49	0.01799922
Ser23	5	2000	0.02	13	1.21	0.009269626
Ser24	5	2000	0.02	3	0.44	0.013942141
Total					34.61	

SN; Series Number
NHN; No. of Hidden Layer
MNEP; Maximum No. of Epoch
DEG; Desired Error Goal
CEP; Converged Epoch
TT; Training Time (Seconds)
SSE; Sum Square Error between the given and predicted values

Table C.6 Statistical Representation for FLOOD FORECASTING Models Training for Local Inflow of the Cheong Pyeong Reservoir (Data Set;1995 08/22/05 – 08/25/10)

SN	NHN	MNEP	DEG	CEP	TT	SSE
Ser01	6	2000	0.005	6	2.81	0.0028671016
Ser02	6	2000	0.005	2	0.87	0.002329762
Ser03	6	2000	0.005	2	0.94	0.0025363291
Ser04	6	2000	0.005	2	0.88	0.0030982564
Ser05	6	2000	0.005	2	0.88	0.0034705721
Ser06	6	2000	0.005	2	0.88	0.0024242783
Ser07	6	2000	0.005	1	0.6	0.0049278046
Ser08	6	2000	0.005	2	0.88	0.0024842101
Ser09	6	2000	0.005	2	0.83	0.0035710493
Ser10	6	2000	0.005	2	0.82	0.0047637563
Ser11	6	2000	0.005	4	1.82	0.004312786
Ser12	6	2000	0.005	4	1.75	0.0034039866
Ser13	6	2000	0.005	2	0.77	0.0035964209
Ser14	6	2000	0.005	2	0.77	0.0045391857
Ser15	6	2000	0.005	3	1.21	0.0039516104
Ser16	6	2000	0.005	1	0.44	0.0048034542
Ser17	6	2000	0.005	1	0.49	0.0045017263
Ser18	6	2000	0.005	2	0.72	0.0018122824
Ser19	6	2000	0.005	2	0.72	0.0030844033
Ser20	6	2000	0.005	2	0.72	0.0023257653
Ser21	6	2000	0.005	2	0.71	0.0031889838
Ser22	6	2000	0.005	2	0.71	0.0033644535
Ser23	6	2000	0.005	2	0.71	0.0040317077
Ser24	6	2000	0.005	2	0.72	0.0044334925
Total					22.65	

SN; Series Number
NHN; No. of Hidden Layer
MNEP; Maximum No. of Epoch
DEG; Desired Error Goal
CEP; Converged Epoch
TT; Training Time (Seconds)
SSE; Sum Square Error between the given and predicted values

Table C.7 Statistical Representation for FLOOD FORECASTING Models Training for Local Inflow of the Yeo Ju Flood Control Point (Data Set;1995 08/22/05 – 08/25/10)

SN	NHN	MNEP	DEG	CEP	TT	SSE
Ser01	9	2000	0.01	5	33.67	0.008221092
Ser02	9	2000	0.01	1	4.51	0.00407682
Ser03	9	2000	0.01	1	4.50	0.0052248875
Ser04	9	2000	0.01	1	6.70	0.0055437102
Ser05	9	2000	0.01	1	6.64	0.0071605414
Ser06	9	2000	0.01	1	6.53	0.0080724967
Ser07	9	2000	0.01	1	6.54	0.0094562968
Ser08	9	2000	0.01	2	12.69	0.0011284342
Ser09	9	2000	0.01	1	6.37	0.0023387765
Ser10	9	2000	0.01	1	6.16	0.0040460285
Ser11	9	2000	0.01	1	6.15	0.0062988134
Ser12	9	2000	0.01	1	6.21	0.0090861043
Ser13	9	2000	0.01	2	12.58	0.0081369924
Ser14	9	2000	0.01	2	14.28	0.0089103275
Ser15	9	2000	0.01	2	9.94	0.0077146317
Ser16	9	2000	0.01	1	6.10	0.0077372033
Ser17	9	2000	0.01	2	9.83	0.0095847509
Ser18	9	2000	0.01	14	93.65	0.0099662912
Ser19	9	2000	0.01	29	230.63	0.0099747734
Ser20	9	2000	0.01	2	9.56	0.0099818576
Ser21	9	2000	0.01	1	5.88	0.007863596
Ser22	9	2000	0.01	1	3.84	0.0055099618
Ser23	9	2000	0.01	1	5.77	0.0032830649
Ser24	9	2000	0.01	1	5.72	0.0021069183
Total					514.45	

SN; Series Number
NHN; No. of Hidden Layer
MNEP; Maximum No. of Epoch
DEG; Desired Error Goal
CEP; Converged Epoch
TT; Training Time (Seconds)
SSE; Sum Square Error between the given and predicted values

Table C.8 Statistical Representation for FLOOD FORECASTING Models Training for Local Inflow of the Pal Dang Reservoir (Data Set;1995 08/22/05 – 08/25/10)

SN	NHN	MNEP	DEG	CEP	TT	SSE
Ser01	8	2000	0.09	4	3.90	0.018533712
Ser02	8	2000	0.09	3	2.19	0.033410351
Ser03	8	2000	0.09	2	1.92	0.070963389
Ser04	8	2000	0.09	4	4.06	0.076070407
Ser05	8	2000	0.09	2	1.70	0.065648819
Ser06	8	2000	0.09	3	2.25	0.022987636
Ser07	8	2000	0.09	5	3.52	0.024948207
Ser08	8	2000	0.09	2	1.32	0.071901392
Ser09	8	2000	0.09	4	3.24	0.027111736
Ser10	8	2000	0.09	4	2.80	0.082505455
Ser11	8	2000	0.09	7	4.84	0.0699287
Ser12	8	2000	0.09	4	3.35	0.082429364
Ser13	8	2000	0.09	3	2.09	0.067702668
Ser14	8	2000	0.09	3	2.14	0.078951168
Ser15	8	2000	0.09	1	0.66	0.082972756
Ser16	8	2000	0.09	2	1.26	0.028814487
Ser17	8	2000	0.09	3	1.87	0.033592274
Ser18	8	2000	0.09	3	2.03	0.052736227
Ser19	8	2000	0.09	3	2.31	0.063919416
Ser20	8	2000	0.09	5	2.80	0.086899967
Ser21	8	2000	0.09	4	2.96	0.088895871
Ser22	8	2000	0.09	8	5.44	0.044434844
Ser23	8	2000	0.09	2	1.20	0.072757951
Ser24	8	2000	0.09	6	3.90	0.084262135
Total					63.75	

SN; Series Number
NHN; No. of Hidden Layer
MNEP; Maximum No. of Epoch
DEG; Desired Error Goal
CEP; Converged Epoch
TT; Training Time (Seconds)
SSE; Sum Square Error between the given and predicted values

Table C.9 Statistical Representation for FLOOD FORECASTING Models Training for Local Inflow of the In Do Gyo Flood Control Point (Data Set;1995 08/22/05 – 08/25/10)

SN	NHN	MNEP	DEG	CEP	TT	SSE
Ser01	5	2000	0.04	9	1.59	0.01205598
Ser02	5	2000	0.04	2	0.44	0.028393241
Ser03	5	2000	0.04	5	0.71	0.038990632
Ser04	5	2000	0.04	10	1.27	0.036652631
Ser05	5	2000	0.04	3	0.49	0.034504033
Ser06	5	2000	0.04	3	0.44	0.036973049
Ser07	5	2000	0.04	1	0.28	0.037136978
Ser08	5	2000	0.04	3	0.49	0.037844207
Ser09	5	2000	0.04	2	0.39	0.035445832
Ser10	5	2000	0.04	3	0.49	0.039897229
Ser11	5	2000	0.04	2	0.39	0.03551969
Ser12	5	2000	0.04	2	0.33	0.024466221
Ser13	5	2000	0.04	4	0.5	0.039853676
Ser14	5	2000	0.04	5	0.6	0.037562321
Ser15	5	2000	0.04	4	0.55	0.037112563
Ser16	5	2000	0.04	7	0.88	0.037594195
Ser17	5	2000	0.04	7	0.88	0.039529692
Ser18	5	2000	0.04	8	0.88	0.030178746
Ser19	5	2000	0.04	9	1.09	0.02580859
Ser20	5	2000	0.04	2	0.33	0.038328271
Ser21	5	2000	0.04	3	0.38	0.033574529
Ser22	5	2000	0.04	2	0.33	0.037125901
Ser23	5	2000	0.04	2	0.33	0.025744355
Ser24	5	2000	0.04	2	0.33	0.033925387
Total					14.39	

SN; Series Number
NHN; No. of Hidden Layer
MNEP; Maximum No. of Epoch
DEG; Desired Error Goal
CEP; Converged Epoch
TT; Training Time (Seconds)
SSE; Sum Square Error between the given and predicted values

APPENDIX D

HRBSDP User-Supplied Subroutine and ROUT Programs

Related Input and Output Files

D1 Subroutine STATE

D2 Subroutine OBJECT and RESULTS

D3 Subroutine READIN

D4 Program ROUT

D5 HRBSDP. DAT file

```
C***************************************************************************
      SUBROUTINE STATE
C***************************************************************************
C  NODE DESCRIPTIONS
C
C
C    NODE 1 = HWA CHEON STORAGE RESERVOIR
C    NODE 2 = SO YANG GANG STORAGE RESERVOIR
C    NODE 3 = CHUNG JU STORAGE RESERVOIR
C    NODE 4 = CHUN CHEON DUMMY RESERVOIR
C    NODE 5 = UI AM DUMMY RESERVOIR
C    NODE 6 = CHEONG PYEONG DUMMY RESERVOIR
C    NODE 7 = YEO JU FLOOD CONTROL POINT
C    NODE 8 = PAL DANG DUMMY RESERVOIR
C    NODE 9 = IN DO GYO FLOOD CONTROL POINT
C    RELATED VARIABLES
C            X(I)    ; STORAGE AT THE BEGINING OF INTERVAL
C            X1(I)   ; STORAGE AT THE END OF INTERVAL
C            U(I)    ; RELEASE AT THE END OF INTERVAL
C            XINF(I); LOCAL INFLOW DURING THE PERIOD
C
C
C  REACH DESCRIPTIONS
C
C
C    REACH 1 => HWACHEON RESERVOIR RELEASE TO CHUNCHEON RESERVOIR UPSTREAM
C    REACH 2 => SOYANGGANG RESERVOIR RELEASE TO UIAM RESERVOIR UPSTREAM
C    REACH 3 => CHUNGJU RESERVOIR RELEASE TO YEOJU FLOOD CONTROL POINT
C               UPSTREAM
C    REACH 4 => CHUNCHEON RESERVOIR RELEASE TO  UIAM RESERVOIR UPSTREAM
C    REACH 5 => UIAM RESERVOIR RELEASE TO CHEONGPYEONG FLOOD CONTROL POINT
C               UPSTREAM
C    REACH 6 => CHEONGPYEONG FLOOD CONTROL POINT DOWNSTREAM TO PALDANG
C               RESERVOIR UPSTREAM
C    REACH 7 => YEOJU FLOOD CONTROL POINT DOWNSTREAM TO PALDANG RESERVOIR
C               UPSTREAM
C    REACH 8 => PALDANG RESERVOIR DOWNSTREAM TO INDOGYO FLOOD CONTROL POINT
C    RELATED VARIABLES
C            AP(I); ROUTING COEFFICIENTS
C
C***************************************************************************
      COMMON/MULTDM/X(10),X1(10),U(10),F,I,J,K(10),L(10),PNALTY
      COMMON/INPUTSTATE/XINF(9,24),AP(8,24)
      COMMON/INPUTOBJ/DFLOOD(9),TSTO(9),XMAX(9),QPLAN(9),SLSTO(9)
      INTEGER IM,JD
C
C***  STATE DYNAMICS FOR THE EACH NODE (INVERTED FORM)
C !!!!!  ORDER OF CALCULATION IS VERY IMPORTANT  !!!!!
C
      IM = MOD(I,24)
      IF(IM.EQ.0) IM = 24
C
      DO 10 JD = 1,3
   10 U(JD) = X(JD) - X1(JD) + XINF(JD,IM)
C
      U(4) = X(4) - X1(4) + XINF(4,IM) + AP(1,IM)*U(1)
C
      U(5) = X(5) - X1(5) + XINF(5,IM) + AP(2,IM)*U(2) + AP(4,IM)*U(4)
C
      U(6) = X(6) - X1(6) + XINF(6,IM) + AP(5,IM)*U(5)
C
      U(7) = X(7) - X1(7) + XINF(7,IM) + AP(3,IM)*U(3)
C
      U(8)=X(8)-X1(8)+XINF(8,IM)+AP(6,IM)*U(7)+AP(7,IM)*U(7)-QPLAN(8)
C
      U(9) = X(9)-X1(9)+XINF(9,IM)+AP(8,IM)*U(8)
C
C
C
      RETURN
      END
```

```
C=====================================================================
      SUBROUTINE OBJECT                                          OB    1
C=====================================================================
C
C  NODE DESCRIPTIONS
C
C
C    NODE 1 = HWA CHEON STORAGE RESERVOIR
C    NODE 2 = SO YANG GANG STORAGE RESERVOIR
C    NODE 3 = CHUNG JU STORAGE RESERVOIR
C    NODE 4 = CHUN CHEON DUMMY RESERVOIR
C    NODE 5 = UI AM DUMMY RESERVOIR
C    NODE 6 = CHEONG PYEONG DUMMY RESERVOIR
C    NODE 7 = YEO JU FLOOD CONTROL POINT
C    NODE 8 = PAL DANG DUMMY RESERVOIR
C    NODE 9 = IN DO GYO FLOOD CONTROL POINT
C    RELATED VARIABLES
C            X(I)    ; STORAGE AT THE BEGINING OF INTERVAL
C            X1(I)   ; STORAGE AT THE END OF INTERVAL
C            U(I)    ; RELEASE AT THE END OF INTERVAL
C            XINF(I); LOCAL INFLOW DURING THE PERIOD
C
C
C  REACH DESCRIPTIONS
C
C
C    REACH 1 => HWACHEON RESERVOIR RELEASE TO CHUNCHEON RESERVOIR UPSTREAM
C    REACH 2 => SOYANGGANG RESERVOIR RELEASE TO UIAM RESERVOIR UPSTREAM
C    REACH 3 => CHUNGJU RESERVOIR RELEASE TO YEOJU FLOOD CONTROL POINT
C               UPSTREAM
C    REACH 4 => CHUNCHEON RESERVOIR RELEASE TO  UIAM RESERVOIR UPSTREAM
C    REACH 5 => UIAM RESERVOIR RELEASE TO CHEONGPYEONG FLOOD CONTROL POINT
C               UPSTREAM
C    REACH 6 => CHEONGPYEONG FLOOD CONTROL POINT DOWNSTREAM TO PALDANG
C               RESERVOIR UPSTREAM
C    REACH 7 => YEOJU FLOOD CONTROL POINT DOWNSTREAM TO PALDANG RESERVOIR
C               UPSTREAM
C    REACH 8 => PALDANG RESERVOIR DOWNSTREAM TO INDOGYO FLOOD CONTROL POINT
C    RELATED VARIABLES
C            AP(I); ROUTING COEFFICIENTS
C
C
      COMMON/MULTDM/X(10),X1(10),U(10),F,I,J,K(10),L(10),PNALTY
      COMMON/INPUTWEIGHT/W1(9),W2(9),W3(9),W4(9),W5(9),W6(9),W7(9)
      COMMON/INPUTOBJ/DFLOOD(9),TSTO(9),XMAX(9),QPLAN(9),SLSTO(9)
      COMMON/OBJ/SPMX(9),AVGX(9),UPRE(9)
      COMMON/PE/PEN1(9),PEN2(9),PEN3(9),PEN4(9),PEN5(9),PEN6(9),PEN7(9)
      COMMON/FFF/F1,F2,F3,F4,F5,F6,F7
      COMMON/TRACE/ITRACE
      LOGICAL ITRACE
C
C
C
      IM = MOD(I,24)
      IF(IM.EQ.0) IM = 24
      DO 2 JD = 1,9
      PEN1(JD)=0.0
      PEN2(JD)=0.0
      PEN4(JD)=0.0
      PEN5(JD)=0.0
    2 PEN6(JD)=0.0
C
C  OBJECTIVE 1
C
      DO 10 JD = 7,9,2
      IF(U(JD).GT.DFLOOD(JD)) THEN
      PEN1(JD) = W1(JD)*(U(JD)-DFLOOD(JD))**2
      ELSE
      PEN1(JD) = 0.0
      ENDIF
   10 CONTINUE
```

```
C
C  OBJECTIVE 2
C
      DO 20 JD = 1,3
      PEN2(JD) = W2(JD)*(X(JD) - TSTO(JD))**2
   20 CONTINUE
C
C  OBJECTIVE 4
C
      DO 40 JD = 8,8
      IF(U(JD).LT.QPLAN(JD)) THEN
      PEN4(JD) = W4(JD)*(U(JD)-QPLAN(JD))**2
      ELSE
      PEN4(JD) = 0.0
      ENDIF
   40 CONTINUE
C
C  OBJECTIVE 5
C
C*** CALCULATE MAXIMUM AVAILABLE SPILL
C
C CALCULATION OF AVERAGE STORAGE
C
      DO 51 JD = 1,3
      AVGX(JD) = (X(JD) + X1(JD))/2.
   51 CONTINUE
C
C HWA CHEON RESERVOIR
C
      IF(AVGX(1).GT.704.2)THEN
      SPMX(1)=(173.62719-(84187274/AVGX(1)**2))**2+185.0
      ELSE
      SPMX(1) =185.0
      ENDIF
C
C SO YANG GANG RESERVOIR
C
      IF(AVGX(2).GT.2100.0)THEN
      SPMX(2)=(299.5864809-80222.0233*ALOG(AVGX(2))/AVGX(2))**2+251.0
      ELSE
      SPMX(2) = 251.0
      END IF
C
C CHUNG JU RESERVOIR
C
      IF(AVGX(3).GT.1308.0)THEN
      SPMX(3) = 0.002842373*(AVGX(3))**2 - 5393.36458 + 828.0
      ELSE
      SPMX(3) = 828.0
      END IF
C
C*** CONVERSION  CMS - TO - MCM
C
      DO 52 JD = 1,3
   52 SPMX(JD) = SPMX(JD)*3600.0/1000000.0

      DO 53 JD = 1,3
      IF(U(JD).GT.SPMX(JD)) THEN
      PEN5(JD) = W5(JD)*(U(JD)-SPMX(JD))**2
      ELSE
      PEN5(JD) = 0.0
      ENDIF
   53 CONTINUE
C
C  OBJECTIVE 6
C
      DO 60 JD = 1,9
      IF (IM.EQ.1) Then
      PEN6(JD) = W6(JD)*((U(JD)-UPRE(JD))**2)*100
      Else
      PEN6(JD) = W6(JD)*U(JD)**2
```

```
      Endif
   60 CONTINUE
C
C  SUMMATION OF PENALY FUNCTIONS
C
      F1 = 0.0
      F2 = 0.0
      F4 = 0.0
      F5 = 0.0
      F6 = 0.0
      DO 80 JD = 1,9
      F1 = F1 + PEN1(JD)
      F2 = F2 + PEN2(JD)
      F4 = F4 + PEN4(JD)
      F5 = F5 + PEN5(JD)
      F6 = F6 + PEN6(JD)
   80 CONTINUE
      F = F1 + F2 + F4 + F5 + F6
C!  PRINT OUT RESULTS
      IF(ITRACE) CALL RESULTS
C!
      RETURN                                                            OB    6
      END                                                               OB    7
C!*********************************************************************************
C!     SUBROUTINE RESULTS FOR HRBSDP
C!*********************************************************************************
C!
      SUBROUTINE RESULTS
      COMMON/MULTDM/X(10),X1(10),U(10),F,I,J,K(10),L(10),PNALTY         OB    2
      COMMON/RES/XFLOW(9,24),QFLOW(9)
C!
C! REWIND THE FILE FOR THE BEGINNING OF A TRACEBACK AND WRITE HEADING LINE
      IF(I.EQ.1) THEN
      REWIND(124)
      REWIND(125)
      REWIND(126)
      REWIND(127)
      END IF
C!  WRITING THE COUSTOMIZE OUTPUT FILE
C
      DO 10 JD = 1,9
   10 QFLOW(JD)=U(JD)*1000000/3600
      WRITE(124,100)(QFLOW(JD),JD=1,8)
      WRITE(125,110)(X(JD),JD=1,5)
      WRITE(125,110)(X(JD),JD=6,9)
      WRITE(126,110)(X1(JD),JD=1,5)
      WRITE(126,110)(X1(JD),JD=6,9)
      WRITE(127,110)(QFLOW(JD),JD=1,9)
C
C!  FORMATS
C
  100 FORMAT(2X,8F10.2)
  110 FORMAT(20X,5G12.6)
      IF(I.EQ.24) THEN
      CLOSE(124)
      CLOSE(125)
      CLOSE(126)
      CLOSE(127)
      END IF
      RETURN
      END
```

```
C***********************************************************************
      SUBROUTINE READIN
C***********************************************************************
      COMMON/INPUTSTATE/XINF(9,24),AP(8,24)
      COMMON/INPUTWEIGHT/W1(9),W2(9),W3(9),W4(9),W5(9),W6(9),W7(9)
      COMMON/INPUTOBJ/DFLOOD(9),TSTO(9),XMAX(9),QPLAN(9),SLSTO(9)
      COMMON/OBJ/SPMX(9),AVGX(9),UPRE(9)
      COMMON/RES/XFLOW(9,24),QFLOW(9)
      INTEGER IM,JD,LD
C***********************************************************************
C
C! Use: UNIT=12 for OPENing GENERAL data file                          RD    2
C! Use: UNIT=13 for OPENing ROUTING COEFFICIENTS data file             RD    2
C! Use: UNIT=124 for OPENing ROUTING INPUT data file                   RD    2
C! Use: UNIT=125-127 for OPENing OUTPUT data file                      RD    2
      OPEN(12,FILE='HRBS.ADD',STATUS='OLD')                            RD    3
      OPEN(13,FILE='ALPHA.ADD',STATUS='OLD')                           RD    3
      OPEN(124,FILE='QOUT.TXT')
      OPEN(125,FILE='XOUT.TXT')
      OPEN(126,FILE='X1OUT.TXT')
      OPEN(127,FILE='UOUT.TXT')
C***********************************************************************
C  READ GENERAL DATA
C
C! READ LOCAL INFLOWS
C
      DO 10 IM = 1,24                                                   RD    4
   10 READ(12,*) (XINF(JD,IM),JD=1,9)                                   RD    5
C
C!  UNIT OF FLOW FROM CMS TO MCM
C
      DO 20 JD = 1,9
        DO 20 IM = 1,24
           XFLOW(JD,IM) = XINF(JD,IM)
   20      XINF(JD,IM) = XINF(JD,IM) * 3600 / 1000000
C
C! READ WEIGHTING FACTORS
C
      DO 30 JD = 1,9
   30  READ(12,*) W1(JD),W2(JD),W3(JD),W4(JD),W5(JD),W6(JD),W7(JD)
C
C! READ DESIGNED FLOOD FOR CONTROL POINT
C
      READ(12,*) (DFLOOD(JD), JD=1,9)
C
C! READ TARGET STORAGE
C
      READ(12,*) (TSTO(JD), JD=1,9)
C
C! READ MAXIMUM STORAGE
C
      READ(12,*) (XMAX(JD), JD=1,9)
C
C! READ PLANNED WATER SUPPLY DISCHARGES FOR DOWNSTREAM AREA
C
      READ(12,*) (QPLAN(JD), JD=1,9)
C
C! READ ENFORCED STORAGE FOR SUMMER PERIOD
C
      READ(12,*) (SLSTO(JD), JD=1,9)
C
C! READ Last Operational Releases
C
      READ(12,*) (UPRE(JD), JD=1,9)
      CLOSE(12)
C***********************************************************************
C  READ ROUTING COEFFICIENTS
C
      DO 40 IM = 1,24
   40 READ(13,*) (AP(LD,IM), LD=1,8)
      CLOSE(13)
```

```
C***************************************************************************
C
C!
C
      DO 50 JD = 1,9
      DFLOOD(JD) = DFLOOD(JD) * 3600 / 1000000
      UPRE(JD) = UPRE(JD) * 3600 / 1000000
   50 QPLAN(JD) = QPLAN(JD) * 3600 / 1000000

      RETURN                                                          RD    6
      END                                                             RD    7
```

```
Public Sub ROUT()

' Routing program by Muskingum Method

Dim COEFFK(7) As Single
Dim COEFFX(7) As Single
Dim COEFFC0(7) As Single
Dim COEFFC1(7) As Single
Dim COEFFC2(7) As Single
Dim QINFLOW(7, 1000) As Single
Dim QOUTFLOW(7, 1000) As Single
Dim ALPHA(7, 1000) As Single

' Initialize the parameters

COEFFK(0) = 2#
COEFFK(1) = 2#
COEFFK(2) = 2#
COEFFK(3) = 5#
COEFFK(4) = 4#
COEFFK(5) = 5#
COEFFK(6) = 6#
COEFFK(7) = 3#
COEFFX(0) = 0.2
COEFFX(1) = 0.2
COEFFX(2) = 0.2
COEFFX(3) = 0.2
COEFFX(4) = 0.2
COEFFX(5) = 0.2
COEFFX(6) = 0.2
COEFFX(7) = 0.4

' Calculates Coeffs.

For I = 0 To 7
COEFFC0(I) = -(COEFFK(I) * COEFFX(I) - 0.5) / (COEFFK(I) - COEFFK(I) * COEFFX(I) + 0.5)
COEFFC1(I) = (COEFFK(I) * COEFFX(I) + 0.5) / (COEFFK(I) - COEFFK(I) * COEFFX(I) + 0.5)
COEFFC2(I) = (COEFFK(I) - COEFFK(I) * COEFFX(I) - 0.5) / (COEFFK(I) - COEFFK(I) *
COEFFX(I) + 0.5)
Next I

For I = 1 To EndPoint
QINFLOW(0, I) = HWRR(I)
QINFLOW(1, I) = SORR(I)
QINFLOW(2, I) = CHRR(I)
QINFLOW(3, I) = CCRR(I)
QINFLOW(4, I) = UARR(I)
QINFLOW(5, I) = CPRR(I)
QINFLOW(6, I) = YJF(I)
QINFLOW(7, I) = PDRR(I)
Next I

EndRoutPt = EndPoint + 24

'If OprCount = 0 Then

'For I = (EndPoint + 1) To EndRoutPt
'QINFLOW(0, I) = HWRR(I)
'QINFLOW(1, I) = SORR(I)
'QINFLOW(2, I) = CHRR(I)
'QINFLOW(3, I) = CCRR(I)
'QINFLOW(4, I) = UARR(I)
'QINFLOW(5, I) = CPRR(I)
'QINFLOW(6, I) = YJF(I)
'QINFLOW(7, I) = PDRR(I)
'Next I

'Else

Open "D:\Hanprojt\Prog\Hrbsdp\QOUT.txt" For Input As #1
```

```
For I = (EndPoint + 1) To EndRoutPt
Input #1, QINFLOW(0, I), QINFLOW(1, I), QINFLOW(2, I), QINFLOW(3, I), QINFLOW(4, I),
QINFLOW(5, I), QINFLOW(6, I), QINFLOW(7, I)
Next I

Close #1
'End If


For I = 0 To 7
QOUTFLOW(I, 1) = QINFLOW(I, 1)
Next I

For I = 2 To EndRoutPt
    For J = 0 To 7
        QOUTFLOW(J, I) = COEFFC0(J) * QINFLOW(J, I) + COEFFC1(J) * QINFLOW(J, I - 1) +
COEFFC2(J) * QOUTFLOW(J, I - 1)
    Next J
Next I

For I = 1 To EndRoutPt
    For J = 0 To 7
        ALPHA(J, I) = QOUTFLOW(J, I) / QINFLOW(J, I)
    Next J
Next I

For I = EndRoutPt - 23 To EndRoutPt
    II = 23 - (EndRoutPt - I)
    For J = 0 To 7
        ROUT_ALPHA(J, II) = ALPHA(J, I)
    Next J
Next I

End Sub
```

```
Real-Time Multi-Reservoir Operation for Han River Basin
Index,Jtype,N,Nd,Md,Jtie,Invert:       1     1    24     9     9     1     1
Istoch,Istatn,Ntrans,Ispl,Itset,Iprint,Itmax:    0     0     0     1     0     1 9000
DELXi,DELXf,DELU     : 7.00000      .700000E-03 .700000E-03
DELXi,DELXf,DELU     : 22.0000      .220000E-02 .220000E-02
DELXi,DELXf,DELU     : 22.0000      .220000E-02 .220000E-02
DELXi,DELXf,DELU     : 1.00000      .100000E-02 .100000E-02
DELXi,DELXf,DELU     : 1.00000      .100000E-02 .100000E-02
DELXi,DELXf,DELU     : 1.00000      .100000E-02 .100000E-02
DELXi,DELXf,DELU     : 1.00000      .100000E-02 .100000E-02
DELXi,DELXf,DELU     : 1.00000      .100000E-02 .100000E-02
DELXi,DELXf,DELU     : 1.00000      .100000E-02 .100000E-02
Splice,Xmult:          2.00000      1.00000      100.000       1  1
RiskLoHi;Misc:         .000000      .000000       1  0  1  0  0  0
Xmin       1           935.470      2508.68      2253.14      136.000      64.0000
Xmin       1           167.000      .000000      226.000      .000000
Xmax       1           935.470      2508.68      2253.14      136.000      64.0000
Xmax       1           167.000      .000000      226.000      .000000
Xmin       2           740.930      2345.00      2134.00      136.000      64.0000
Xmin       2           167.000      .000000      226.000      .000000
Xmax       2           1018.40      2872.00      2750.00      136.000      64.0000
Xmax       2           167.000      .000000      226.000      .000000
Xmin       3           740.930      2345.00      2134.00      136.000      64.0000
Xmin       3           167.000      .000000      226.000      .000000
Xmax       3           1018.40      2872.00      2750.00      136.000      64.0000
Xmax       3           167.000      .000000      226.000      .000000
Xmin       4           740.930      2345.00      2134.00      136.000      64.0000
Xmin       4           167.000      .000000      226.000      .000000
Xmax       4           1018.40      2872.00      2750.00      136.000      64.0000
Xmax       4           167.000      .000000      226.000      .000000
Xmin       5           740.930      2345.00      2134.00      136.000      64.0000
Xmin       5           167.000      .000000      226.000      .000000
Xmax       5           1018.40      2872.00      2750.00      136.000      64.0000
Xmax       5           167.000      .000000      226.000      .000000
Xmin       6           740.930      2345.00      2134.00      136.000      64.0000
Xmin       6           167.000      .000000      226.000      .000000
Xmax       6           1018.40      2872.00      2750.00      136.000      64.0000
Xmax       6           167.000      .000000      226.000      .000000
Xmin       7           740.930      2345.00      2134.00      136.000      64.0000
Xmin       7           167.000      .000000      226.000      .000000
Xmax       7           1018.40      2872.00      2750.00      136.000      64.0000
Xmax       7           167.000      .000000      226.000      .000000
Xmin       8           740.930      2345.00      2134.00      136.000      64.0000
Xmin       8           167.000      .000000      226.000      .000000
Xmax       8           1018.40      2872.00      2750.00      136.000      64.0000
Xmax       8           167.000      .000000      226.000      .000000
Xmin       9           740.930      2345.00      2134.00      136.000      64.0000
Xmin       9           167.000      .000000      226.000      .000000
Xmax       9           1018.40      2872.00      2750.00      136.000      64.0000
Xmax       9           167.000      .000000      226.000      .000000
Xmin      10           740.930      2345.00      2134.00      136.000      64.0000
Xmin      10           167.000      .000000      226.000      .000000
Xmax      10           1018.40      2872.00      2750.00      136.000      64.0000
Xmax      10           167.000      .000000      226.000      .000000
Xmin      11           740.930      2345.00      2134.00      136.000      64.0000
Xmin      11           167.000      .000000      226.000      .000000
Xmax      11           1018.40      2872.00      2750.00      136.000      64.0000
Xmax      11           167.000      .000000      226.000      .000000
Xmin      12           740.930      2345.00      2134.00      136.000      64.0000
Xmin      12           167.000      .000000      226.000      .000000
Xmax      12           1018.40      2872.00      2750.00      136.000      64.0000
Xmax      12           167.000      .000000      226.000      .000000
Xmin      13           740.930      2345.00      2134.00      136.000      64.0000
Xmin      13           167.000      .000000      226.000      .000000
Xmax      13           1018.40      2872.00      2750.00      136.000      64.0000
Xmax      13           167.000      .000000      226.000      .000000
Xmin      14           740.930      2345.00      2134.00      136.000      64.0000
Xmin      14           167.000      .000000      226.000      .000000
Xmax      14           1018.40      2872.00      2750.00      136.000      64.0000
Xmax      14           167.000      .000000      226.000      .000000
Xmin      15           740.930      2345.00      2134.00      136.000      64.0000
```

Xmin	15	167.000	.000000	226.000	.000000	
Xmax	15	1018.40	2872.00	2750.00	136.000	64.0000
Xmax	15	167.000	.000000	226.000	.000000	
Xmin	16	740.930	2345.00	2134.00	136.000	64.0000
Xmin	16	167.000	.000000	226.000	.000000	
Xmax	16	1018.40	2872.00	2750.00	136.000	64.0000
Xmax	16	167.000	.000000	226.000	.000000	
Xmin	17	740.930	2345.00	2134.00	136.000	64.0000
Xmin	17	167.000	.000000	226.000	.000000	
Xmax	17	1018.40	2872.00	2750.00	136.000	64.0000
Xmax	17	167.000	.000000	226.000	.000000	
Xmin	18	740.930	2345.00	2134.00	136.000	64.0000
Xmin	18	167.000	.000000	226.000	.000000	
Xmax	18	1018.40	2872.00	2750.00	136.000	64.0000
Xmax	18	167.000	.000000	226.000	.000000	
Xmin	19	740.930	2345.00	2134.00	136.000	64.0000
Xmin	19	167.000	.000000	226.000	.000000	
Xmax	19	1018.40	2872.00	2750.00	136.000	64.0000
Xmax	19	167.000	.000000	226.000	.000000	
Xmin	20	740.930	2345.00	2134.00	136.000	64.0000
Xmin	20	167.000	.000000	226.000	.000000	
Xmax	20	1018.40	2872.00	2750.00	136.000	64.0000
Xmax	20	167.000	.000000	226.000	.000000	
Xmin	21	740.930	2345.00	2134.00	136.000	64.0000
Xmin	21	167.000	.000000	226.000	.000000	
Xmax	21	1018.40	2872.00	2750.00	136.000	64.0000
Xmax	21	167.000	.000000	226.000	.000000	
Xmin	22	740.930	2345.00	2134.00	136.000	64.0000
Xmin	22	167.000	.000000	226.000	.000000	
Xmax	22	1018.40	2872.00	2750.00	136.000	64.0000
Xmax	22	167.000	.000000	226.000	.000000	
Xmin	23	740.930	2345.00	2134.00	136.000	64.0000
Xmin	23	167.000	.000000	226.000	.000000	
Xmax	23	1018.40	2872.00	2750.00	136.000	64.0000
Xmax	23	167.000	.000000	226.000	.000000	
Xmin	24	740.930	2345.00	2134.00	136.000	64.0000
Xmin	24	167.000	.000000	226.000	.000000	
Xmax	24	1018.40	2872.00	2750.00	136.000	64.0000
Xmax	24	167.000	.000000	226.000	.000000	
Xmin	25	803.300	2543.00	2385.00	136.000	64.0000
Xmin	25	167.000	.000000	226.000	.000000	
Xmax	25	900.000	2640.55	2655.00	136.000	64.0000
Xmax	25	167.000	.000000	226.000	.000000	
Umin	1	.500000	.500000	.500000	.500000	.500000
Umin	1	.500000	.500000	.500000	.500000	
Umax	1	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	1	72.0000	47.5300	136.800	133.200	
Umin	2	.000000	.000000	.000000	.000000	.000000
Umin	2	.000000	.000000	.000000	.000000	
Umax	2	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	2	72.0000	47.5300	136.800	133.200	
Umin	3	.000000	.000000	.000000	.000000	.000000
Umin	3	.000000	.000000	.000000	.000000	
Umax	3	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	3	72.0000	47.5300	136.800	133.200	
Umin	4	.000000	.000000	.000000	.000000	.000000
Umin	4	.000000	.000000	.000000	.000000	
Umax	4	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	4	72.0000	47.5300	136.800	133.200	
Umin	5	.000000	.000000	.000000	.000000	.000000
Umin	5	.000000	.000000	.000000	.000000	
Umax	5	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	5	72.0000	47.5300	136.800	133.200	
Umin	6	.000000	.000000	.000000	.000000	.000000
Umin	6	.000000	.000000	.000000	.000000	
Umax	6	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	6	72.0000	47.5300	136.800	133.200	
Umin	7	.000000	.000000	.000000	.000000	.000000
Umin	7	.000000	.000000	.000000	.000000	
Umax	7	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	7	72.0000	47.5300	136.800	133.200	

Umin	8	.000000	.000000	.000000	.000000	.000000
Umin	8	.000000	.000000	.000000	.000000	
Umax	8	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	8	72.0000	47.5300	136.800	133.200	
Umin	9	.000000	.000000	.000000	.000000	.000000
Umin	9	.000000	.000000	.000000	.000000	
Umax	9	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	9	72.0000	47.5300	136.800	133.200	
Umin	10	.000000	.000000	.000000	.000000	.000000
Umin	10	.000000	.000000	.000000	.000000	
Umax	10	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	10	72.0000	47.5300	136.800	133.200	
Umin	11	.000000	.000000	.000000	.000000	.000000
Umin	11	.000000	.000000	.000000	.000000	
Umax	11	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	11	72.0000	47.5300	136.800	133.200	
Umin	12	.000000	.000000	.000000	.000000	.000000
Umin	12	.000000	.000000	.000000	.000000	
Umax	12	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	12	72.0000	47.5300	136.800	133.200	
Umin	13	.000000	.000000	.000000	.000000	.000000
Umin	13	.000000	.000000	.000000	.000000	
Umax	13	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	13	72.0000	47.5300	136.800	133.200	
Umin	14	.000000	.000000	.000000	.000000	.000000
Umin	14	.000000	.000000	.000000	.000000	
Umax	14	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	14	72.0000	47.5300	136.800	133.200	
Umin	15	.000000	.000000	.000000	.000000	.000000
Umin	15	.000000	.000000	.000000	.000000	
Umax	15	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	15	72.0000	47.5300	136.800	133.200	
Umin	16	.000000	.000000	.000000	.000000	.000000
Umin	16	.000000	.000000	.000000	.000000	
Umax	16	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	16	72.0000	47.5300	136.800	133.200	
Umin	17	.000000	.000000	.000000	.000000	.000000
Umin	17	.000000	.000000	.000000	.000000	
Umax	17	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	17	72.0000	47.5300	136.800	133.200	
Umin	18	.000000	.000000	.000000	.000000	.000000
Umin	18	.000000	.000000	.000000	.000000	
Umax	18	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	18	72.0000	47.5300	136.800	133.200	
Umin	19	.000000	.000000	.000000	.000000	.000000
Umin	19	.000000	.000000	.000000	.000000	
Umax	19	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	19	72.0000	47.5300	136.800	133.200	
Umin	20	.000000	.000000	.000000	.000000	.000000
Umin	20	.000000	.000000	.000000	.000000	
Umax	20	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	20	72.0000	47.5300	136.800	133.200	
Umin	21	.000000	.000000	.000000	.000000	.000000
Umin	21	.000000	.000000	.000000	.000000	
Umax	21	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	21	72.0000	47.5300	136.800	133.200	
Umin	22	.000000	.000000	.000000	.000000	.000000
Umin	22	.000000	.000000	.000000	.000000	
Umax	22	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	22	72.0000	47.5300	136.800	133.200	
Umin	23	.000000	.000000	.000000	.000000	.000000
Umin	23	.000000	.000000	.000000	.000000	
Umax	23	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	23	72.0000	47.5300	136.800	133.200	
Umin	24	.000000	.000000	.000000	.000000	.000000
Umin	24	.000000	.000000	.000000	.000000	
Umax	24	34.2000	37.8000	74.1310	45.3600	57.6000
Umax	24	72.0000	47.5300	136.800	133.200	
Xtraj	1	935.470	2508.68	2253.14	136.000	64.0000
Xtraj	1	167.000	.000000	226.000	.000000	
Xtraj	2	880.930	2609.00	2442.00	136.000	64.0000

Xtraj	2	167.000	.000000	226.000	.000000	
Xtraj	3	880.930	2609.00	2442.00	136.000	64.0000
Xtraj	3	167.000	.000000	226.000	.000000	
Xtraj	4	880.930	2609.00	2442.00	136.000	64.0000
Xtraj	4	167.000	.000000	226.000	.000000	
Xtraj	5	880.930	2609.00	2442.00	136.000	64.0000
Xtraj	5	167.000	.000000	226.000	.000000	
Xtraj	6	880.930	2609.00	2442.00	136.000	64.0000
Xtraj	6	167.000	.000000	226.000	.000000	
Xtraj	7	880.930	2609.00	2442.00	136.000	64.0000
Xtraj	7	167.000	.000000	226.000	.000000	
Xtraj	8	880.930	2609.00	2442.00	136.000	64.0000
Xtraj	8	167.000	.000000	226.000	.000000	
Xtraj	9	880.930	2609.00	2442.00	136.000	64.0000
Xtraj	9	167.000	.000000	226.000	.000000	
Xtraj	10	880.930	2609.00	2442.00	136.000	64.0000
Xtraj	10	167.000	.000000	226.000	.000000	
Xtraj	11	880.930	2609.00	2442.00	136.000	64.0000
Xtraj	11	167.000	.000000	226.000	.000000	
Xtraj	12	880.930	2609.00	2442.00	136.000	64.0000
Xtraj	12	167.000	.000000	226.000	.000000	
Xtraj	13	880.930	2609.00	2442.00	136.000	64.0000
Xtraj	13	167.000	.000000	226.000	.000000	
Xtraj	14	880.930	2609.00	2442.00	136.000	64.0000
Xtraj	14	167.000	.000000	226.000	.000000	
Xtraj	15	880.930	2609.00	2442.00	136.000	64.0000
Xtraj	15	167.000	.000000	226.000	.000000	
Xtraj	16	880.930	2609.00	2442.00	136.000	64.0000
Xtraj	16	167.000	.000000	226.000	.000000	
Xtraj	17	880.930	2609.00	2442.00	136.000	64.0000
Xtraj	17	167.000	.000000	226.000	.000000	
Xtraj	18	880.930	2609.00	2442.00	136.000	64.0000
Xtraj	18	167.000	.000000	226.000	.000000	
Xtraj	19	880.930	2609.00	2442.00	136.000	64.0000
Xtraj	19	167.000	.000000	226.000	.000000	
Xtraj	20	880.930	2609.00	2442.00	136.000	64.0000
Xtraj	20	167.000	.000000	226.000	.000000	
Xtraj	21	880.930	2609.00	2442.00	136.000	64.0000
Xtraj	21	167.000	.000000	226.000	.000000	
Xtraj	22	880.930	2609.00	2442.00	136.000	64.0000
Xtraj	22	167.000	.000000	226.000	.000000	
Xtraj	23	880.930	2609.00	2442.00	136.000	64.0000
Xtraj	23	167.000	.000000	226.000	.000000	
Xtraj	24	880.930	2609.00	2442.00	136.000	64.0000
Xtraj	24	167.000	.000000	226.000	.000000	
Xtraj	25	852.300	2587.00	2517.00	136.000	64.0000
Xtraj	25	167.000	.000000	226.000	.000000	