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Post-Seminar Proceedings of the International Joint Seminar on

# Reduction of Natural and Environmental Disasters in Water Environment

**July 18-21, 1995**

**Seoul National University**
**Seoul, Korea**

Edited
by
Nani G. Bhowmik, Illinois State Water Survey
Il Won Seo, Seoul National University

November 1996

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## ABSTRACT

These proceedings contain some of the materials presented during the International Joint Seminar on "Reduction of Natural and Environmental Disasters in Water Environment." The seminar was held July 18-21, 1995, at the Cultural Center of Seoul National University. Materials contained in this post-seminar proceedings include deliberations during the opening ceremony, the seminar program, session summaries, recommendations and remarks presented during the closing ceremony, and a list of participants. These proceedings also contain two of the 30 papers presented during the seminar. The other 28 papers appear in the main proceedings published by Seoul National University and edited by Jung Ho Sonu, Kil Seong Lee, Il Won Seo, and Nani G. Bhowmik.

# Foreword

This is a supplementary volume to the proceedings published by the Department of Civil Engineering, Seoul National University, during the seminar on the "Reduction of Natural and Environmental Disasters in Water Environment." The seminar was held from July 18-21, 1995, at the Cultural Center of Seoul National University. A total of 272 professionals participated: 260 from Korea and 12 from the United States. A list of participants appears at the end of these proceedings.

The seminar was an unquestionable success. Technical presentations were of the highest quality, the discussions were extremely fruitful, and the one-to-one interactions were very productive. Seminar participants were able to get acquainted during a field trip to the Han River in Seoul during which they exchanged views and thoughts on this important subject of prevention of disasters in water environment. Seminar participants also visited the Chungju Multipurpose Dam site about 150 km from Seoul to observe water resources development and management in Korea.

Participants had another opportunity to informally discuss subjects of mutual interest during a two-day field trip to the southern city of Kungju hosted by the local organizing committee.

This volume of the post-seminar proceedings, published by the Illinois State Water Survey, contains the following items:

- Materials presented during the opening ceremony,
- The final program schedule and session moderators names,
- A summary report for each session from session moderators,
- A brief summary of the concluding session with some "future recommendations,"
- Two technical papers that were not available during the seminar because of the late invitation to the participants, and
- A list of participants.

The seminar organizers believe that the seminar was a great success. The participants enjoyed the format and the timely subject matter. It is hoped that similar seminars can be held in the future to address other topics of mutual interest to the United States and Korea.

The seminar co-conveners are grateful and most appreciative of the support provided by the Korea Science and Engineering Foundation; U.S. National Science Foundation; Korean Ministry of Home Affairs; Korea Water Resources Corporation; Korean Ministry of Construction and Transportation; Korea Institute of Construction Technology; Daewoo Corporation; Saman Engineering Consultants Co., Ltd.; Seoul National University; and the Illinois State Water Survey, Champaign, Illinois, U.S.A.

November 1996

Nani G. Bhowmik
Il Won Seo

# Acknowledgments

The organizers of this seminar want to express their sincere gratitude and thanks to the U.S. National Science Foundation, and Dr. Gerald A. Edwards, Senior Program Manager for the East Asia and Pacific Region, who provided the travel support for the U.S. delegation to attend this seminar and present their technical talks. Seoul National University provided all local support in terms of facilities and day-to-day operations.

Sincere thanks are also extended to the sponsors of the seminar — Korea Science and Engineering Foundation, Korean Ministry of Home Affairs, Ministry of Construction and Transportation, Korea Water Resources Corporation, Korea Institute of Construction Technology, Daewoo Corporation, and Saman Engineering Consultants Co., Ltd. — for their support of the seminar. Thanks are also extended to the Illinois State Water Survey for publishing this volume as a Miscellaneous Publication. The co-editors also express their appreciation to Lori Nappe who prepared the draft copy, Becky Howard who prepared the camera-ready copy of the proceedings, and Eva Kingston who provided the technical editing support.

# Local Organizing Committee

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Co-Chairman
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- S.T. Lee, Professor, Youngnam University, Korea
- H. K. Lee, Professor, Seoul National University, Korea
- H.S. Chung, Director General, Ministry of Home Affair, Korea
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- M. P. Shim, Professor, Inha University, Korea
- H. Woo, Director, Korea Institute of Construction Technology, Korea
- D.H. Yoo, Professor, Ajou University, Korea
- K.S. Lee, Professor, Seoul National University, Korea
- K. P. Hong, Director, Ministry of Environment, Korea

# Sponsors for the Seminar

- United States National Science Foundation
- Korea Science and Engineering Foundation
- Korean Ministry of Home Affairs
- Korean Ministry of Construction and Transportation
- Korean Water Resources Corporation
- Korea Institute of Construction Technology
- Daewoo Corporation
- Saman Engineering Consultants, Co., Ltd.

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# Seminar Program

## Monday, July 17, 1995

Local visit and trip to the Han River

## Tuesday, July 18, 1995

| | |
|---|---|
| **09:30~15:00** | **Registration** |
| **10:00~10:40** | **Opening Ceremony**<br>*Moderator: Dr. Il Won Seo*<br>Vice President Dr. Jung Ho Sonu (now President), Seoul National University<br>Mr. K.H. Kim, President, Korea Water Resources Association<br>*Dr. Nani G. Bhowmik,* U.S. Coordinator |
| **Session I**<br>**10:40~12:10** | **Flood Control in Korea, China, and Japan**<br>*Moderators: Dr. Nani G. Bhowmik and Dr. Il Won Seo*<br>1. "Introduction of the KOWACO's Decision Support System for Real-Time Flood Control"<br>*Hee Sung Lee, Korea Water Resources Association*<br>*2.* "Flood Control Aspect for the Three Gorges Project on the Yangtze River"<br>*Renshou Fu, Tsinghua University, China*<br>3. "River Improvement Works in the Modern Age of Japan"<br>*Nobuyuki Tamai, University of Tokyo, Japan* |
| **12:10-13:30** | **Lunch** |
| **Session II**<br>**13:30~15:30** | **Forecasting, Structural and Nonstructural Measures (I)**<br>*Moderators: Dr. Chih Ted Yang and Dr. B.H. Seoh*<br>1. "Scientific and Engineering Issues in Design and Forecasting for Floods"<br>*W.H.C. Maxwell, University of Illinois, USA.*<br>*2.* "A Comparison of Flood Forecasting Systems in Korea and the U.S.A."<br>*W.C. Cho, D.H. Bae, and K.W. Seo, Yonsei University*<br>3. "Reservoir Operations During Flood Period for Flood Control and Conservation Purposes"<br>*M.P. Shim, Inha University, Korea*<br>4. "Flood Management—The TVA Experience"<br>*B. Miller, A. Whitlock, and R.C. Hughes, Tennessee Valley Authority, U.S.A.* |

**15:30~16:00** **Coffee Break**

**Session III** **Forecasting, Structural and Nonstructural Measures (II)**
**16:00~17:00** *Moderators: Dr. Barbara Miller and Dr. S. Kim*

1. "Dam Safety and Nonstructural Damage Reduction Measures"
   *W.J. Graham and Chih T. Yang, Bureau of Reclamation, U.S.A.*
2. "Channel Junction Effects in Channel Network Flow Simulation"
   *G.W. Choi and K.S. Ahn, University of Incheon; S.J. Ahn, Choong Buk University, Korea*
3. "Finite Element Simulation on 2-DIM. Depositing Turbidity Currents"
   *Sung-Uk Choi and Marcelo Garcia, University of Illinois, U.S.A.*

**17:30-19:30** **Icebreaker Reception**

## Wednesday, July 19, 1995

**09:30~15:00** **Registration**

**Session IV** **Impacts of Floods (I)**
**10:00~12:00** *Moderators: Dr. James Ruff and Dr. M.P. Shim*

1. "Impacts of the 1993 Flood on the Upper Mississippi and Missouri River Basins in the USA"
   *Nani G. Bhowmik, Illinois State Water Survey, U.S.A.*
2. "A Modified Rational Method in Small Alluvial Channels"
   *W.C. Cho, J.-H. Heo, and D.-H. Kim, Yonsei University, Korea*
3. "An Experimental Study of Backwater Effects Caused by the Covered Reach of Urban Streams"
   *Y.N. Yoon, J.H. Ahn, and J.K Kim, Korea University, Korea*
4. "Riprap Design for Local Scour Protection at a Circular Bridge Pier"
   *T.H. Yoon, S.B. Yoon, and K.S. Yoon, Hanyang University, Korea*

**12:00~13:30** **Lunch**

**Session V** **Impacts of Floods (II)**
**13:30~15:30** *Moderators: Dr. Gary Freeman and Dr. D.H. Yoo*

1. "Stream Stability and Scour at Highway Bridges"
   *E.V. Richardson and P.F. Lagasse, Ayres Association, U.S.A.*
2. "Local Scour at Bridge Piers and Protective Measures"
   *J.K. Lee, Hanyang University*
3. "Velocity and Discharge Measurements at Selected Locations on the Mississippi River During the Great Flood of 1993 Using an Acoustic Doppler Current Profiler"
   *David Admiraal and Misganaw Demissie, Illinois State Water Survey, U.S.A.*
4. "Optimal Control Approaches for Sedimentation and Flood control in Rivers"
   *Larry W. Mays, Arizona State University, U.S.A.*

**15:30~16:00** **Coffee Break**

**Session VI** **Science and Risks**
**16:00~18:00** *Moderators: Dr. Larry W. Mays and Dr. B.H. Jun*

1. "Scientific Assessment and Strategy Team's (SAST) Achievement Related to the 1993 Flood"
   *Gary Freeman, U.S. Army Waterways Experiment Station, U.S.A.*
2. "Hydrological Safety Analysis of the Existing Dams in Korea"
   *S.-K. Ko, K.S. Jung, and C. Chung, KOWACO, Korea*
3. "Design Flood Impacts on Evaluating Dam Failure Mechanisms"
   *Steve Abt, R. Wittier, and J.R. Ruff, Colorado State University, U.S.A.*
4. "Bed Load Transport on a Flat Bed"
   *D.H. Yoo, Ajou University, Korea*

## Thursday, July 20, 1995

**09:30~15:00** **Registration**

**Session VII** **Environmental Concerns**
**10:00~12:00** *Moderators: Dr. Misganaw Demissie and Dr. H.S. Woo*

1. "Dispersion and Storage Processes of Pollutants in Natural Streams"
   *I.W. Seo and D.Y. Yu, Seoul National University, Korea*
2. "Experimental Study of Alluvial Fans"
   *K.X. Whipple and Gary Parker, University of Minnesota, USA.*

3. "A Multidimensional Finite Element Model for the Analyses of Eutrophication and Thermal Pollution Problem"
   *J.-H. Kim, Kangwon University, Korea*
4. "A Numerical Method for Unsteady Dispersion in Turbulent Shear Flow"
   *K.S. Jun, Sung Kyun Kwan University, Korea*

**12:00~13:30** **Lunch**

**Session VIII** **Risks and Environmental Concerns**
**13:30~15:30** *Moderators: Dr. Gary Parker and Dr. S.M. Chung*

1. "Risk Change Caused by Forestal Damage Due to a Typhoons"
   *S.T. Lee, Yeungnam University; Muneo Hirano and K Park, Kyushu University, Korea*
2. "Propagation of Two-Dimensional Floodwaves through Broken Levee"
   *K.Y. Han, Kyungpook University; J.T. Lee, Kyonggi University*
3. "Analysis of the Effect of Dilution and Flushing at the 1994 Water-Quality Accident in the Nakdong River"
   *H. Woo and Y. Kim, KICT*
4. "Sediment Load During Hood Events for Illinois Streams"
   *Misganaw Demissie, Illinois State Water Survey, U.S.A.*

**15:30~16:00** **Coffee Break**

**Session IX** **Open Forum**
**16:00~17:00** *Moderators: Dr. Nani G. Bhowmik and Dr. Il Won Seo*
Summary Reports by Session Moderators
Open Discussion

**17:00~17:30** **Closing Ceremony**
*Moderator: Dr. Il Won Seo*
Dr. Jung Ho Sonu, Now President, Seoul National University, Korea
Dr. Nani G. Bhowmik, Illinois State Water Survey, U.S.A.

**17:30-19:30** **Seminar Banquet**

## Friday, July 21, 1995

**08:30~18:30** Field Trip to the Chungju Dam Site

# Opening Ceremony
## Moderator: Dr. Il Won Seo

## Opening Address

Good morning, ladies and gentlemen. I'd like to welcome all of you to the International Joint Seminar, "Reduction of Natural and Environmental Disasters in Water Environment." It is a great pleasure for me to announce the opening of the seminar, which is to be held at Seoul National University.

This seminar is aimed at discussing and searching for the solution for the various disasters in water environment which in recent years came to be a great concern throughout the whole world. Today, our water environment issues are associated not only with protecting and conserving our own nation's environment, but also with managing and developing the water environment on a global scale. So, the recognition and prevention of the natural disasters and pollution problems in water environment are the common problems on which all the countries need to work together. I strongly hope this joint seminar is going to form the cornerstone of the international cooperative research on water environment.

In Korea, the various forms of land development have caused a number of changes in natural and social environments. But the economic growth and urbanization have complicated and increased the environmental disasters even more. Recently, the environmental disasters caused by urbanization and industrialization, as well as the natural disasters in rivers and coastal areas, have reached a very critical state. Since our disaster prevention technology is not sufficiently developed, there is an urgent need for long-term and systematic research projects for the prevention of the complex disasters in water environment. So, I believe that this seminar will be of great help in improving the situation in Korea. I also believe that this joint seminar will provide many opportunities for the attendees to share information on the disaster prevention technology and furthermore to start cooperative relationships.

Finally, I'd like to thank the Dean of the Engineering College, the President of Korea Water Resources Association, and all the experts and scientists participating in the presentations of papers and the follow-up discussions.

Thank you.

***Professor Jung Ho Sonu***
***Vice President (now President)***
***Seoul National University***

# Address by U.S. Coordinator

Good morning, Vice President Dr. Sonu, Dr. Han, Dean of Engineering College, Vice President Kwon, Korea Water Resources Association, distinguished participants, friends, colleagues, and ladies and gentlemen.

It is a distinct pleasure and honor to welcome all of you to this joint U.S.-Korean seminar, "Reduction of Natural and Environmental Disasters in Water Environment." I also bring welcome and greetings from Dr. Gerald A. Edwards, Senior Program Manager, U.S. National Science Foundation, which supported this seminar. We hope this will be a rewarding and fruitful seminar for all of you and that it will meet your expectations.

I would be remiss if I did not express my sincere gratitude and thanks to the local committee, Dr. Sonu, Dr. Lee, Dr. II Won Seo, and other professors from the Civil Engineering Department, Seoul National University, who worked hard to make all the local arrangements for this seminar. They also printed an outstanding proceedings of the seminar.

I must also express my sincere thanks to Seoul National University for making available this beautiful venue for our seminar. Sincere thanks and gratitude are also extended to Korea Science and Engineering Foundation, Korea Water Resources Association, Korea Institute of Construction Technology, and Korea Water Resources Corporation, and all other local hosts for their support.

The goal of this seminar is to bring together some leaders and students from the engineering professions of both Korea and the United States for a three-day seminar that includes presentation of formal papers, informal discussions, one-on-one interactions, and a foundation for future cooperation. We are confident that you and your colleagues will take this opportunity to renew old acquaintances, foster professional cooperation, and, most important of all, enjoy the seminar.

Floods in the United States and many other countries, man-made and natural changes, encroachment on floodplains, impacts of floods on rivers, and streams, and future management of floodplains are all extremely important issues. These are some of the impacts of natural disasters that we must discuss. We have a group of speakers from both countries who will share their experiences with you on all these aspects.

Finally, we want to express our sincere thanks to all the speakers from both countries who agreed to spend several days on the campus of Seoul National University, share their knowledge and expertise, and be present here to make this seminar a great success. I take off my hat to all of you. With this, I believe we are ready to start our seminar. Thank you very much.

***Nani G. Bhowmik***
***Principal Scientist and Head***
***Hydrology Division***
***Illinois State Water Survey***

# Session I

## Flood Control in Korea, China, and Japan

### Moderators: Dr. Nani G. Bhowmik and Dr. Il Won Seo

"Introduction of the KOWACO's Decision Support System for Real-Time Flood Control"
*Hee Sung Lee, Korea Water Resources Corporation*

"Flood Control Aspect for the Three Gorges Project on the Yangtze River"
*Renshou Fu, Tsinghua University, China*

"River Improvement Works in the Modern Age of Japan"
*Nobuyuki Tamai, University of Tokyo, Japan*

Two papers were presented in this session although three papers were originally scheduled. The first paper was presented by Mr. H.S. Lee, Vice-President, Korea Water Resources Corporation. Mr. Lee discussed the real-time flood forecasting system for the multipurpose reservoir. His talk concentrated on how hydrometeorological data are collected, sorted, and utilized in the forecasting of flood warning systems. He also discussed how man and machine must work in unison to arrive at a workable forecasting system. The three components of this system are: a database sub-system, a model sub-system, and a dialogue sub-system. He gave an excellent overview of the system used in Korea. Discussion concentrated on the system of forecasting and warning. Floodplain encroachment was also discussed and it was indicated that in a country such as Korea, floodplains must also be used for human habitation.

The final paper was presented by Professor Tamai from Japan on river improvement works in Japan. Even though historically the improvement works in Japan were evaluated based on flood control, Professor Tamai indicated that in recent times safety concerns have attained much higher attention. Concerns for environment and biological habitats are being incorporated in river engineering works. Biological diversity, basinwide management, mass balance for the watershed, and consideration of high flows to low flows must also be incorporated in river engineering works.

Discussions included problems with sedimentation, aquatic habitats, and environmental concepts, and operational principles in the management of rivers.

The second paper that was scheduled to be presented was by Professor Fu from China on the flood control aspects of the Three Gorges Project on the Yangtze River. Here, Professor Fu discussed the following five subtopics: flood characteristics of the Yangtze River, discharge capacity of the river reach below the project area, disaster associated with floods, flood prevention/control by the project, and the operation scheme of the three Gorges Project. Professor Fu also mentioned that sedimentation is one of the major problems of this project. Unfortunately, this very interesting paper was not orally presented, but the paper does appear in the proceedings.

# Session II

## Forecasting, Structural and Nonstructural Measures (I)

### Moderators: Dr. Chih Ted Yang and Dr. B.H. Seoh

"Scientific and Engineering Issues in Design and Forecasting for Floods"
*W.H.C. Maxwell, University of Illinois, U.S.A.*

"A Comparison of Flood Forecasting Systems in Korea and the U.S.A."
*W.C. Cho, D.H. Bae, and K.W. Seo, Yonsei University, Korea*

"Reservoir Operations During Flood Period for Flood Control and Conservation Purposes"
*M.P. Shim, Inha University*

"Flood Management —The TVA Experience"
*B. Miller, A. Whitlock, and R.C. Hughes, Tennessee Valley Authority, U.S.A.*

Paper One assesses problem areas identified for the 1993 flood on the Mississippi and Missouri River basins. Valuable data were collected and analyzed by federal and state agencies as the flood event progressed. Major areas deserving future emphasis are the need for highly trained teams for collecting, transmitting, and assembling field data during floods, and refinement of real-time forecasting.

Paper Two provides a comparison of the storage function method (SFM) for the flood forecasting system in Korea and the Sacramento Soil Moisture Accounting Model (SSMAM) used in the United States based on the study of the Pyungchang River basin in Korea. The parameter used in SFM is highly nonlinear and a more accurate parameter is needed in the future to improve the accuracy of SFM. SSMAM coupled with a kinematic channel routing model can be applied to the Pyungchang River basin over long periods with daily resolution. However, for a single flood event, the SSMAM results are sensitive to the initial soil moisture condition.

Paper three proposes reservoir operating rules during floods to deal with conflicts between flood control and water conservation. Variable restricted water levels are used for shorter durations, which can be derived from reallocation of flood capacity of the reservoir and the frequency and magnitude of past floods. The preliminary release scheme and variable restricted water levels are used to develop optimum reservoir operation rules based on forecasted incoming floods and the needed or allowable downstream release rate.

Paper four provides an overview of the Tennessee Valley Authority (TVA) flood management program, including reservoir system flood control capabilities, valleywide flood risk reduction activities, and the role of technological advances and agency streamlining on future operations. TVA's future flood control and management approach will combine traditional structural control with nonstructural aspects of flood risk reduction.

# Session III

## Forecasting, Structural, and Nonstructural Measures (II)
### Moderators: Dr. Barbara A. Miller and Dr. S. Kim

"Dam Safety and Nonstructural Damage Reduction Measures"
*W.J. Graham and Chih T. Yang, Bureau of Reclamation, U.S.A.*

"Channel Junction effects in Channel Network Flood Simulation"
*G.W. Choi and K.S. Ahn, University of Incheon, Korea; S.J. Ahn, Choong Buk University, Korea*

"Finite Element Simulation on 2-DIM. Depositing Turbidity Currents"
*Sung-Uk Choi and Marcelo Garcia, University of Illinois, U.S.A.*

A total of three papers were presented in this session. The first paper presented by Chih Ted Yang provided a brief history of dam failures in the United States and the impact on the evolution of U.S. dam safety policy. It also described the gradual shift from structural to nonstructural approaches to improving dam safety. It illustrated how measures such as inundation mapping, dam failure warning systems, and emergency preparedness programs can reduce the loss of life in the event of dam failure.

The discussion period addressed issues relating to the cost effectiveness of nonstructural approaches, the use of the Probable Maximum Hood (PMF) in the U.S. for safety, standards, and the high cost of meeting PMF requirements through structural means. It was pointed out that PMF is a "moving target" that always seems to increase. The use of an independent review board at the Bureau of Reclamation and Design safety standards for Korean dams were also discussed.

The second paper presented by G.W. Choi discussed a channel network model for simulating the effects of channel junctions. The model utilizes continuity and momentum equations between two adjacent cross sections in a channel and the continuity equation at the channel junction. The model was formulated using a four-point implicit finite difference scheme. Lateral inflow angles in the equation were obtained from experimental results between the lateral inflow angles at the channel junction angles. The model was verified using Webber and Greated's experimental data. Model simulations showed good agreement with the experimental data. The model appears to be useful for simulating channel networks with junctions.

The discussion period focused on the distinguishing characteristics of the proposed model versus other models, comparisons of results from this model and other models, and the general applicability of the model.

The third paper presented by Sung-Uk Choi discussed a finite element numerical method for simulating the spread and dilution of turbidity currents, such as sediment-laden underflows. The governing equations are a hyperbolic system of partial differential equations. The Petrov-Galerkin formulation is used for spatial discretization and a second-order finite difference scheme is used for time integration. A deforming grid technique is used to deal with the moving boundary of a propagating front, while changes in bed elevation are simulated using a double finite element technique. The numerical model has been used successfully to simulate the results of laboratory experiments.

During the discussion period, the significance of including a sediment entrainment term was addressed. It was suggested that such a term might improve the simulations of observed data. Issues relating to the applicability of the model to water quality modeling and the importance of dispersion considerations were also discussed.

# Session IV

## Impacts of Floods (I)
### Moderators: Dr. James Ruff and Dr. M. P. Shim

"Impacts of the 1993 Flood on the Upper Mississippi and Missouri River Basins in the USA"
*Nani G. Bhowmik, Illinois State Water Survey, U.S.A.*

"Riprap Design for Local Scour Protection at a Circular Bridge Pier"
*T.H. Yoon, S.B. Yoon, and K.S. Yoon, Hanyang University, Korea*

"An Experimental Study of Backwater Effects Caused by the Covered Reach of Urban Streams"
*Y.N. Yoon, J.H. Ahn, and J.K Kim, Korea University, Korea*

"A Modified Rational Method in Small Alluvial Channels"
*W.C. Cho, J.-H. Heo, D.-H. Kim, Yonsei University, Korea*

Dr. Nani Bhowmik presented an overview of the 1993 flood on the Mississippi River and some of its tributaries. The theme of the paper was the cause and effect of this extreme flood event. Major impacts were scour, erosion, sediment movement, aggradation, degradation, and channel changes. These had impacts on the economy, water quality, transportation, and all aspects of quality of life. Sediment affected a large area of the floodplains in the upper basin states.

Dr. E.V. Richardson commented that the dams on the Missouri River alleviated some impacts by storing water during the critical period. Significant flooding occurred in the lower 200 miles of the Missouri River and at the confluence with the Mississippi River. Dr. Gary Freeman stated that, only a small percentage of land was covered by sediment and those lands produced bumper crops in 1994.

The third paper presented by Dr. Yong Nam Yoon discussed the backwater effects of bridge pier arrays in covered reaches of urban streams. This is a significant problem in Korea.

The fourth paper by W.C. Cho compared the regime method, Chang's rational method, and the modified rational method through application to natural alluvial channels. The regime method was found to be best for the design of small channels, but not for natural channels with relatively large flow. In applying the modified rational method for stable beds, it was recommended that the sediment transport equation be selected by considering the hydraulic characteristics.

The modified rational method gives similar results to those provided by the Engelund-Hansen formula for narrow channels, the Ackers-White formula for wide channels and nonfine sand, and Yang's formula for wide channels. The modified rational method also gave better results for various sediment diameters and channel geometries than Chang's rational method.

Discussion centered on the assumption of some of the parameters made in the analysis. One suggestion made was that because of the large uncertainties involved in the various deterministic equations of these methods (sediment-transport equation) that these methods would lend themselves rather easily to risk-based procedures that attempt to account for the various uncertainties associated with the input parameters.

# Session V

## Impacts of Floods (II)

### Moderators: Dr. Gary Freeman and Dr. D. H. Yoo

"Stream Stability and Scour at Highway Bridges"
*E.V. Richardson and P.F. Lagasse, Ayres Association, U.S.A.*

"Local Scour at Bridge Piers and Protective Measures"
*J.K. Lee, Hanyang University, Korea*

"Velocity and Discharge Measurements at Selected Locations on the Mississippi River During the Great Flood of 1993 Using an Acoustic Doppler Current Profiler"
*David Admiraal and Misganaw Demissie, Illinois State Water Survey, U.S.A.*

"Optimal Control Approaches for Sedimentation and Flood Control in Rivers"
*Larry W. Mays, Arizona State University, U.S.A.*

The session began with Dr. Richardson presenting a paper on stream stability and scour at highway bridges. The paper discussed bridge failures in the United States and resulting programs initiated to prevent future failures. Dr. Richardson also discussed methods for calculating scour at bridge piers. Discussion focused on whether Korea had a manual for calculation of bridge pier scour and on methods for determining deteriorating equation parameters.

The second paper by J.K Lee presented research being performed to gain further understanding of scour at bridge piers. Dr. Lee presented three methods for protection of piers from scour. Discussion focused on methods to be used in conducting research on this topic.

The third paper was presented by David Admiraal and concerned the use of an acoustic Doppler Current Profiler (ADCP) for the measurement of velocities in the Mississippi River during the 1993 flood. Discussion about the paper focused on whether the method could be used to estimate the velocity of bed loads in rivers. It would appear that further research in this area may be warranted.

The final paper of the session was presented by Dr. Larry Mays, who gave several examples of the optimization of water control facilities to meet the demands of various users within the system. The paper presented information that should be very applicable as Korea's water control infrastructure continues to expand.

Overall the session was well received and of value to all present.

# Session VI

# Science and Risks

## Moderators: Dr. Larry W. Mays and Dr. B.H. Jun

"Scientific Assessment and Strategy Team's (SAST) Achievement Related to the 1993 Flood"
*Gary Freeman, U.S. Army Waterways Experiment Station, U.S.A.*

"Hydrological Safety Analysis of the Existing Dams in Korea"
*S.-K. Ko, K.S. Jung, and C. Chung, KOWACO, Korea*

"Design Flood Impacts on Evaluating Dam Failure Mechanisms"
*Steve Abt, R. Wittier, and J.R. Ruff, Colorado State University, U.S.A.*

"Bed Load Transport on a Flat Bed"
*D.H. Yoon, Ajou University, Korea*

The first paper by Gary Freeman summarized very nicely the efforts of the Scientific Assessment and Strategy Team (SAST). He emphasized that the savings in flood damage as a result of the flood protection far exceeded the damage that occurred. As a result of the efforts of this team, an extensive amount of knowledge and data have been collected and analyzed that should be beneficial in future efforts to improve floodplain practices in the United States and elsewhere. Discussion centered on what had been learned and how this will improve our thinking.

The second paper by K.S. Jung was aimed at evaluating the design flood and suggested alternatives to improve the flood controlling capacity according to the current design criteria for dams constructed 10 to 20 years ago. Newly estimated PMF's exceeded previous values as a result of more reliable flood storm event records. Also global climate change was stated as a reason for increasing peaks. To cope with the newly estimated PMF's, five alternatives were considered: 1) allocation of extra flood control space, 2) construction of extra spillway facilities, 3) heightening of existing dams, 4) construction of upstream flood control dams, and 5) fuse plug spillways. Discussion centered on the fact that these are all structural alternatives and nonstructural alternatives are not being considered.

The moderators feel that a sixth alternative should be added that could include various non-structural alternatives to be used in conjunction with structural alternatives. Another aspect not covered by the paper, but briefly noted through the suggestion of allocation of extra flood control space, would be to develop real-time management models for the various reservoir systems.

The third paper by Jim Ruff concentrated on identifying three critical areas for evaluating dam safety that warrant further research: 1) embankment face and spillway protection from overtopping, 2) erosion at dam foundation and embankments from overtopping, and 3) breach mechanisms. He described two ongoing and proposed research programs at Colorado State University and anticipates that each program will enhance in the evaluation and design of proposed dams and determine the safety of existing dams.

Dr. Dong Hoon Yoon reviewed several existing sediment transport equations and existing data in order to recommend another bed load transport equation. Some improvements were noted for Van Rijn's formula, but satisfactory improvements were not found when the refined equation was compared with Brown and with Engelund-Hansen's equations.

# Session VII

## Environmental Concerns
## Moderators: Dr. Misganaw Demissie and Dr. H.S. Woo

"Dispersion and Storage Processes of Pollutants in Natural Streams"
*I.W. Seo, D.Y. Yu, Seoul National University, Korea*

"Experimental Study of Alluvial Fans"
*K.X. Whipple and Gary Parker, University of Minnesota, U.S. A.*

"A Multidimensional Finite Element Model for the Analyses of Eutrophication and Thermal Pollution Problem"
*J.-H. Kim, Kangwon University, Korea*

"A Numerical Method for Unsteady Dispersion in Turbulent Shear Flow"
*K.S. Jun, Sung Kyun Kwan University, Korea*

Three of the presentations involved numerical methods in computing mixing processes in streams and lakes while the presentation by Dr. Parker was based on experimental data. The presentation by Mr. Yu included the development of a mathematical model for predicting pollutant dispersion and transport in natural streams during low-flow conditions. The most important consideration for pollutant transport during low flows is the storage and release of the pollutant from storage zones created by irregular channel forms including pools and riffles. The presentation discussed the superiority of the storage zone models over the one-dimensional dispersion model. The Storage-Diffusion Model was found to represent the real situation better than the Storage-Exchange Model. The models were evaluated based on extensive experimental data collected in the laboratory.

The presentation by Professor Kim concerned the application of a Multidimensional Finite Element Model for evaluating water quality problems in lakes including eutrophication and thermal pollution.

# Session VIII

## Risks and Environmental Concerns
### Moderators: Dr. Gary Parker and Dr. S.M. Chung

"Risk Change Caused by Forestal Damage Due to a Typhoon"
*S.T. Lee, Yeungnam University; Muneo Hirano and K. Park, Kyushu University, Korea*

"Propagation of Two-Dimensional Floodwaves through Broken Levees"
*K.Y. Han, Kyungpook University; J.T. Lee, Kyonggi University, Korea*

"Analysis of the Effect of Dilution and Flushing at the 1994 Water-Quality Accident in the Nakdong River"
*H. Woo and Y. Kim, KICT, Korea*

"Sediment Load During Flood Events for Illinois Streams"
*Misganaw Demissie, Illinois State Water Survey, U.S.A.*

The first presentation by M. Hirano documented the forest damage in Japan caused by typhoons. The uprooting and overtopping of trees was related to such disasters as slope failures and resulting landslides, debris flows, and flooding exacerbated by a plethora of woody debris. An attempt was made to evaluate the risk involved, and to determine the time span after damage for deleterious effects to continue. Discussion concerning the paper centered on the use of cryptomeria monoculture as a means of providing forest cover in Japan. It was speculated that a mix of more typically occurring species of trees might be associated with a somewhat reduced risk.

The second presentation given by K.Y. Han concerned a numerical model for the computation of flooding associated with levee breaching. It was then applied to a practical example in Korea, with some encouraging results. There was some discussion of the numerical method used in the calculation. In addition, the issue as to how to represent the time growth of the initial breach was the subject of some discussion. Finally, some comments were made in regard to an extension of the model to describe sediment transport as well as water flow.

H. Woo gave the third presentation about an accident or series of accidents, during 1994 that led to the introduction of a significant amount of ammonia into the Nakdong River, which serves as a water supply for a large population. The precise nature of the accidents is not known, but the result was a noticeable reduction in water quality, characterized by an objectionable odor. A large amount of water stored in a reservoir was used over a 62-day period to flush the contaminant from the water, and the conclusion of the paper was that much of the water used in this way was unnecessary. Questions were asked about the role of bioactivity in self-cleaning and the requirements of a more sophisticated predictive model and the use of a real-time monitoring system.

Misganaw Demissie gave the last presentation on sediment loads during flood events. It was determined that most of the annual sediment load of several streams in Illinois was carried by the four largest floods of the year. This result was then used to develop several regression relations to estimate the annual sediment load based on the largest, largest two, largest three, and largest four floods of the year. The discussion centered on the methods used to measure sediment load. One participant, E.V. Richardson, then presented an outline of methods of estimating reservoir sedimentation.

The four papers were received with interest and generated useful discussion.

# Session IX

## Open Forum

### Moderators: Dr. Nani G. Bhowmik and Dr. Il Won Seo

On Thursday, July 20, 1995, from about 1715 to 1745, an open forum was conducted at which all the participants were asked to discuss the seminar and make appropriate suggestions and recommendations for future activities. The general consensus was that the seminar was an overwhelming success and that the participants liked the format, would like to continue such dialogue, and would like to see this type of seminar continued. A fairly detailed suggestion by Mr. Ju-Chang Kim for future activities follows.

> Disasters in water environment can be categorized in two ways: natural events and events related to human activities. Natural disasters include land slides, floods in mountain valleys, and drought. Disasters related to human activities include construction of dams, levees, and bridges, and the eventual failure of these structures.
>
> Disasters due to dam failure, levee breach, and bridge failure are major disasters in the water environment and could be prevented or reduced by structural and/or nonstructural measures.
>
> The purpose of the International Joint Seminar to reduce disasters in water environment could be attained through appropriate follow-up actions.
>
> Therefore, follow-up actions that can be undertaken by the seminar organizers are as follows:
>
> Establish a permanent study group on the reduction of disasters in water environment.
> - The group may be a sub-body of Seoul National University or Korea Water Resources Association.
> - Group activities would include conducting seminars, providing consulting services to the government authorities concerned, and research.
> - Group membership should be open to the experts and organizations concerned.
>
> Set forth a proposition to the Government Authorities/National Assembly to make them more aware of disasters in water environment. Among the suggestions are:
> - To inspect major dams, levees, and bridge piers periodically and keep records of inspections.

- To operate a special alert team, specialized for dam breaks, levee breaches, and bridge pier failures during flooding periods.
- To conduct early warning and evacuation exercises for dam failure and levee breach once or twice a year and at the time of Civil Air Defense exercises, depending on localities.
- To make or revise the design criteria for reduction of disasters in water environment. For example, inundation mapping in the case of dam or levee failures would be prepared and included in the design document.
- To encourage universities and institutes to study nonstructural flood control measures that could minimize the loss of human lives in disasters.
- To refine and supplement laws, ordinances, regulations, design criteria, and operation and maintenance guidelines for education of disasters.

Other discussions included various techniques used in flood forecasting in the United States and Korea, various technical data and methods used in both countries, and a general appreciation of the coordinators for their hard work in arranging this joint seminar.

Dr. Woo, KICT, also suggested that specific topics be considered in future seminars. The following recommendations for future interactions are based on this and other informal discussions.

## Recommendations

The seminar participants would like to suggest the following course of action for consideration by the respective sponsors from both countries.

1. Continue dialogue on a one-to-one basis.

2. Arrange future joint seminars on very specific topics:
    - Water quality problems of rivers and lakes (inland water)
    - Alluvial river management
    - Environmental concerns for rivers
    - Failure of hydraulic structures, e.g., dams, levees, bridge piers
    - Droughts

3. Develop joint research projects on subjects related to water resources, disaster in water environment, rivers and ecosystem based management, water management, impacts and effects of extreme events such as floods, droughts, and comparative analyses of river basins from the United States and Korea.

It is hoped that the Korea Science and Engineering Foundation and the United States National Science Foundation will consider these recommendations in their future actions and/or consideration in the support of joint seminars between the United States and Korea.

# Closing Ceremony
## Moderator: Dr. Il Won Seo

### Dr. Jungho Sonu, Vice President
### Seoul National University

Talk not available.

### Dr. Nani G. Bhowmik
### Illinois State Water Survey, U.S.A.

Good afternoon Vice President Dr. Sonu, Dr. Seo, distinguished participants, ladies and gentlemen. It is a distinct pleasure to share with you my comments and observations of the seminar during this concluding session. I am extremely pleased with the deliberations of the seminar, the quality of the papers and presentations, and the intellectual and lively discussions that followed.

Approximately two years ago when Dr. Seo and I started to discuss this seminar, we were not sure how the whole thing would work out. When we separately talked with the Korea Science and Engineering Foundation in Korea and the National Science Foundation in the United States, both agencies encouraged us to initiate such a project. We subsequently submitted the proposal, internal and external reviewers apparently liked it, the National Science Foundation and the Korea Science and Engineering Foundation agreed with the reviewers, and the project has thus been founded.

We tried to invite outstanding scientists, engineers, researchers, and students from both countries. We are pleased to have a very good mix of them.

Obviously, you also realize that it took a tremendous amount of hard work to come to this concluding session. I must congratulate the local organizing committees for a super job. We must express our sincere gratitude to the speakers and the participants and thank our sponsors, the National Science Foundation in the USA, my organization, the Illinois State Water Survey, and Korea Science and Engineering Foundation, Korea Institute of Construction Technology, Korea Water Resrouces Corporation, Ministry of Construction and Transportation, Ministry of Home Affairs, Korean Water Resources Association, Daewoo Corporation, Saman Engineering Consultants Company, Ltd., Seoul National University, and the Honorable Vice President Dr. Sonu, in particular, for without their outstanding support we could not have pulled it together.

Let's talk briefly now of where we go from here.

1. We will take the reports from the session chairs, addresses during the opening and closing ceremonies, and two other papers to prepare a post-seminar proceedings.

2. We hope you have developed contacts and will work with each other closely.

3. We may initiate joint research projects.

4. We also hope to try to arrange another seminar in three to four years. We will obviously need your support, encouragement, counsel, and input in this endeavor.

5. We will definitely keep the lines of communication open so that future activities can be pursued in a timely fashion.

At least these are our thoughts at the present time. If you have recommendations, suggestions, or ideas for us, please let Dr. Seo and/or me know about it. I must also express our thanks to Dr. Woo for his comments on the future direction of the joint seminar. I can assure you that your ideas will definitely be considered in any future activities.

I would not be doing my job if I did not thank my American colleagues, who graciously agreed to come here and spend a week and share their experiences.

Finally, I am delighted to be here. We thank our hosts for their wonderful hospitality and I am sure all the U.S. participants will agree with me that it was a very good seminar and we enjoyed our stay in Seoul. We are going to return home with lots of sweet and wonderful memories. I again thank all of you for your participation in this seminar and hope to see you at future seminars.

# Field Trip

## Chungju Multipurpose Dam Site

Seminar participants went on a field trip to the Chungju Multipurpose Dam site on July 21, 1995. This dam is located about 150 km from Seoul, and the trip took the entire day.

The trip started at 0830 hours and concluded at 1830 hours. Chungju Multipurpose Dam is one of the water resources development works that is part of an integrated development plan for four major river basins in Korea. The main purpose of this project is to provide flood control, water supply, and power generation for the peak demand by constructing the largest concrete gravity dam on the South Han River, northeast of Chungju.

The dam site has a total drainage area of 6,648 $km^2$. The dam has a height of 97.5 m, crest length of 447 m, usable storage volume of 902,000 $m^3$ , total storage volume of 2,750 x $10^6$ $m^3$ , normal high water level of 141 m, flood water level of 145 m, and an installed generating capacity of 400 MW by four turbine units.

There is also a regulating dam with a storage capacity of 30 x $10^6$ $m^3$ and power-generating capacity of 12 MW with two units. The regulation dam is located 19 km below the main dam. The dam also has a flood control capacity of 600 x $10^6$ $m^3$ , and the annual water supply rate is 3,380 x $10^6$ $m^3$.

This field trip was exceptionally educational for the participants. The dam is operated by the Korea Water Resources Corporation.

# List of Participants

| | |
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| Eun Ho Choi | Young Dong Jr. College |

# Additional Papers Not Included in the Original Proceedings

# SCIENTIFIC ASSESSMENT AND STRATEGY TEAM'S (SAST) ACHIEVEMENT RELATED TO THE 1993 FLOOD

By Gary E. Freeman[1] and S.K. Nanda[2]

**ABSTRACT:** As a result of the 1993 flood the White House established the Scientific Assessment and Strategy Team (SAST) to provide scientific advice and assistance to officials responsible for making decisions with respect to flood recovery in the Upper Mississippi River Basin of the United States. The SAST consisted of an interdisciplinary team of senior scientists and engineers from Natural Resources Conservation Service, United States Geological Survey, US Army Corps of Engineers, National Biological Service, Federal Emergency Management Agency, and the Environmental Protection Agency. This multi-disciplinary team developed a vast multi-layer, multi-resolution database consisting of over 250 gigabytes of information covering the Upper Mississippi River basin. Much of these data are now available via the INTERNET. The locating, obtaining, and conversion of the data was extremely difficult, leading to a recommendation for an on-line source or at least an on-line listing of available data. Parts of the data were analyzed and scientific bases were established for discussions concerning levee effects on flood stages, effects of wetlands on flooding, effects of man's increased intervention in the floodplains and uplands, and proposals regarding floodways on the nations rivers. The data collected indicated that the 1993 flooding could not be attributed to man's intervention on the floodplain but to the excessive amount of rainfall in the basin.

## INTRODUCTION

The Scientific Assessment and Strategy Team (SAST) was formed by a directive of the White House on November 24, 1993, to provide scientific advice and assistance to Federal officials responsible for making decisions with respect to flood recovery in the upper Mississippi and Missouri River Basins (1). The upper Mississippi River Basin is defined as the basin above the confluence of the Mississippi River with the Ohio River at Cairo, IL. The portion of the Missouri River basin that was studied intensively was the portion from Gavin's Point Dam near Sioux City, IA to the confluence with the Mississippi River.

The SAST is an interdisciplinary team composed of senior scientists and engineers from the Department of Agriculture (Natural Resources Conservation Service - NRCS), Department of Defense (U.S. Army Corps of Engineers - Corps), Department of the Interior (Fish and Wildlife Service - FWS, National Biological Service - NBS and U.S. Geological Survey - USGS), Environmental Protection Agency (EPA) and the Federal Emergency Management Agency (FEMA).

The SAST was also incorporated as a part of the Interagency Floodplain Management Review Committee (FMRC) on January 10, 1994 by directive of the Office of Management and Budget, the Office of Environmental Policy, and the Department of Agriculture. The SAST had responsibilities to support the FMRC in addition to previously assigned responsibilities to obtain, analyze, manage, and distribute scientific data and information. As a part of the FMRC the SAST participated in the preparation and review of the FMRC report to the Administration Floodplain Management Task Force. The FMRC report has since become known as the Galloway report since BG Gerald E. Galloway headed the FMRC. Data and analyses supplied by SAST were either included in the FMRC report or were the basis for many of the recommendations made within the report.

The SAST will produce five report volumes which include background reports and workshop proceedings. The five volumes to be published are as follows:

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| Volume 1 | **Preliminary Report** provides general scientific background and specific narrowly defined analyses to the full FMRC for use in deliberations to produce the *Report of the Interagency Floodplain Management Review Committee to the Administration Floodplain Management Task Force* (Galloway Report). Published June 1994 as *A Blueprint for Change Part V: Science for Floodplain Management into the 21st Century.* |
| Volume 2 | **Database Report** provides a detailed description of the data and the database for users. This includes metadata, descriptions of the strengths and weaknesses of the data, acquisition methods, data maintenance plans, and data distribution methods. |
| Volume 3 | **Overview of River-Floodplain Ecology in the Upper Mississippi River Basin** contains a series of papers commissioned by the SAST to provide background information about the ecology of the Mississippi and Missouri Rivers. These papers are being published to ensure that this publicly funded analysis is readily available to the public. |
| Volume 4 | **Selected Hydrologic and Hydraulic Studies in the Upper Mississippi River Basin** contains a series of papers commissioned by the SAST to provide background information about the hydrology and hydraulics of the Mississippi and Missouri Rivers. These papers will be published to ensure that this publicly funded analysis is readily available to the public. |
| Volume 5 | **Proceedings of the SAST Hydraulic, Hydrologic, and Ecologic Modeling Workshop** contains papers presented by workshop speakers and selected discussions of the workshop participants. |

Additional reports and scientific papers will be published in the scientific literature of the various disciplines as the analyzed data become available.

## SAST DATABASE

Vast amounts of data were aggregated by the SAST for use in both nonspatial and GIS analyses. Numerous federal, state, and local government agencies undertook data collection efforts during the flood of 1993. Each agency collected data in the amount, type, and format that were most useful in fulfilling their mission. One of the largest problems facing the SAST was the location of data collected by the various agencies. Some agencies had collected large amounts of data but only those directly involved in its collection or use were aware the data's existence. Other agencies had data readily available but data validation was ongoing and data could not be obtained until validated. The data that was only known to those who obtained the data comprised a vast amount of valuable data but required a large amount of detective work to discover its existence. New data sets were uncovered throughout the SAST effort and it is certain that valuable existing data sets were not located during the SAST effort.

As a direct result of the vast amount of time and energy expended uncovering and locating data, SAST recommended a data clearinghouse be set up. In the clearinghouse, data remains on-line or near-line, owned and maintained by the agency that collected the data and most logically can make use of the data, but is available electronically to other agencies who need the data in on-going operations, studies, or during emergency situations. Organizations which produce specialized data should at the very least produce a list of data available in an electronic format so the data can be located in an emergency situation and to reduce the duplication of effort in data collection.

The nonstandard formats of the data also created problems for the SAST effort. When data was obtained it may or may not translate correctly with the accompanying descriptors (attributes). Additionally the time required to convert the data was often long with numerous difficulties.

## DATA COLLECTED BY SAST

Data gathered during the SAST effort was used for analysis, to provide background, or as an aid in understanding related problems. The data came from a wide variety of sources and included:

1. Flood extent data: generated for SAST from satellite imagery for the major floodplains with widths greater than 1 kilometer,

2. Superfund sites on the National Priorities List and Toxic Release Inventory (TRI) sites;

3. Permitted discharges under the Permit Compliance System;

4. Public water systems;

5. Hydraulic data used for the modeling of the Mississippi River from near Hannibal, Missouri to Cairo, Illinois; '

6. Levee location and elevation data, where available, for the Mississippi and Missouri Rivers as well as levee break information;

7. Period of record daily flow data for about SO long-term USGS stations on the mainstem Mississippi, Missouri, Illinois, and Des Moines Rivers, plus a few major tributaries;

8. Peak flow data for the 154 gages at which major 1993 floods were reported in USGS Circular 1120-A;

9. Daily, monthly, and annual mean flow data (period of record through 1988) for selected long-term sites suitable for climate variation studies;

10. Daily reservoir stage data at major reservoirs in the study area for the 1993 water year,

11. Climate data for the period of record for climate divisions in Iowa, Illinois, Kansas, Minnesota, Missouri, Norm and South Dakota, Nebraska, and Wisconsin;

12. Daily precipitation and temperature data for April-September 1993 for individual observation sites in Iowa, Illinois, Minnesota, Missouri, and Wisconsin;

13. National Wetlands Inventory (NWI) data for the basin;

14. Point locations of sightings of rare and endangered species developed by The Nature Conservancy, generalized into vertebrate, invertebrate, plan, and community, limited to within six miles of the floodplains for major rivers and tributaries - data cannot be used outside the SAST by prior agreement with The Nature Conservancy;

15. The North American Waterfowl Plan Joint Venture Areas consisting of waterfowl habitat areas of major concern;

16. Resource inventories of floodplain and ecological data for the Mississippi River from Gutenberg, Iowa to Cairo, Illinois - includes sport and commercial fishing areas, spawning areas, mussel beds, and important wildlife areas such as cormorant rookeries and eagle wintering areas;

17. Ownership data for wildlife refuges in the floodplains of the Mississippi, Missouri, and Illinois Rivers, as well as state lands and natural preserves in Illinois, Wisconsin, and Minnesota;

18. Critical Infrastructure including hospitals, bridges, railroads, roads, point source facilities (in ARC/INFO format and wastewater treatment facilities, airports, and electricity generating plants, and impacted water facilities (in tabular format);

19. Land use/land cover for selected reaches of the Mississippi River for 1989 and 1891-94 and data for the Missouri River for 1879;

20. Numerous other data sets that may be for only one state or local area such as drainage ditch maps, digital elevation models of selected drainage basins, etc.

The data was all provided to SAST by the collectors/owners of the data. In many cases SAST provided for the conversion of the data to digital form whereas previously the data existed only in the form of paper maps or tables.

## ACCESSING THE SAST DATABASE

The SAST database can be accessed via the Internet with an World Wide Web browser (Mosaic, Netscape, etc) using the following uniform resource locator (URL):

http://edcwww.cr.usgs.gov/sast-home.html

The portion of the SAST database available for public distribution is continuing to expand as more and more data is quality assured and placed on-line. A demo of the database is also available through an X-windows based interface at the same location as above. The demo requires X Window software running on you computer to function properly. The demo allows the user to view the extent of the flood and overlay various data layers to observe the impact of the flood on different resources. Data can be downloaded for use by various agencies, local governments, and educational institutions. The availability of this data will reduce the amount of time and effort spent collecting data that has been previously obtained by SAST or other agencies and will facilitate rapid and better informed decisions during both emergency and non-emergency situations.

## ANALYSIS OF DATA BY SAST

The SAST effort was limited to ten weeks at the EROS Data Center near Sioux Falls, South Dakota. The amount of time necessary to find, collect, translate, and transform the data into a usable form was very large, consequently, the time available for analysis of data was limited. In spite of this time constraint, significant amounts of data were analyzed and significant findings produced. Data analysis was divided into two areas - the natural system and the engineered system. Within the natural system analysis were the hydrology and physiography of the region, floodplain geomorphology, and floodplain ecology. The engineered system included the levee and flood protection systems, economic data, and upland management options.

SAST contributions to understanding the impacts of the 1993 flood varied by discipline due to differing amounts of data available and differing amounts of time available for analysis during the teams stay in Sioux Falls, South Dakota and after their return to their normal duty stations. Some of the SAST findings are well understood within the various technical communities but needed to be demonstrated in the context of the SAST exercise. This was necessary to assure balance in the study efforts and to demonstrate the effects of alternatives being discussed for analysis - both the uplands and within the floodplains.

## DATA CONCERNING THE NATURAL SYSTEM

The timing of the storms in the Upper Mississippi River basin increased the peaks of the 1993 flood. The early storms were in the upper areas of the basin and ensuing storm patterns moved southward approximately following the peak of the flooding. The later storms added additional water to the peak flows moving down the rivers from the upper basin. Thus the flood peaks reinforced each other increasing downstream flood peaks and durations.

The flood control reservoirs within the basin varied significantly in their capacities and affects on flooding depending on their storage volumes and location within the basin. In the Missouri River basin, nearly all rainfall fell below the location of the six large mainstem reservoirs and thus their effect, while significant, was limited. Other reservoirs on the Missouri system were filled to maximum storage - even beyond in some cases. Reservoirs on the Mississippi River were small compared to the size of their drainage areas and the amount of water passing through the reservoirs. These reservoirs usually had a significant beneficial impact on flooding and damages on the tributaries where they were located, but produced only minor effects on the Mississippi River stages.

The flood waters entering the system above Gavins point dam on the Missouri River were contained in the mainstem reservoirs and the base flow of the river was lowered as much as possible to reduce downstream flooding. Reservoirs on the Kansas River and its tributaries reduced Kansas River flows by about one third. One the Missouri River, reservoirs reduced the average flow for July at Hermann, Missouri by about 36%. Without the reservoir system in place the floodwalls at St Louis as well as additional agricultural levee systems would have been overtopped resulting in significantly larger damages.

A misconception widely reported during and immediately after the flood was that the basin would have had the capability to store the floodwaters in the uplands either in the soil or in wetlands if man had not disrupted the natural system. Water holding capacities for the flooded areas were estimated from the USDA STATSGO database and compared with rainfall amounts. It is estimated that the soils in the flood area can hold about 10 inches of water. Rainfall amounts over the flood area during the June to September 1993 period varied from 15 to 30 inches. Individual storms produced 4-6 inches within a few hours overwhelming the natural storage capacities of the soils and wetlands in the area. Based on this analysis and other information it was concluded that the soils in the area could not have absorbed the rainfall and that a major flood should be expected from rainfall events of this nature - whether the land is in agricultural production or in its natural state.

Large portions of the natural wetlands have been drained in the basin and converted to farmland. The amount of land considered to be wetlands in 1780 ranged from 5.5 percent in South Dakota to 28 percent in Minnesota. The states of Iowa, Missouri, and North Dakota are all estimated to have had about 11 percent wetlands while Illinois had about 23 percent and Wisconsin had 27 percent wetlands. The amount of these wetlands converted to agricultural use ranges from a low of 34 percent to a high of 93 percent in Iowa. Most of these wetlands and former wetlands were filled with water - at least to some extent - either by storms earlier in the winter and spring or by the early summer storms. This allowed more water to runoff than would occur in a more normal year when wetlands and low lying agricultural areas were more likely to retain water and reduce downstream flood peaks. The data indicated a major hydrometeorlogical event that would produce major flooding regardless of any modifications in the floodplain or with the watersheds.

The geomorphology of the floodplains along the Mississippi and Missouri Rivers differs significantly. The discharge volume of the upper Mississippi River is similar to that of the Missouri River, but the Missouri's sediment discharge is five times that of the upper Mississippi River. The resulting floodplain slope on the Missouri River that is about twice that of the Mississippi River below St. Louis. This steeper slope and relatively narrow floodplain resulted in higher velocity flows and more damage to the Missouri River floodplain from the 1993 flood. On the Missouri River numerous deep scour holes are present with associated sand splays, while many fewer but relatively larger splays are present along the Mississippi River.

Part of the difference in floodplain damages due to scour and erosion is probably due to the relative number of levees along the rivers; however, this aspect has not been fully analyzed. Along the middle Mississippi River, for example, levees tend to enclose large tracts of land where one or two levee breaches could flood tens of thousands of acres, while the numerous levees on the Missouri River may only protect several hundred to a few thousand acres. Each levee breach has an associated scour hole and sand splay which resulted in damages to land and nearby structures. Analysis indicates that in the Glasgow to St. Louis reach of the Missouri River approximately 5% to 7% of the land was substantially damaged with 90% to 95% of this damage due to scour and deposition directly associated with levee breaches.

The geomorphological analysis was able to delineate the "high-energy" zones of conveyance along the river and the zones of more passive flooding using conventional aerial photography. This corresponds closely to the conveyance zone used in hydraulic design and modeling. This delineation of high energy zones confirms the logic of the original Pick-Sloan plan that called for levee setbacks along the Missouri River to produce a floodway of 3,000 to 5,000 feet. This floodway has not been protected over most of the Missouri river's length. The Federal levees that have been built along the River have maintained this floodway; but private levees have been built near the bank of the Missouri river throughout much of its length.

The ecology of the Upper Missippi and Missouri River basins' major rivers has been greatly modified from that of the natural rivers. Many of the natural inhabitants of the basins' rivers are under stress or endangered. The changing of sediment loads, the construction of levees, and the changes in river hydrographs due to irrigation, navigation, municipal water supply, power production, and recreation have created these habitat problems for many species in the basin. The change of the basin and floodplains from natural prairie and forests to agricultural lands has also had an affect on habitat and the number of species found along the rivers. Commercial fishing in the Illinois River, for example, has dropped from 24 million pounds or 178 lbs/acre in 1908 to 4 lbs/acre in the 1970's (3).

Preliminary 1993 flood data indicate a resurgence in the number of young of the year for fish species where young of the year have not been seen in significant numbers for several years. The scour holes and associated features are currently providing habitat on the Missouri River for fish and other forms of wildlife.

## ANALYSIS OF THE ENGINEERED SYSTEM

The descriptor, "engineered system" may be overly broad - attributing to engineering, actions undertaken by individual farmers, society in general, and governmental agencies which have resulted in modifications to the natural state of the basin. Engineering is here taken to include everything from the burning of prairie by the Native Americans during the hunting of buffalo to the building of modern dams on the rivers and tributaries.. It includes all impacts that man has had upon the floodplains and within the basin. This analysis focused on two aspects of the basin, the levee system and its affects, and the effects of man on the uplands including the amount of flood reductions possible from varying current land management practices.

### The Uplands

The methods described herein as nonstructural methods of flood reduction have long been encouraged in the United States. Usually the methods have been associated with other goals such as capturing the maximum amount of rainfall for agricultural crops, restoring prairie potholes for the use of waterfowl, or preventing the erosion of soil. These methods, while practiced to accomplish other goals, can provide some flood reduction benefits. The NRCS for example, has encouraged the protection of farmland to reduce runoff and erosion - both of which affect flooding in a basin.

The effects of wetlands and land practices were evaluated for four watersheds within the Upper Mississippi River Basin. The four basins evaluated were:

> Boone River Basin above the gage near Webster City, IA - a relatively flat watershed with low relief prairie pothole terrain, 840 square miles,
>
> West Fork Cedar River above the gage near Finchford, IA - a relatively flat watershed but having a well defined drainage system, 850 sq. miles,
>
> Whitebreast Creek above the gage near Dallas, IA - a relatively steep watershed with well incised drainage, 380 sq. miles,
>
> Redwood River basin above Redwood Falls, MN - a high relief pothole watershed in the upper portion and a low relief pothole watershed in the lower portion of the basin, 700 sq. miles.

The object of the modeling effort was to demonstrate the effect of various management, land use, and storage practices on me outflow hydrographs for differing types of basins. Alternatives selected for the Boone River, West Fork Cedar River, and Whitebreast Creek were:

1. Maximizing wetland storage in upland and/*or* floodplain areas as applicable,

2. Demonstrating the effect of the Conservation Reserve Program (CRP) lands on flooding,

3. Maximizing infiltration by using all applicable land treatments such as conservation tillage, terraces, and permanent cover,

4. Flood prevention structures - i.e., traditional NRCS small (Public Law 566) watershed structures to temporarily store water and release it slowly,

5. A combination of all non-structural practices - i.e., alternatives 1-3, and,

6. A combination of all possible alternatives - alternative 5 plus alternative 4 to demonstrate the maximum possible reduction for the watershed without the inundation of large areas for medium to large reservoirs.

When treatments were used in an alternative, the treatment was assumed to apply to 100% of the acreage within the watershed. This assumption was unrealistically high but the object was to determine the maximum effect that could be obtained from a treatment. This tended to overestimate the obtainable effect

Alternative 3, the maximum infiltration option, included conservation tillage on all agricultural lands, terraces on lands with slopes from 5 to 14 percent (C and D slopes), and permanent cover (grass, trees) on all lands with slopes greater than 14 percent. This alternative also included the effects of current CRP lands which were intended to be highly erodible lands.

The Redwood River basin was modeled with a different set of alternatives. The object of the Redwood River study was to model the affect of wetlands on flood peaks. The six alternatives studied evaluated the restoration of:

a. all depressional hydric soils with detention structures (19% of watershed),

b. 50% of all depressional hydric soils as in alternative a (10% of watershed),

c. 25% of all depressional hydric soils as in alternative a (5% of watershed),

d. small wetlands with 50% assumed to be landlocked - i.e. 50% had no outlet to stream after restoration while the remaining 50% served as detention structures,

e. large wetlands and lakes over 100 acres in size, and

f. large and small wetlands (combine alternatives a and e) with no assumption of landlocked wetlands.

Since the goal of the Redwood River study was to determine the effect of wetlands, no NRCS land treatments (CRP or maximum infiltration) were applied to the Redwood River basin. Additionally, with the exception of alternative d, the wetlands were assumed to be restored as detention storage areas. This assumption means that the water stored in the wedand would be released slowly through a control structure over a period of several days, making full storage of the wedand available for a subsequent storm. Using the full storage maximized the effect of wedands on flood peaks in the watershed. The cyclical filling and draining of the wedand by floodwaters may have negative affects on wedands but could be designed to include a smaller wetland in the lower elevations and use additional lands during storm events to detain water on the upland areas surrounding the wetland.

The various land treatments and land practices are not all applicable to all watersheds. The construction of detention basins, for example, is most economically feasible in watersheds with incised drainage channels where a small dam can impound a relatively large amount of water. A tour of the West Fork Cedar River revealed very few sites for detention storage and, since the number was deemed too few to provide a significant impact, the detention basin option was not modeled for the West Fork Cedar River. Similarly, too few wetland sites were available to produce a noticeable impact; and this option was not modeled for the West Fork Cedar River as well. It should be noted that an off stream wildlife site exists in the basin, but a shallow depth of water (perhaps 4-5 feet) covers several hundred acres. This makes the construction of detention basins or wetlands a very land-intensive undertaking within the West Fork Cedar River Basin. This is not to say that there are no opportunities within the basin, but the opportunities were not deemed sufficient to make a noticeable difference in model results without involving large tracts of land.

The models used for the studies consisted of the NRCS TR-20 model for the Redwood River and Whitebreast Creek basins, and the CORPS HEC-1 model for the Boone and West Fork Cedar River basins.

**Results of Watershed Studies:** The results of the four watershed studies described above are presented in Table 1. The results of the Redwood River study are included for comparison, even though the studies are not totally comparable. The Redwood River, while not modeled for the same alternatives, did correspond to three cases studied for the other three basins. The maximum reduction for the Redwood basin is also shown in Table 1 for comparison, but it must be remembered that the Redwood basin included no upland land treatments which could increase the maximum flood peak reductions.

The model studies indicated that, for the basins studied, floodplain wetlands played only a minor role in flood peak reductions. A 3% maximum reduction due to wetlands was obtained in the Redwood River basin model for the 100 year storm and no reduction in the incised Whitebreast Creek watershed model. Wetlands in the uplands produced a 10% reduction in flood peak for the 100 year storm in the Redwood River basin but only a 5% reduction in the Boone River basin. The modeling of wetlands in the Boone River basin was hampered by the lack of high resolution topographic data. The wetland areas were estimated from 1:24,000 USGS topographic maps. A more detailed study using better elevation data may produce slightly different results but any wetland studies should be bounded on the upper limit by approximately the values obtained on the Redwood River watershed.

The CRP lands produced reductions in flood peaks ranging from 4% for Whitebreast Creek for the 100 year flood down to 1% for the Boone River Basin. The Maximum infiltration option produced reductions as high as 20% for Whitebreast Creek but only 2% to 4% on the Boone and West Fork Cedar River basins for the 100 year storm.

Detention structures were modeled only on Whitebreast Creek and in the Redwood River basin. Reductions ranged from 28% on Whitebreast Creek for the 100 year flood - probably due to the routing of stored water - to 11% for the 100 year storm on the Redwood River. There is some concern about the trends demonstrated by the Whitebreast Creek study as compared to the Redwood River but additional investigation has not been accomplished.

The maximum flood peak reduction for all the basins for the 100 year storm ranged from 4% on the West Fork Cedar River, where wetland and detention structure sites were not abundant to nearly 40% on Whitebreast Creek. The results from Whitebreast Creek caused some concern given the increasing reductions with storm size, and further analysis should be performed prior to extending the results from Whitebreast Creek to other areas within

Table 1. Peak and Volume Reductions for Watershed Studies.

| Flood Peak and Volume Reduction by Watershed and Treatment (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Return Period | Boone River | | West Fork Cedar River | | Whitebreast Creek | | Redwood River | |
| | Peak | Vol | Peak | Volume | Peak | Vol | Peak | Volume |
| Floodplain Wetlands (Alt e) | | | | | | | | |
| 1 | 5 | 0 | | | 1 | *** | 6 | 1 |
| 5 | 3 | 0 | | | 1 | | 5 | 1 |
| 25 | 2 | 0 | | | 2 | | 3 | 1 |
| 100 | 2 | 0 | | | 0 | | 3 | 0 |
| Upland Wedands or Potholes (Alt a) | | | | | | | | |
| 1 | 9 | 7 | | | | | 23 | 2 |
| 5 | 8 | 4 | | | | | 15 | 3 |
| 25 | 7 | 1 | | | | | 11 | 4 |
| 100 | 5 | 0 | | | | | 10 | 2 |
| Conservation Reserve Program (CRP) | | | | | | | | |
| 1 | 3 | 2 | 7 | 6 | 4 | | | |
| 5 | 1 | 1 | 5 | 4 | 4 | | | |
| 25 | 1 | 1 | 4 | 3 | 4 | | | |
| 100 | 1 | 1 | 3 | 3 | 4 | | | |
| Maximum Infiltration (FSA) - Includes CRP Reductions | | | | | | | | |
| 1 | 6 | 4 | 15* | 14 | 21 | | | |
| 5 | 3 | 3 | 11* | 10 | 15 | | | |
| 25 | 2 | 2 | 8* | 8 | 18 | | | |
| 100 | 2 | 2 | 7* | 7 | 20 | | | |
| Detention Structures (Alt f) | | | | | | | | |
| 1 | | | | | 8 | | 26 | 4 |
| 5 | | | | | 15 | | 16 | 4 |
| 25 | | | | | 27 | | 12 | 5 |
| 100 | | | | | 28 | | 11 | 3 |
| Total of All Applicable Treatments (Alt d) | | | | | | | | |
| 1 | 18 | 12 | 15* | 14 | 29 | | 27 | 11 |
| 5 | 14 | 8 | 11* | 10 | 21 | | 21 | 12 |
| 25 | 12 | 4 | 8* | 8 | 37 | | 17 | 12 |
| 100 | 9 | 2 | 7* | 7 | 40 | | 16 | 11 |

* In the original SAST Table these numbers were incorrectly reported without the CRP effects which are included in the FSA programs and are included in other watersheds.

** This table is taken from the Preliminary Report of the Scientific Assessment and Strategy Team with the Total of All Treatments for the West Fork Cedar River Revised to the correct peak values.

*** Adequate data could not be obtained to determine volume reductions for Whitebreast Creek.

the basin. If larger storms were modeled in this basin (greater than 100 year), the peak reductions should begin to decrease and eventually approach zero as detention structures exceed their design capacities. Results of the Whitebreast Creek study should be used with caution as previously noted.

The analysis of volume reductions by the various alternatives is also presented in Table 1. This work was accomplished in a follow-on effort funded by the Corps of Engineers. It can be noted that for alternatives where water is retained on the watershed (infiltrated or stored permanently) the volume reductions and the peak flow reductions are very similar. For cases where the water is simply stored and then released - such as in detention ponds - the volume reductions are minimal and only the timing of the flow is changed. The direct comparison of volume reductions between watersheds is not recommended since differing storm periods were used in the modeling effort to get the watersheds to peak.

**Conclusions:** The hydrologic model studies showed clearly that there is no single type of land treatment that is applicable to all watersheds in the upper Mississippi River basin. They also showed that while wetlands may be effective for smaller, more frequent storms, their effect is reduced as storm size increases. The NRCS practices can produce significant reductions in flood peaks in steeper watersheds where improved infiltration and detention structures can retain significant amounts of water on the watershed during a storm. These same practices have much less affect on flat watersheds where water moves slowly and has more time to infiltrate.

## The Floodplains

Humans have lived in the upper Mississippi River Basin for several thousand years. The floodplain played an important role in some of these early cultures which had substantial populations, earthworks, and material production (4-6). Human impacts in the basin within the last 200 years have included clearing of the floodplains and upland areas for agricultural production, removal of snags from the channels for navigation, construction of navigation dams, protection of cities and floodplains by the construction of levees, and the construction of large multipurpose reservoirs to provide power, water for irrigation, municipal/ rural/industrial water supplies, recreation, flood control, and other public benefits. Thus man must not be viewed as an outsider to the floodplains but as an integral part of the river and surrounding areas - one who should be considered in the balance of competing interests.

**Levees:** As lands were developed for agriculture and commerce, towns and cities began to grow on the floodplain, increasing demands for protection from flooding. This led to the construction of levees and reservoirs to reduce flooding within the basin. During the 1993 flood many of these levees - especially the private levees - were overwhelmed by the huge volume of floodwaters. Where the levees breached large scour holes developed and concentrated velocities damaged nearby homes and structures. It should be noted that levees are designed to overtop at some flow and return the floodplain storage to the system. This storage in turn reduces flood stages and moderates flows downstream to some degree - depending on the amount of storage in relation to the flood volume.

The concerns of environmental groups and others raised serious questions regarding the effect of levees. Some groups indicated that the levee system was the cause of the flood while other groups wanted to evaluate the effect of the levees. In an attempt to answer these questions SAST commissioned Dr. Robert L. Barkau to test several levee scenarios with the UNET mathematical hydraulic model to demonstrate the effect of the levees on the flood of 1993.

The data were not readily available to allow the application of the UNET model for the entire river reaches mat were flooded during the 1993 flood. The data were available to construct the model from near Hannibal, MO to Cairo, IL on the Mississippi River, from Hermann, MO to the mouth on the Missouri River, and from near Meridosia, IL to the mouth of the Illinois River. The results indicated that for a hypothetical system with no agricultural levees and short crops or grasslands over the entire floodplain, the levee system increased water surface profiles at St. Louis by about 2.5 feet. This combination was considered unlikely for a no levee condition. A more probable condition includes trees and tall crops as well as the grasslands, which would result in a much lower change in stage as a result of the simulated removal of the levee system. The difference depends on the final mix of crops, forests, wetlands, meadows, etc. and the resulting resistance to flow. This simulation assumed the urban levees near St. Louis were left in place and only agricultural levees were removed. The model showed minimal reductions at St. Louis with some areas of significant reduction downstream. The downstream areas were still flooded by 15 to 20 feet of water however.

The highest reduction in flood stage was as Chester, IL where for the best case (Manning's n = 0.04 - again considered unlikely) the model indicated a 10.7 foot reduction in flood stage. Some of the Manning's n values used in this study are higher than those often associated with river modeling, the calibration of the model indicated that values in the .080 to .320 range would predict the floodplain roughness values for this simulation better than lower values. At the higher n values reductions in the flood elevation ranged from 7 feet at Chester (n = 0.080) to almost no change at most locations (n = 0.320) depending on the assumptions for the floodplain. If no conveyance were allowed on the floodplains and the floodplains were only used for storage, flood elevations would be higher than those of the 1993 flood.

Another option was the modeling of levees that were high enough and strong enough to prevent failure during the 1993 flood as shown in the Infinite Height Levee column. For this case, flood elevations increased by less than 2 feet in St. Louis with the maximum increase being 2.7 feet at Waters Point just downstream from St. Louis. The main reason for the increase in flood elevation at St. Louis and points downstream is that the failure of the Harrisonville and Columbia levee districts near the peak of the flood lowered flood stages in St. Louis and points downstream by about 2 feet or more. The effects of the levees on smaller floods were also analyzed and produced results that follow those of the 1993 flood with levee affects being less for smaller floods. The Corps follow-on study indicated that the effects extending the no levee overtopping scenario to the entire basin would have raised the flood stage at St. Louis by about 6 feet - enough to overtop the floodwall and produce several billion dollars in additional damages.

**Conclusion;** The hydraulic study indicated that the removal of levees would have an impact on flood stages; however, the types, density, and amount of vegetation on the floodplain has a major impact on flood stages. For very dense vegetation on the floodplain stages could actually increase and the vegetative effects could overcome any stage reduction from levee removal.

## REPORT CONCLUSIONS

The SAST effort resulted in the assembling of huge amounts of data relating to the 1993 flood and to the Upper Mississippi River Basin. This data, some of which have not yet been fully analyzed, indicate that the 1993 flood was caused by nature; and, while man has had significant impacts within the basin, this event would have been a major flood regardless of man's intervention in the basin.

The impact of levees and upland land treatments were evaluated; and, while we cannot state that the levees had no overall impact on flooding, we can state that the levees did not cause this flood nor did man's impacts in the uplands. The fact that the storm was a meteorological event unprecedented in recent history was the major cause of flooding; in fact, this flood is not unlike major floods of the more distant past. Additionally, floods of this magnitude can be expected in the future.

This flood does, however, give us a chance to evaluate how we use our floodplains, how we value them, and what we feel we should use them for in the future. The data provided by SAST and those associated with SAST have helped provide a basis for discussions about floods, flooding, and land use for the present and the future.

This study also points out the importance of viewing the system as a whole, rather than viewing each piece individually and separately. The bringing together of senior scientists and engineers from the differing agencies and disciplines gave the project a synergism that is lacking in many studies. This synergism enabled those participating in this project to evaluate their ideas, biases, and beliefs from other perspectives. This gathering of disciplines and broadening of perspectives is, perhaps, the greatest contribution of SAST to the management of Floodplains and Flooding.

The 1993 flood and the knowledge gained from the data obtained is applicable to floodplains throughout the world. In the construction of flood reduction facilities such as reservoirs and levees, it must be remembered that unless the system is designed to contain the probable maximum flood, the capacity of the system will be exceeded at some future date. When the design protection level is exceeded, major damages will result - especially if development is allowed in that portion of the floodplain that experiences a lowered risk of flooding from the more common events due to the construction of flood reduction projects. This reduced flooding gives the perception to the public that the floodplain is now safe for development. This idea not only is false but leads to significantly increased damages when the flood protection capacity of the system is finally exceeded. This can result in numerous deaths and significant property damages in areas that are perceived as "safe" from flooding. As water resources professionals we should strive to increase awareness that the reduction of flooding occurs only up to the design flood and that any storm larger than the design value will not be contained within the reservoir, levee, or flood reduction system - resulting in possible deaths and certainly increased flood damages if development is allowed in the protected areas. The SAST effort did not suggest the abandonment of the floodplain - only the wise use for purposes that are compatible with flooding, such as agriculture and development that must be done in the floodplain. If the development can be done outside the floodplain then it should not be placed in the floodplain simply because land prices are lower or for the convenience of those involved.

The mention of product names does not imply endorsement of products by the U.S. Government, any agency thereof, or by SAST. The use of product names is for general reference only. The views expressed in this paper are those of the author and do not necessarily represent those of the US Army Corps of Engineers or the United States Government.

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# Optimal Control Approaches for Sedimentation and Flood Control in Rivers

by

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## Abstract

The objective of this paper is to briefly describe some new optimal control approaches for sedimentation and flood control in river-reservoir systems. These approaches are based upon solving large scale nonlinear discrete time optimal control problems by interfacing optimizers and simulators in an optimal control framework. This paper presents two optimal control type methodologies for determining reservoir releases in a river-reservoir system under flooding conditions. The first is an optimization model for the real-time operation of these systems in which the U.S. National Weather Service DWOPER code is interfaced with the nonlinear programming optimizer GRG2. The second is an optimization model for determining reservoir releases that minimize the effects of sedimentation in which the U.S. Army Corps of Engineers HEC-6 code is interfaced with a discrete differential dynamic approach. Both of these models and the respective solution procedures are briefly described.

## 1. Problem Identification: Real-Time Operation

Real-time operation of multi-reservoir systems involves various hydrologic, hydraulic, operational, technical and institutional considerations. For efficient operation, a monitoring system is essential that 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 for the watersheds whose outputs (runoff from rainfall) are not gauged. A flow routing procedure is needed to predict the impacts of observed and/or predicted inflow hydrographs on the downstream parts of the river system. A reservoir operation policy or methodology is another component which reflects the flood control objectives of the system, the operational and institutional constraints on flood operations, and other system-related considerations. An integral part of these components is a reservoir operation model that predicts the results of a given operation policy for forecasted flood hydrographs.

Flood forecasting in general, and real-time flood forecasting in particular, have always been an important problem in operational hydrology, especially when the operation of storage reservoirs is involved. The forecasting problem, as in most hydrological problems, can be viewed as a system with inputs and outputs. The system output is related to its causative input through a process, either linear or nonlinear. In the reservoir management problem, the system is the river system that includes a main river and its tributaries, catchments, and natural and manmade structures on the path of the flood waters. The system inputs are inflow hydrographs at the upstream ends of the river system, and runoff from the rainfall (and snowmelt, where applicable) in the intervening catchments. The system outputs are flow rates and/or water levels at control points of the river system. The operations involved are the operations of the reservoir(s) in order to control flood waters. The term 'forecasting' refers to the prediction of the discharges and water surface elevations at various points of a river system as a result of the observed portion of a flood hydrograph.

The real-time reservoir operation problem involves the operation of a reservoir system by making decisions on reservoir releases as information becomes available with relatively short time intervals which may vary between several minutes and several hours. A new methodology is presented for operating a reservoir system under flooding conditions that incorporates: (a) a simulation model that adequately simulates the hydraulics of the system for a given flood hydrograph and a set of operating decisions, and (b) a systematic way that will improve the trial decisions made previously and generate a set of operating decisions that would cause the least damage to the protected areas (Unver and Mays, 1990).

The model presented in this paper has the following characteristics:

(1) It is deterministic as the inflow hydrographs have to be provided by the user.
(2) It has provisions to incorporate runoff from rainfall, through an option to generate runoff hydrographs resulting from given (deterministic) rainfalls hyetographs through a submodule based on a U.S. Soil Conservation Service (SCS) procedure, developed for an earlier real-time flood forecasting model (Unver et al., 1987). In case runoff hydrographs are obtained externally, they can be input to the model.
(3) The releases from reservoirs are realized through the operation of controlled outlet structures (gates) which are hydraulically described by a discharge versus gate setting relationship for various headwater elevations.
(4) Reservoirs which are not controlled by gates, i.e. run-of-the-river type reservoirs, are treated like other flow structures such as bridges, levees, and weirs.
(5) The channel flow as well as the flow through reservoirs and various regulating structures are simulated by state-of-the art methods, thus the magnitudes and timing of flood flows are accurately estimated.
(6) The data required for computer implementation is basically standard and may be readily available to most potential users as flow routing is accomplished by a modified version of the U.S. National Weather Service DWOPER (Dynamic Wave OPERation) Model (Fread, 1982), and optimization through a widely used nonlinear optimization code, GRG2 (Lasdon and Waren, 1983).

## 2. Problem Formulation: Real-Time Operation

### 2.1. PROBLEM STATEMENT

The optimization problem for the operation of multi-reservoir systems under flooding conditions (Unver and Mays, 1990) can be stated as

(1) Objective:

$$\text{Minimize } z = f(h, Q). \tag{1}$$

(2) Constraints:

(a) Hydraulic constraints defined by the Saint-Venant equations for one-dimensional gradually varied unsteady flow and other relationships such as upstream, downstream, and internal boundary conditions and initial conditions that describe the flow in the different components of a river-reservoir system,

$$g\ (\mathbf{h}, \mathbf{Q}, \mathbf{r}) = 0. \tag{2}$$

(b) Bounds on discharges defined by minimum and maximum allowable reservoir releases and flow rates at specified locations,

$$\underline{\mathbf{Q}} \le \mathbf{Q} \le \overline{\mathbf{Q}}. \tag{3}$$

(c) Bounds on elevations defined by minimum and maximum allowable water surface elevations at specified locations (including reservoir levels),

$$\underline{\mathbf{h}} \le \mathbf{h} \le \overline{\mathbf{h}}. \tag{4}$$

(d) Physical and operational bounds on gate operations,

$$0 \le \underline{\mathbf{r}} \le \mathbf{r} \le \overline{\mathbf{r}} \le 1. \tag{5}$$

(e) Other constraints such as operating rules, target storages, storage capacities, etc.

$$\mathbf{W}\ (\mathbf{r}) \le 0. \tag{6}$$

The objective z is defined by minimizing the total flood damage or deviations from target levels or water surface elevations in flood areas or spills from reservoirs or maximizing storage in reservoirs. The variables h and Q are, respectively, the water surface elevation and the discharge at the computational points and r is the gate setting, all given in matrix form to consider the time and space dimensions of the problem. Bars above and below a variable denote the upper and lower bounds for that variable, respectively.

## 2.2 CONSTRAINTS

The constraints of the model can be divided into two groups: the hydraulic constraints (Equation 2)) and the operational constraints (Equations (3)-(6)). The hydraulic constraints are equally constraints consisting of the equations that describe the flow in the system. These are (a) the Saint-Venant equations for all computational reaches except internal boundary reaches, (b) relationships to describe the upstream and downstream boundary conditions in addition to the Saint-Venant equations for the extremities, and (c) internal boundary conditions including the continuity equation and a flow relationship.

Internal boundary conditions describe flow that cannot be described by the Saint-Venant equations such as critical flow resulting from flow over a spillway or waterfall. Your operational constraints are basically greater-than or less-than type constraints that define the variable bounds, operational targets, structural limitations, capacities, etc. Options for the operator to get or limit the values of certain variables are also classified under this category. The solution methodology used in this study separately solves the hydraulic and operational constraints. The hydraulic constraints are solved implicitly by the simulation model, DWOPER, whereas the operational constraints are solved by the optimization model, GRG2 (Figure 1). The DWOPER model performs the unsteady flow computations.

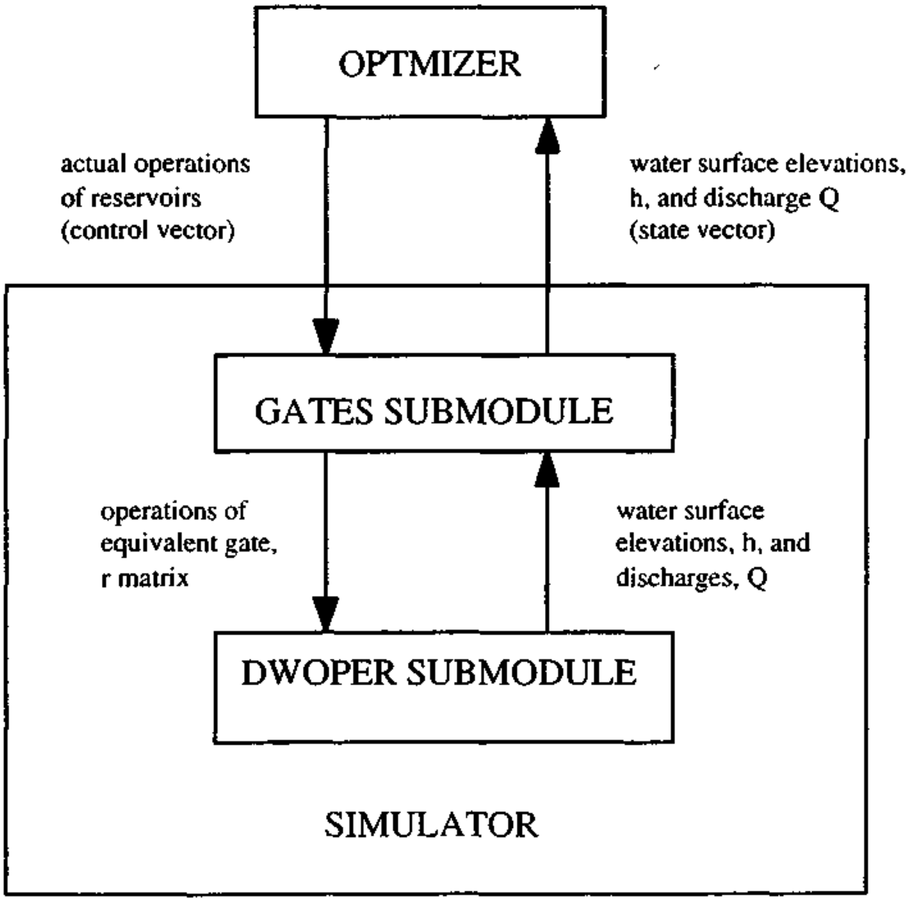

Figure 1. Optimal control approach to operations problem.

Bound constraints are used to impose operational or optimization-related requirements. Nonnegativity constraints on discharges are not used because discharges are allowed to take on negative values in order to be able to realistically represent the reverse flow phenomena (backwater effects) due to a rising lake or due to large tributary inflows into a lake. Nonnegativity of water surface elevations is always satisfied since the system hydraulics are solved implicidy by the simulation model, DWOPER. The lower limits on elevations and discharges can be used to impose water quality considerations minimum required reservoir releases, and other policy requirements. The upper bounds on elevations and discharges can be used to set the maximum allowable levels (values beyond are either catastrophic or physically impossible) such as the overtopping elevations for major structures, spillway capacities, etc.

The third model variable, gate openings, are allowed to vary between zero and one, which corresponds to zero and one hundred percent opening of the available total gate area, respectively. The upper and lower bound on the model variables are expressed mathematically as

$$\underline{Q}_i^j \le Q_i^j \le \overline{Q}_i^j, \quad \forall\, i,j, \tag{7}$$

$$\underline{h}_i^j \le h_i^j \le \overline{h}_i^j, \quad \forall\, i,j, \tag{8}$$

$$0 \le \underline{r}_i^j \le r_i^j \le \overline{r}_i^j \le .1, \quad \forall\, i,j:\ i \in I_r \tag{9}$$

where variables with a bar above them denote upper limits; those with a bar below them denote lower limits; i and j are respectively the time and location index; and I is the set containing the reservoir locations. Q, h, and r denote the discharge, water surface elevation, and gate opening, respectively.

The bounds on gate settings are intended primarily to reflect the physical limitations on gate operations as well as to enable the operator to prescribe any portion(s) of the operation for any reservoir(s). Operational constraints other than bounds can be imposed for various purposes. The maximum allowable rates of change of gate openings, for instance, for a given reservoir, can be specified through this formulation, as a time-dependent constraint. This particular formulation may be very useful, especially for cases where sharp changes in gate operations, i.e. sudden openings and closures, are not desirable or physically impossible. It is handled by setting an upper bound to the change in the percentage of gate opening from one time step to the next. This constraint can also be used to model another important aspect of gate operations for very short time intervals, i.e. the gradual settings that have to be followed when opening or closing a gate. For this case, the gate cannot be opened (or closed) by more than a certain percentage during a given time intervals. This can be expressed in mathematical terms as follows:

$$-r_{ci} \le r_i^{j+1} - r_i^j \le r_{oi}, \quad i \in I_r \tag{10}$$

where $r_c$ and $r_0$ are the maximum allowable (or possible) percentages by which to open and close the gate. This constraint can be used to model manually operated gates, for example, for all or a portion of the time intervals. The same constraint can be used, for example, to incorporate an operational rule that ties the operations of a reservoir to those of the upstream reservoir such as a multi-site constraint.

## 3. Solution Approach: Real-Time Operation

### 3.1. OVERVIEW

The optimization problem stated above is a large mathematical programming problem for most real-world situations. In modeling a river system, computational points are used to discretize the river channels and reservoirs. Each computational point, for each time step of the operation, contributes two flow variables (water surface elevation and discharge) and two hydraulic constraints (the Saint-Venant equations or other flow relations) to the problem. In addition, each reservoir contributes another variable (the setting of the equivalent gate) per time step. The external boundaries each contribute an additional hydraulic relationship. Thus, a typical 24 hour operation horizon with 2 hour time steps for a river system with 5 reservoirs and 150 computational points would give rise to a problem with more than 7200 flow equations (two times the product of the number of time steps and computational nodes) and over 7200 flow variables. This is beyond the capacity of existing nonlinear programming codes. The logical approach in solving a problem this large would be to reduce its size. Traditionally, the problem size has been reduced by replacing the unsteady flow equations by more simplistic relationships. In this work, a different approach is taken to alleviate the dimensionality problem. The optimum control model presented here leads to an efficient algorithm to solve the optimization problem without sacrificing the hydraulic model accuracy.

The basic idea is to solve the hydraulic constraints (Saint-Venant equations) using an unsteady flow routing model such as the U.S. National Weather Service Dynamic Wave Operational (DWOPER) model. For each iteration of the optimization model, the simulator (DWOPER) solves for the water surface elevations, h, and the flow rates, Q, given the gate operations which are the control variables (Figure 1). This allows the constraints and the objective function of the reservoir optimization problem to be viewed as a function of only the controllable variables. Since there are relatively few controllable variables, the resulting reduced problem is easier to solve. The major remaining difficulty is to compute the first partial derivatives of the objective and constraint functions with. respect to the controllable variables. Once the derivatives are determined, several efficient nonlinear optimization routines could be used to solve the reduced optimization problem.

## 3.2 THE REDUCED PROBLEM

The operations problem (Equations (1) - (6)), referred to as the general operations model (GOM) has certain characteristics that can be used in reducing it to a smaller problem. The GOM has the general structure of a discrete time control with three basic groups of constraints: those concerning the state of the system (hydraulic constraints) and those describing the system controls (bound and operation constraints). The GOM yields to an efficient solution algorithm when the state variables (discharges and water surface elevations) and the control variables (gate settings) are treated separately, in a coordinated manner. The hydraulic constraints (Equation (2)) can be solved sequentially forward in time for the water surface elevations, h and the flow rates, Q by using the DWOPER simulation model, once the gate settings, r are specified. The general optimal control approach to the real-time reservoir operation problem is shown in Figure I. Through this simulator-optimizer formulation, the problem is solved efficiently by incorporating the simulation model into a procedure when a set of a gate operations, r, (control vector) is chosen, the simulation model is run subject to the selected control vector, to solve the hydraulic constraint set, g, for the elevations and discharges (state vector). Then the objective function is evaluated, the bound constraints are checked for any violations and the procedure is repeated with an updated set of gate operations until a convergence criterion is satisfied and no bound constraints are violated.

It must be noted that the optimization is performed only on the gate settings in this procedure. The new optimization problem, called the reduced operations model (ROM) has $N_r$*T variables compared to the (2N*T+$N_r$*T) variables of the GOM, where N, T, and $N_r$ are the total number of computational points, time steps, and reservoirs, respectively. The number of constraint equations has also been reduced by the same amount, (2N*T), with the elimination of the hydraulic constraints, g. The transformation of the operations problem is shown in Figure 2, along with the problem size at each step of the transformation for an example system. The problem size for an example with 100 computational points, 5 reservoirs, and 48 time steps is drastically reduced, from over 9000 variables and constraints to 120 variables and 120 bound constraints because of the simulator-optimizer formulation.

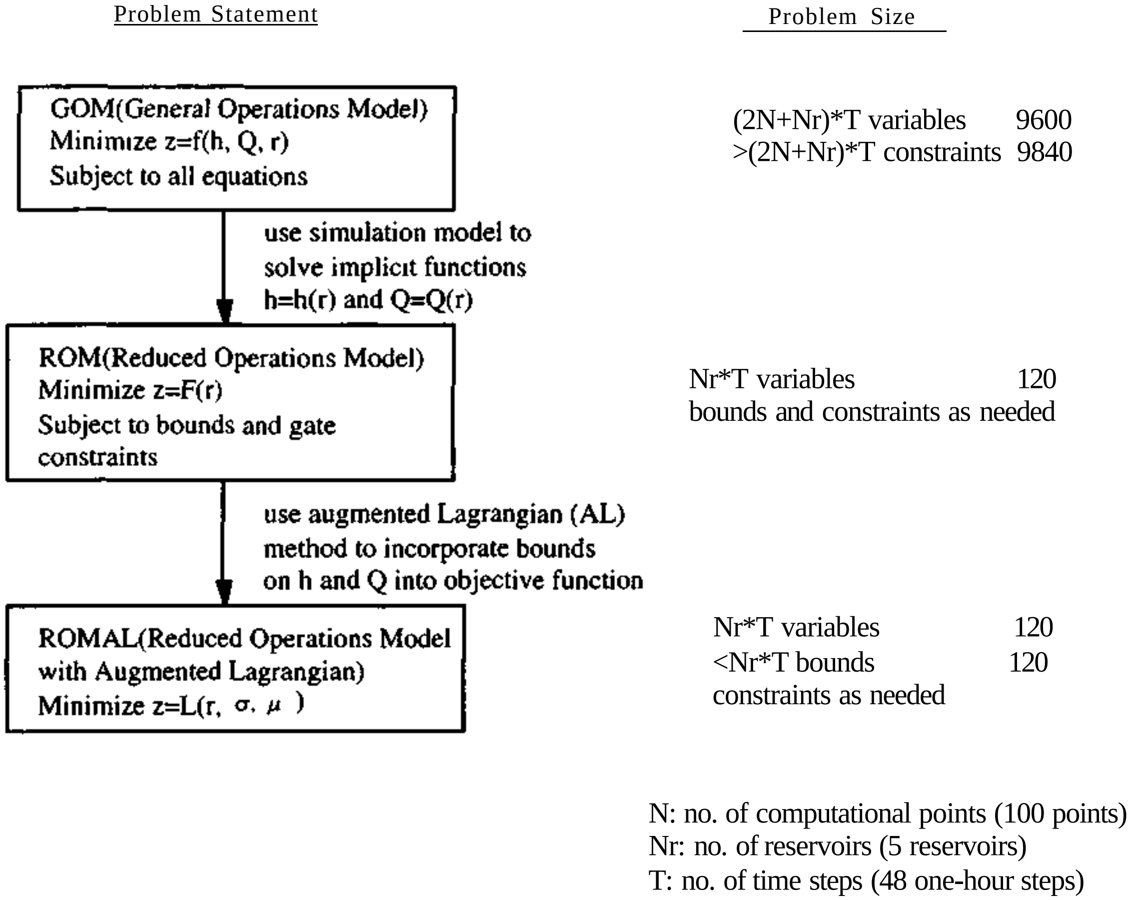

Figure 2. Transformation of operations problem

The hydraulic constraint set, g, has a special staircase banded structure that can be exploited to construct an efficient overall algorithm. The model presented herein combines the simulation model, DWOPER, and the optimization model, GRG2, within the framework of an optimum control formulation. The transformation of the original problem into the reduced one is similar to the generalized reduced gradient approach, which is also used to solve the reduced (transformed) problem.

The original problem, GOM, can be converted into a reduced problem as suggested by the implicit function theorem (Luenberger, 1973). The implicit function theorem states that if some of the problem variables can be solved in terms of the remaining variables, then a reduced problem can be devised which can be manipulated more easily. The approach is applied to the problem given by Equations (1) - (6) in such a way that the hydraulic constraints (Equation (2)) are handled separately by the simulator and the other constraints by the optimizer. The simulation model computes the values of the state variable, h and Q for given values of the control variables r and the optimization model seeks the optimal values of r that will minimize the objective function. The implicit function theorem states that h(r) and Q(r) exist if and only if the basic matrix (the Jacobian of the system of equations given by (Equation (2)) is nonsingular. This condition is always satisfied when a solution is possible, as the simulator (DWOPER), uses the same matrix for the finite-difference unsteady flow computations.

Expressing the water surface elevation and discharge as a function of the control variable, **r**,

$$\mathbf{h} = \mathbf{h}(\mathbf{r}) \tag{11}$$

and

$$\mathbf{Q} = \mathbf{Q}(\mathbf{r}), \tag{12}$$

then, the objective function, now called the reduced objective function is expressed as

Minimize $$z = \mathbf{F}(\mathbf{r}) = \mathbf{f}[\mathbf{h}(\mathbf{r}), \mathbf{Q}(\mathbf{r})]. \tag{13}$$

The objective function can be evaluated once the state variables, **h** and **Q**, are computed for the given set of control variables, **r**.

The reduced problem, which is called the reduced operations model (ROM), is now expressed by the reduced objective function, Equation (13), subject to Equation (3)-(6). The ROM is much smaller in size than the GOM with the simulator determining the implicit functions $\mathbf{h}(\mathbf{r})$ and $\mathbf{Q}(\mathbf{r})$, by performing the unsteady flow computations thus eliminating the constraint matrix g that describes the hydraulics.

In solving the ROM by a nonlinear programming algorithm, the Jacobian of the matrix $\mathbf{g}(\mathbf{h},\mathbf{Q},\mathbf{r})$ will be required as well as the gradients of the functions $\mathbf{F}(\mathbf{r})$, $\mathbf{h}(\mathbf{r})$, and $\mathbf{Q}(\mathbf{r})$, which are also called the reduced gradients. The Jacobian matrix is defined as

$$\mathbf{J}(\mathbf{h},\mathbf{Q},\mathbf{r}) = [\partial \mathbf{g}/\partial \mathrm{h}, \partial \mathbf{g}/\partial \mathbf{Q}, \partial \mathbf{g}/\partial \mathbf{r}] = [\mathbf{B},\mathbf{C}] \tag{14}$$

or

$$\mathbf{J}(\mathbf{y},\mathbf{r}) = [\partial \mathbf{g}/\partial \mathbf{y}, \partial \mathbf{g}/\partial \mathbf{r}] = [\mathbf{B},\mathbf{C}], \tag{15}$$

where y denotes the state variable **(h,Q)** and **B** is the basis matrix. The basis matrix of the optimal control problem is the same as the Jacobian matrix used in the Newton-Raphson solution procedure in the simulation model (DWOPER). Thus, the two elements of the Jacobian matrix **J** are available (with the basis **B** explicitly) computed, and terms in **C** already available) after a simulation run. The basis matrix is a banded sparse matrix with at most four nonzero elements in each row around the matrix's main diagonal.

The reduced gradients can be calculated by applying the two-step scheme used by Lasdon and Mantell (1978) and also by Wanakule et al. (1986). Letting $B_t = \partial g_t/\partial y_t$ denote the basis matrix for time step t, the following scheme is adapted for the ROM:

(i) Solve the system of finite difference equations for the last time step T to find the values of the Lagrange multiplier $II_T$

$$\Pi_T \mathbf{B}_T = \partial \mathrm{f}/\partial \mathrm{y}_T, \tag{16}$$

then solve for the $Il_t$ backward in time

$$\Pi_t B_t = \partial f/\partial y_{t'} - \Pi_{t+1}(\partial ft/\partial y_{t'}), \text{ for } t = T - 1, T - 2, \ldots,2,1. \tag{17}$$

(ii) Calculate the value of the reduced gradient

$$\partial F/\partial r_{t'} = \partial f/\partial r_{t'} - \Pi_t\,(\partial g_t/\partial r_t), \text{ for } t = 1,2,\ldots,T. \tag{18}$$

The Lagrange multipliers, IT, can be used in a sensitivity analysis as they show the effect of a small change in the corresponding term in the objective value.

### 3.3 SOLUTION OF REDUCED PROBLEM

The reduced problem, ROM, can be solved by a nonlinear programming algorithm. As the reduced problem still contains bound-type constraints on the state variables h and Q, the algorithm adopted should have provisions to assure the feasibility of the simulation model solutions for the state variables. An augmented Lagrangian (AL) algorithm that incorporates the bounds on the state variables into the objective function is used for this purpose. An application of this type can be found in Hsin (1981) where the bounds on the state variables are violated until the solution converges. The reduced problem with AL terms is

$$\min L_A\,(r, \mu, \sigma) = F(\mathbf{r}) + 0.5\,\textstyle\sum_i \sigma_i \min\,[0, (b_i - \mu_i/\sigma_i)]^2 + 0.5 \sum_i \mu_i^{\,2}/\sigma_i\,, \tag{19}$$

where i denotes the constant set which is formed of the bounds on the state variables, i.e. the water surface elevations and discharges, and $\sigma_1$, and $\mu_1$ are, respectively, the penalty weight and the Lagrange multiplier associated with the ith bound. The term $b_1$ is the violation term defined as

$$b_i = \min\left[\left(y_i - \underline{y}_i\right),\ \left(\bar{y}_i - y_i\right)\right] \tag{20}$$

The constraints of the new problem are the bounds on the control variables and the operating constraints.

A reduced gradient approach is adopted to solve the reduced problem with AL terms. This new problem, which will be referred to as the reduced operations model with augmented Lagrangian (ROMAL) can be expressed as

$$\text{Minimize } L_A\,(\mathbf{r},\sigma,\mu) \tag{21}$$

subject to Equations (5) and (6).

The solution to this is a two-step procedure with an inner and an outer problem that must be solved. The objective function of this inner-outer problem combination is

$$\min_{\sigma,\mu}\left[\min_{\mathbf{r}\in S} L_A\left(\mathbf{r},\sigma,\mu\right)\right], \tag{22}$$

where r is selected from S, the set of feasible gate settings defined by Equation (5). The inner problem involves the optimization of the augmented Lagrangian objective by using GRG2 to determine optimal values of r while keeping μ and σ fixed. Then the outer problem is iterated by updating the values of μ and σ for the next solution run of the inner problem. The overall optimization is attained when μ and σ need no further updating, within a given tolerance interval. The updating formula used for μ is

$$\mu_i^{(k+1)} = \begin{cases} \mu_i^{(k)} - \sigma_i b_i, & \text{if } c_i < \mu_i / \sigma_i, \\ 0 & \text{otherwise,} \end{cases} \tag{23}$$

where k is the number of the current iteration. The value of σ is normally adjusted once during early iterations and then kept constant (Powell, 1978).

In applying the generalized reduced gradient approach to the ROMAL formulation the gradient of the new objective function is evaluated as

$$\nabla L_A(\mathbf{r}, \mu, \sigma) = \partial L_A / \partial r_i - \pi(\partial g / \partial r_i), \quad \text{for all } i = 1 \text{ to } 2N. \tag{24}$$

The solution of the inner problem, i.e. finding the optimal r for fixed μ and σ is accomplished by GRG2(Lasdon and Waren, 1983), which is based on the generalized reduced gradient technique. The basic steps of the optimal control algorithm are shown in Figure 3.

## 4. Problem Identification: Sediment Control

Sedimentation occurring in reservoirs and rivers are always associated with floods being stored or conveyed. In rivers, sedimentation, which refers to either deposition or scouring of a river bed, is caused principally by the passage of flood events. Continued sedimentation in the river over time physically diminishes the channel capability to contain flows posing a major threat to the economics of the system. For instance, the rise of channel bed profile due to aggradation reduces the conveyance capacity of the channel. As aggradation processes become chronic, flood encroachment into the flood plain follows leading to property damages, probable loss of lives, and endangerment in the means of livelihood of the community.

Scouring (or degradation) on the other hand, threatens in-stream and bank structures like flood levees, bridge piers, as well as underground utility lines. Either way, if said sedimentation processes are left unchecked or uncontrolled in the system, there could be serious economic consequences. Interestingly, under a given flood event or series of flood events, both aggradation and degradation phenomena occur side-by-side across the channel and simultaneously in the same river. Any bed change, however, as a result of sediment movements due to floods, is a sign of channel instability, and efforts must be pursued to minimize such instability in the channel. Since flood events are known to be the principal instigator of bed mobility, focus must be made on how such flood events could be altered or modified into a series of events that permits the least bed changes in the river.

There has been a minimal effort in the past to develop an optimization procedure to determine the optimal control of sedimentation occurring in alluvial rivers. On the other hand, there has been major concentration in modeling efforts in the last two decades to develop simulation codes to predict the bed material movement in alluvial streams. Since the development of HEC-6 by the Hydrologic Engineering Center of the U. S. Army Corps of Engineers (U. S. Army Corps of Engineers, 1977), over forty-seven (47) other sedimentation codes have been developed.

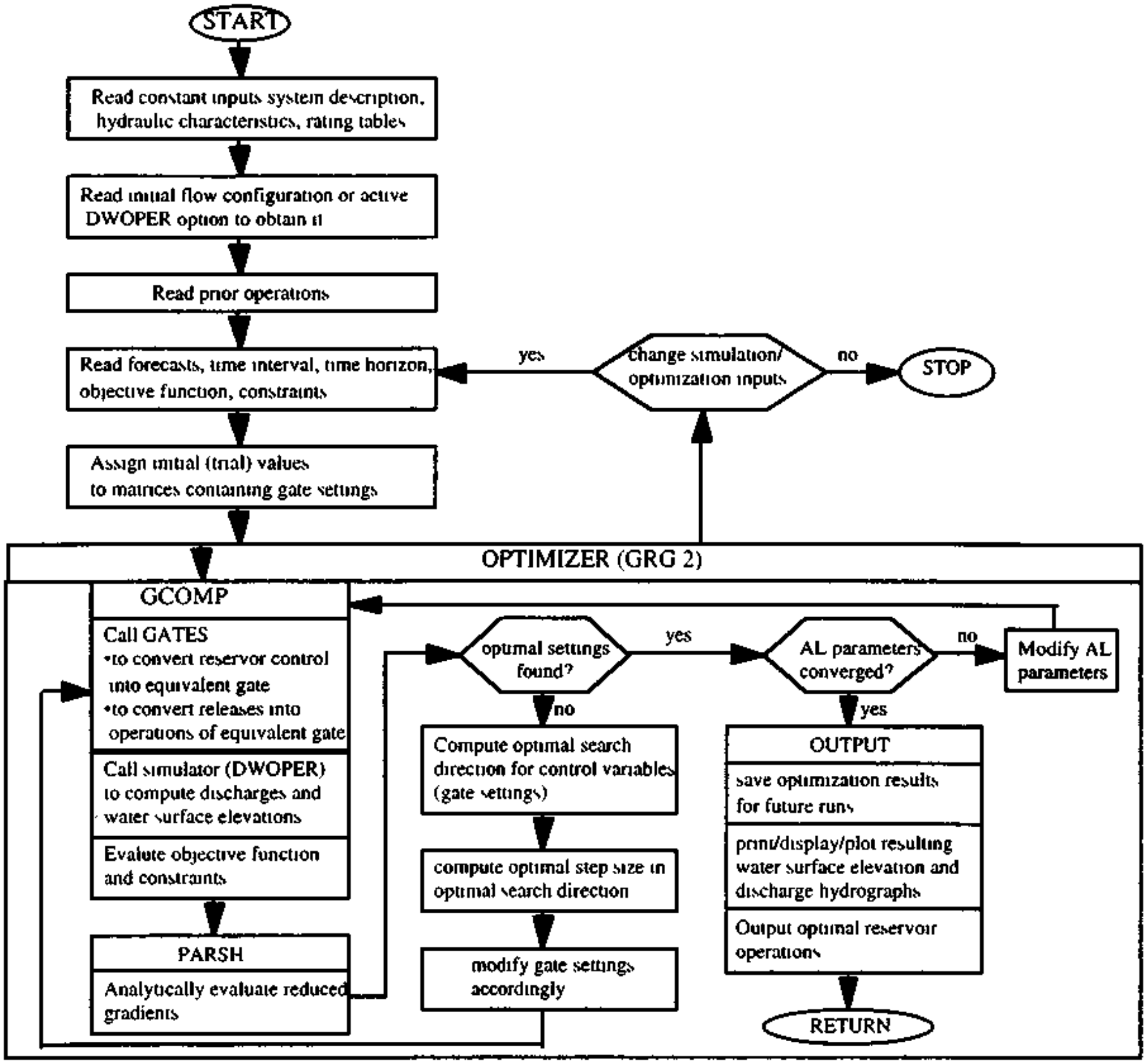

Figure 3. Block of optimal control algorithm.

A simple system described by the interaction of a reservoir and a river as shown in Figure 4 is used to describe the mathematical model. More complex system with multiple reservoirs and downstream river channels can be analyzed by the new methodology. Since the mobility and transport of sediments in the downstream river are directly associated with the reservoir releases, the determination of the optimal releases are critical in the analysis because they have direct bearing on the hydraulics and sedimentation processes in the river downstream. The optimization model that addresses such sedimentation control problems is expressed as follows:

**Minimize** ***[the sum of aggradation and degradation depths at key locations along the river reach]***

**Subject to:** ***the system's governing physical equations;***
***the boundary conditions;***
***the operating, budgetary, and design constraints.***

Carriaga and Mays (1995) developed nonlinear programming models to determine reservoir releases for sediment control. Uncertainties were also considered on some sediment transport parameters identified - like the sediment load and mean grain size - leading to the formulation of three chance-constrained models. The optimization problem was also formulated in a multi-stage decision process and solved using the conventional dynamic programming (DP) methodology. In this DP problem, the approach was extended to discrete differential dynamic programming (DDDP) approach. The optimization problem was also formulated and solved using a simplified differential dynamic programming (DDP) methodology.

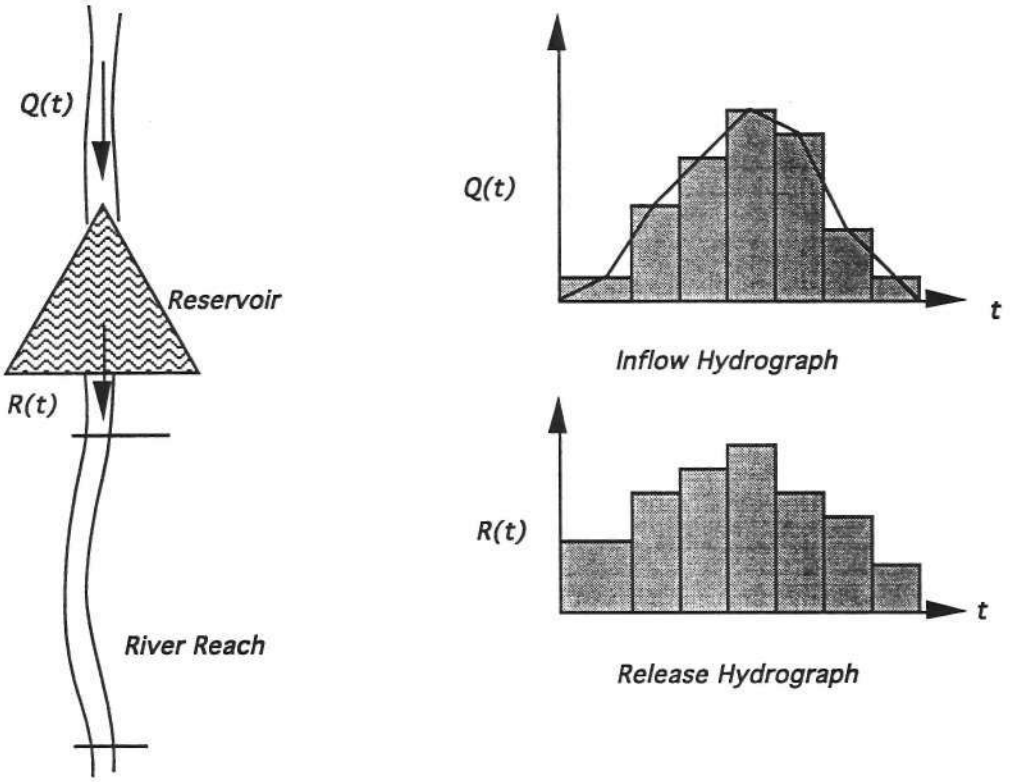

Figure 4. Sketch of the system for the sedimentation problem

## 5 . Problem Formulation: Sediment Control

### 5.1 OPTIMIZATION PROBLEM

The optimization problem is a discrete-time optimal control problem with the following form:

$$\text{Min } Z(\mathbf{u}) = \sum_t f_t(\mathbf{x}_t, \mathbf{u}_t, t) = \sum_t (\mathbf{a}_t + \mathbf{b}_t) \qquad t=1,2,\ldots,T \qquad (25)$$

$$\text{subject to:} \qquad \mathbf{x}_{t+1} = \mathbf{g}_t(\mathbf{x}_t, \mathbf{u}_t, t) \qquad t = 1,2,\ldots,T\text{-}1 \quad (26)$$

$$\mathbf{h}_t(\mathbf{x}_t, \mathbf{u}_t, t) \leq 0 \qquad t = 1,2,\ldots,T \qquad (27)$$

where Z(**u**) is the objective function (sum of aggradation and degradation depths in downstream river) or the overall cost associated with the control policy (reservoir releases), **u**; t is the simulation time step; T is the total number of simulation time steps; $\mathbf{x}_t$ is the state vector (reservoir storage level and downstream river bed elevations) at the starting time t (having dimension I); $\mathbf{u}_t$ is the control vector during time t (having dimension m); $\mathbf{f}_t$ is the cost or loss function during time step t, given $\mathbf{x}_t$, $\mathbf{u}_t$, and t; $\mathbf{a}_t$ is the aggradation depth at time t (having dimension I-1); $\mathbf{b}_t$ is the degradation depth at time t (having dimension I-1); $\mathbf{g}_t$ is the transition equation or the governing equation for the simulation model (reservoir operation model and sediment transport routing model), given $\mathbf{x}_t$, $\mathbf{u}_t$, and t; and $\mathbf{h}_t$ is the set of constraints or boundary conditions on the control and state vectors.

The loss function, $\mathbf{f}_t(\mathbf{x}_t,\mathbf{u}_t,t)$, defined by equation (25), can be approximated by using the following quadratic form,

$$f_t(\mathbf{x}_t, \mathbf{u}_t, t) = \frac{1}{2}\delta_x^T \mathbf{A}_t \delta_x + \delta_x^T \mathbf{B}_t \delta_u + \frac{1}{2}\delta_u^T \mathbf{C}_t \delta_u + \mathbf{D}_t \delta_u + \mathbf{E}_t \delta_x \quad \text{for } t=1,2,\ldots,T \qquad (28)$$

where $\mathbf{A}_t$, $\mathbf{B}_t$, $\mathbf{C}_t$, $\mathbf{D}_t$, and $\mathbf{E}_t$, are the parameters at time period t determined from the first- and second-order derivatives of the loss function, $\mathbf{f}_t(\mathbf{x}_t,\mathbf{u}_t,t)$, and the state transition function, $\mathbf{g}_t(\mathbf{x}_t,\mathbf{u}_t,t)$; $\delta_x$ and $\delta_u$ are the increment changes between the current and the previous values of the state **x** and control **u**. The DDP concept is to minimize the quadratic approximation as presented in equation (28). Estimation of parameters $A_t$, $B_t$, $C_t$, $D_t$, and $\mathbf{E}_t$ in the work of Mayne (1966) was based on an unconstrained problem. A reduced problem is, therefore, essential in order to use the original formulation for the above parameters.

The DDP algorithm requires an initial state vector (reservoir storage and bed elevation at time t = 1) designated as **x**(l) and a nominal control policy, $\mathbf{u}^c$, expressed as,

$$\mathbf{u}^c = (\mathbf{u}^c(1), \mathbf{u}^c(2), \ldots, \mathbf{u}^c(T)) \qquad (29)$$

From these initial values, $\mathbf{x}^c$ could be determined using the transition equation (simulator) in (26) expressed as follows:

$$\mathbf{x}^c = (\mathbf{x}^c(1), \mathbf{x}^c(2), \ldots, \mathbf{x}^c(T+1)) \qquad (30)$$

The state transition functions generally expressed by equation (26) for the system defined include: (i) the hydrologic routing for the reservoir described by the mass-balance equation; and, (ii) the hydraulic and sediment routing for the alluvial river performed by the HEC-6 code. In addition to the transition equations are the bound constraints for the control and state variables plus the boundary condition for the state variable.

The system model is described basically by the relations involved associated with the reservoir operation and the river hydraulics and sedimentation. Before presenting the governing equations involved, the state and control variables must be defined first. The state variable, **x**, represents the storage state, S, of the reservoir and the bed elevations, E, at various sections of the river, viz.:

$$x_t = \begin{bmatrix} \text{Bed Elevation, E} \\ \text{Storage State, S} \end{bmatrix} = \begin{bmatrix} x_{i,,t};\ i = ..., I-1 \\ x_{I,t} \end{bmatrix} \qquad \text{for } t=1,2,...,T \qquad (31)$$

Thus, the state of the reservoir-river system at the start of any period t can be described by the vector of river bed elevations and storage state. The control variable, **u**, represents the reservoir release expressed as,

$$u_t = [\text{Reservoir Release, R}] \qquad \text{for } t=1,2,...,T \qquad (32)$$

## 5.2 RESERVOIR OPERATION CONSTRAINTS

The following equations for the reservoir operation include the mass balance equation (33), the release and storage state bounds (34 and 35), and the boundary condition (36) that defines the end-of-the-operation storage state of the reservoir,

$$S_{t+1} = S_t + Q_t - R_t - L_t + P_t - D_t \qquad t = 1,2, ..., T \qquad (33)$$

$$R_{min,t} \leq R_t \leq R_{max,t} \qquad t = 1,2, ..., T \qquad (34)$$

$$S_{min,t} \leq S_t \leq S_{max,\,t} \qquad t = 1,2, ...,T \qquad (35)$$

$$S_T = S_{max,T} \qquad (36)$$

where $S_t$ and $S_{t+1}$ are the beginning and ending storage states, respectively, of the reservoir during time (t); $Q_t$ is the inflow; $R_t$ is the release; $L_t$ is the seepage flow; $P_t$ is the excess rainfall/precipitation; $D_t$ is the evaporation loss; $R_{min,t,}$ and $R_{max,t,}$ are the minimum and maximum releases, respectively, at time period t; $S_{min,tt}$ and $S_{max,t}$ are the minimum and maximum storages of the reservoir at time period t; and $S_{max,T}$ is the target storage state at the end of reservoir operation.

## 5.3 RIVER HYDRAULICS AND SEDIMENTATION CONSTRAINTS

The HEC-6 code (U. S. Army Corps of Engineers, 1991) is used to solve the hydraulic and sediment transport routing constraints each time the optimizer requires these solutions. The one-dimensional physical governing equations are the conservation of mass and energy, and some established empirical relations. The steady-state flow continuity is expressed as,

$$\frac{\partial R_t}{\partial l_c} - q_t = 0 \qquad t=1,2,3,\ldots,T \tag{37}$$

where $R_t$ is the release discharge from the reservoir; $q_t$ is the lateral inflow rate per unit length; and, $l_c$ is the distance along the channel. The energy equation is expressed as,

$$E_{i+1,t} + d_{i+1,t} + \frac{\alpha_{i+1,t} V_{i+1,t}^2}{2g} = E_{i,t} + d_{i,t} + \frac{\alpha_{i,t} V_{i,t}^2}{2g} + h_{i,t} \qquad t = 1,2,\ldots,T;\ i = 1,2,\ldots,I-1 \tag{38}$$

where $E_{i,t}$ is the bed elevation at station (i) and at time (t) measured from a designated reference datum; $d_{i,t}$ is the depth of flow at station (i) during time (t); $\alpha_t$ is the energy distribution coefficient associated with station (i) and at time (t); $h_{i,t}$ is the energy loss from station (i+1) to station (i) during time (t); $V_{i,t}$ is the flow velocity at station (i) during time (t); and, g is the gravitational constant. The sediment continuity (routing) equation (Exner equation) is expressed as,

$$\frac{\partial G_{i,t}}{\partial l_c} + \gamma_s(1-\eta)W_i \frac{\partial E_{i,t}}{\partial t} - q_{s_t} = 0 \qquad I=1,2,\ldots,\ I-1 \text{ and } t=1,2,\ldots,T \tag{39}$$

where $G_{i,t}$ is the sediment discharge at section (i) and at time period (t); $qs_t$ is the lateral or local sediment input during time (t) from bank or tributaries per unit length; $\gamma_s$ is the specific weight of bed material; $\eta$ is the porosity of the bed sediment material; and $W_i$ is the average width of the movable bed between sections (i) and (i+1). The sediment transport equation is expressed in general form as,

$$G_{i,t} = \Phi_{i,t}(R,C_w,W,d,r,V,S_e,f,\nu,\rho,\rho_s,\mu_g,\sigma_g,\omega,g,\lambda,S_s,S_c,f_s,C_T,C_F) \tag{40}$$

where the parameters inside the parenthesis are the variables that define the sediment load $G_{i,t;}$ $\mathbf{\Phi}_{i,t}$ indicates that the parameters enumerated vary in time (t) and in space (i); $C_w$ is the concentration of wash load; r is the hydraulic radius of the channel; $S_e$ is the energy gradient; f is the Darcy-Weisbach friction factor; V is the fluid kinematic viscosity; $\rho$ is the fluid density; $\rho_s$ is the particle density; $\mu_g$ is the geometric mean size of the bed material sediments; $\sigma_g$ is the geometric standard deviation of the bed material; $\omega$ is the mean settling velocity of the sediment particle; Sp is the plan-form geometry; $\lambda$ is the apparent dynamic viscosity; $S_s$ is the shape factor of the sediment particles; $S_c$ is the shape factor of the channel reach; $f_s$ is the seepage force in the channel bed; $C_T$ is the concentration of bed-material discharge; and, $C_F$ is the fine material concentration. Equations (34), (35), and (36) cause the problem to be constrained. In order to follow the algorithm proposed by Yakowitz and Rutherford (1984), the constrained optimization problem must be converted into an unconstrained format using a penalty function method.

## 6. Solution Procedure: Sediment Control

### 6.1 PENALTY FUNCTION METHOD

A penalty function method is used for the purpose of converting a constrained problem into an unconstrained problem by adding to the objective function a term that prescribes a high cost (penalty) for violation of the constraint. Since equations (34), (35), and (36) cause the problem to be constrained, a reduced problem that fits the original DDP problem must be derived. The procedure would result in a reduced problem expressed as,

$$\underset{\mathbf{u}}{\mathrm{Min}}\, Z = \sum_t \mathbf{F}_t(\mathbf{x}_t, \mathbf{u}_t, t) = \sum_t \mathbf{f}_t(\mathbf{x}_t, \mathbf{u}_t, t) + \sum_t \phi_t \mathbf{Y}_t(\mathbf{x}_t, \mathbf{u}_t) \tag{41}$$

subject to the transition equations defined by the mass-balance equation (i.e., equation (30)) and the governing equations for the river hydraulics and sedimentation (i.e., equations (37), (38), (39), and (40)) to be solved by the HEC-6 code. In equation (41), $\mathbf{f}_t(\mathbf{x}_t,\mathbf{u}_t,t)$ is the original objective function of the constrained DDP problem; $\phi_t$ is the penalty weight (or cost) associated with the penalty function $\mathbf{Y}_t(\mathbf{x}_t,\mathbf{u}_t)$; and $\mathbf{F}_t(\mathbf{x}_t,\mathbf{u}_t,t)$ is the objective function of the reduced problem during time period t.

The hyperbolic penalty function introduced by Lin (1990) is used for the constrained sedimentation control problem because of its analytical characteristics as described by Culver and Shoemaker (1992 and 1993) in their groundwater remediation studies.

## 6.2 EVALUATION OF DERIVATIVES

The DDP method requires the computation of the first- and second-order derivatives of the objective function in equation (17) defined as,

$$\frac{\partial \mathbf{F}}{\partial \mathbf{x}}, \frac{\partial \mathbf{F}}{\partial \mathbf{u}}, \frac{\partial^2 \mathbf{F}}{\partial \mathbf{x}^2}, \frac{\partial^2 \mathbf{F}}{\partial \mathbf{u}^2}, \text{ and } \frac{\partial^2 \mathbf{F}}{\partial \mathbf{x}\partial \mathbf{u}} \tag{42}$$

and the derivatives of the state transition equations, expressed as,

$$\frac{\partial \mathbf{g}}{\partial \mathbf{x}}, \frac{\partial \mathbf{g}}{\partial \mathbf{u}}, \frac{\partial^2 \mathbf{g}}{\partial \mathbf{x}^2}, \frac{\partial^2 \mathbf{g}}{\partial \mathbf{u}^2}, \text{ and } \frac{\partial^2 \mathbf{g}}{\partial \mathbf{x}\partial \mathbf{u}} \tag{43}$$

For the evaluation of the above derivatives (i.e. equations (42) and (43)), a combination of numerical and analytical approaches was used. The derivatives of the state transition equation for the river model which is solved by the HEC-6 code represented by equations (37), (38), (39) and (40) and the original objective function, $\mathbf{f}_t(\mathbf{x}_t,\mathbf{u}_t,t)$ in equation (25), were evaluated numerically by forward-difference scheme.

The derivatives of the mass-balance equation for the reservoir defined by equation (33) and the penalty terms associated with the violation of the bound constraints (in equations (34) and (35)) and boundary condition (in equation (36)) were evaluated analytically. This is because the penalty function generally represented by $\mathbf{Y}_t(\mathbf{x}_t,\mathbf{u}_t)$ which is a term in the objective function of the reduced problem, is explicitly defined. Thus, the gradients and the Hessian matrices could be evaluated from the function expressions. However, the gradient and Hessian matrices of the original objective function, $\mathbf{f}_t(\mathbf{x}_t,\mathbf{u}_t,t)$, which defines the summation of bed changes (i.e., $\mathbf{a}_t + \mathbf{b}_t$) along the river at time period t, is solved by forward-difference scheme.

The Jacobian matrices and the second derivatives of the state transition equations, defined by the mass-balance and the bed change equations, generally expressed as, $gt(x_t,u_t,t)$, are evaluated analytically and numerically. Since the mass-balance equation for the reservoir model is defined explicitly, the Jacobian matrix and the second derivatives are evaluated analytically. For the bed change equation which is solved by the HEC-6 code, the forward difference-scheme is used to numerically evaluate the Jacobian and the second derivatives.

## 6.3 DDP ALGORITHM

The interfacing approach of the optimizer and simulation models is simply represented by Figure 5. However, Figure 6 which was modified from the flow chart developed by Culver and Shoemaker (1992) describes in detail the steps involved in the solution approach. As presented in Figure 6 an initial or 'nominal' control (or release) policy must be specified for the first simulation in order to calculate the current state (or condition) of the system, $\mathbf{x}_t$, in each time period t, and the value of the objective function, Z [Steps (0) and (1)].

Each iteration could be divided into two parts, the backward and forward sweeps. In the backward sweep [Step (2)], an update to the current control policy is calculated through a series of matrix computations that involve derivative information. In the forward sweep [Step (3)], the transition equations (or simulation models) are used to recalculate the state of the system and the value of the objective function using the updated control policy. The two-part iteration [Steps (2) and (3)] continues until the calculated control policy converges.

The optimal control approach presented eliminates simplification of the problem required by most optimization techniques. The solution approach has effectively interfaced the simulation models with an optimization technique without simplication involved in the formulation. The hyperbolic function as used in the solution approach has forced the solution into the feasible region although the nominal policy initially violates the release and the state bounds. The performance of the hyperbolic penalty function for this problem confirmed the findings of Lin (1990) and Culver and Shoemaker (1992, 1993).

There is no guarantee of global optimality; however, optimal solution can be approached through the use of various initial control policies. The apparent success of the application to a single reservoir-river system can be extended to solve a reservoir-river network. Other possible case study scenarios to be investigated include the modeling of the stations at or around: (i) the sites of active mining activities; (ii) tributaries entering the river system; (ii) the sites where fine sediment aggregates are found; and, (iv) locations of crossing utility lines.

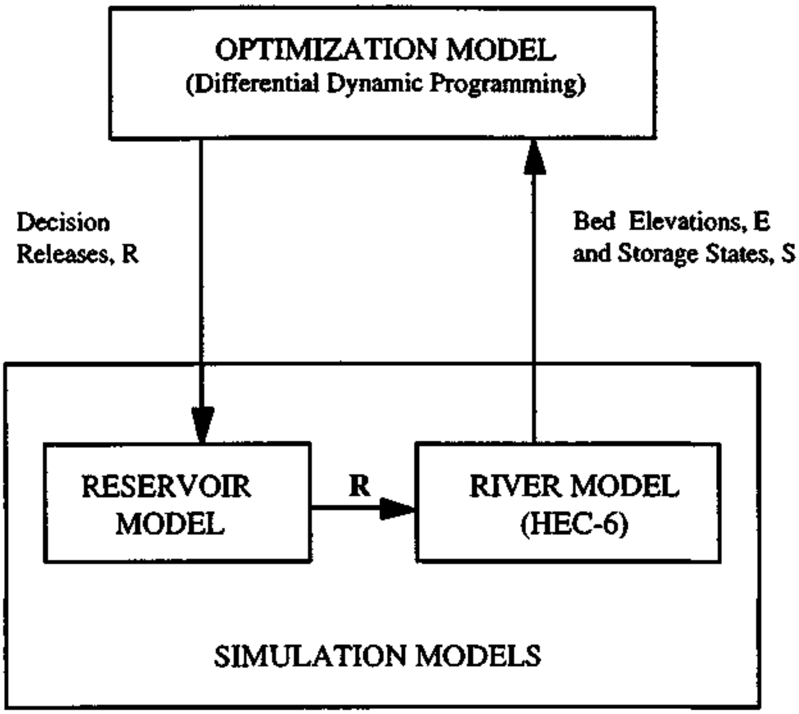

Figure 5. Schematic of the optimal control approach for the sedimentation problem

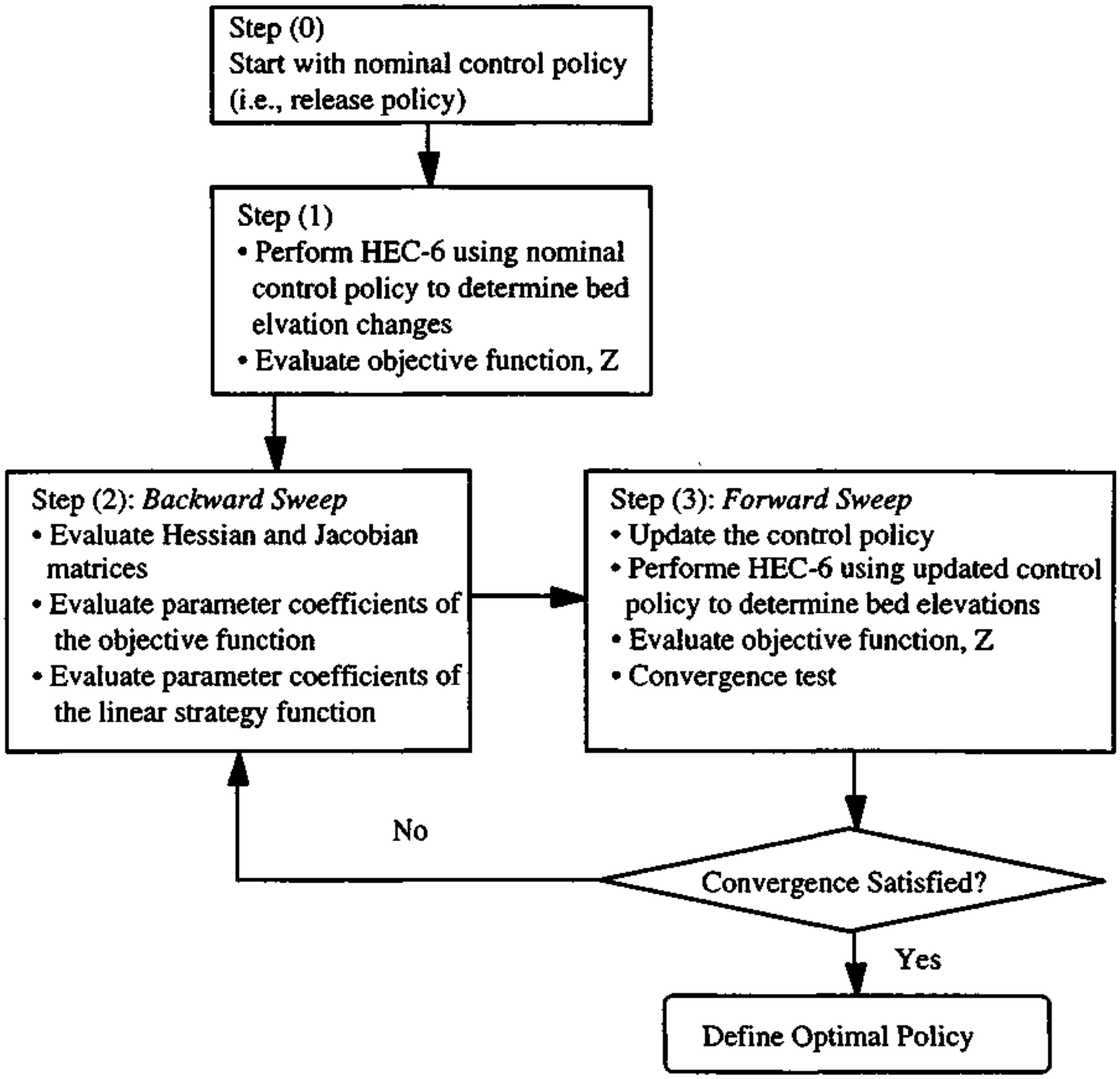

Figure 6. Diagram of the optimization algorithm for the sedimentation control problem

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# Corrected Page (Page 81) of the First Proceedings of the Article by Miller Entitled *Flood Management —The TVA Experience*

## Key Program Activities

TVA has met its responsibilities to reduce flood damages in the Tennessee Valley through 5 primary activities:

- Development and application of flood risk information
- Floodplain management technical assistance
- Flood hazard mitigation planning and projects
- Public education and awareness
- Stewardship of TVA lands and facilities

**Flood Risk Information.** Accurate information on the magnitude, extent, and likelihood of flooding at particular locations is a vital key to effective flood management. Throughout its history, TVA has been involved in the collection, analysis, and interpretation of flood risk information. Since the 1950's, TVA has produced approximately 600 flood reports and flood insurance studies (in conjunction with the Federal Emergency Management Agency) for specific communities, as well as for the planning of TVA facilities. These reports include detailed information and maps on flood history, flood profiles, and flooded areas for a range of flood magnitudes, including the 1 percent and 0.2 percent chance floods ("100- and 500- year" floods, respectively). This quantitative flood data has provided the technical basis for the enactment and enforcement of community floodplain regulations and for the exploration of alternative solutions to local flood problems. Additionally, TVA has historically responded to over 1000 requests a year for site-specific information for use by local officials, building professionals, and private citizens to assist in planning and designing large projects (roads, bridges, government facilities, shopping centers, etc.) and building or purchasing homes (TVA, 1983).

TVA utilizes a computerized Flood Information Management System (FTMS) to assist in the storage and retrieval of accurate, up-to-date flood information. FIMS includes data on over 6000 stream miles (9700 km) in the Tennessee Valley, which includes the majority of the Valley streams responsible for causing major flood damages. FIMS stores information such as computed profiles, historic floods, stream gage locations, flood insurance studies, flood damage reduction studies, cross-section data, dam failure profiles, and bibliographic data.

**Floodplain Management Technical Assistance.** Historically, a key component of TVA's flood risk reduction program has been the provision of technical assistance to floodprone communities across the Valley. A broad range of assistance has been provided to community officials, commercial interests, and private citizens, including: interpretation and application of flood risk information; guidance in the administration and enforcement of local and NFIP floodplain regulations; evaluations of the potential effects of proposed projects on flood risk; identification and implementation of mitigation options to address specific flooding problems; information on the flood risk of an existing or proposed home or business site; and educational workshops and seminars. The key has been to integrate floodplain management into the legislative, administrative, economic, and judicial framework and constraints present at the local level. The

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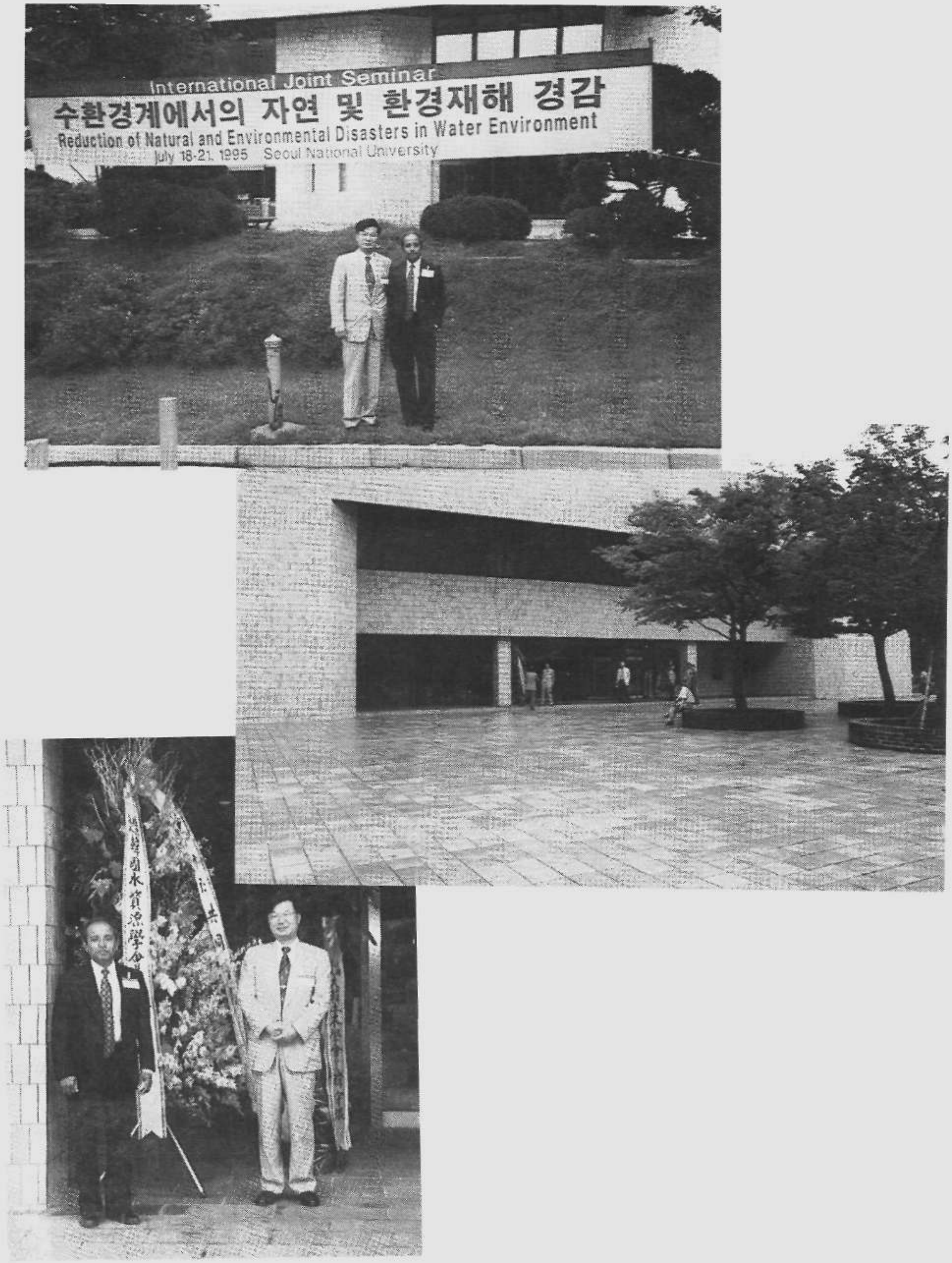
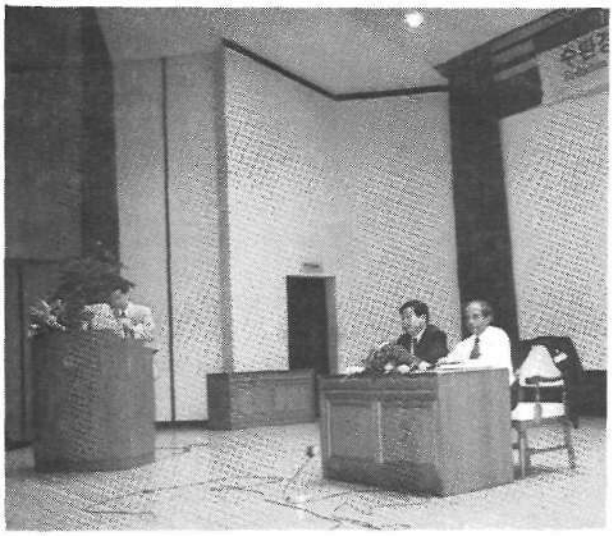
# Pictorial Overview of the Seminar

# Workshop Site:
# Seoul National University Cultural Center



# Opening Session



# Podium Presentations

# More Podium Presentations

# Field Trip

# The Han River

# Other Activities

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