

Mathematical Modeling in Irrigation and Flood Management

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Abstract The economy of Bangladesh predominantly depends upon agriculture. About 70 % of the population is dependent on agriculture. In the next 25 years, the population of the country is expected to increase by 40 %. This increase of population will increase the food demand of about 29 %. The changes in the agricultural area have important implications for food production as the reduced area implies an increase in cropping intensity on the remaining land. Planned utilization and efficient management of water resources for irrigation is one of the most crucial elements for achieving desired changes in agricultural production which calls for application of an integrated hydrological modeling tool. Most of the irrigation projects in Bangladesh are implemented 30–40 years ago. Nowadays, lots of infrastructural changes have been occurred. The irrigation canal command area conceived earlier has been changed, and many drainage routes have been blocked. As the hydraulic events are dynamic and changes occur every year, it is very difficult to provide solution of these complex situations for the normal prevailing method without modeling technique. Modeling technique can provide sustainable solution considering impacts of different scenarios for irrigation, flood, and drainage improvements. This paper highlights the case study of Teesta Barrage Project (TBP) Phase-I. This case study shows how the state-of-the-art technologies could be used for irrigation and flood management in irrigation project. The application of modeling tool in TBP phase-I opens up a new dimension of models as a very useful tool in Command Area Development Project. After the completion of TBP Phase-I, the project experienced water-logging problems at several locations coupled with

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the fact that the potential irrigable areas did not get irrigation. Under CAD project of TBP phase-I, IWM carried out detailed hydraulic model study for the irrigation and drainage systems in an integrated way to find remedial measures. A comprehensive data collection program including topographic survey has been carried out in connection with this study. Updated topographic map has been developed, and command area has been redelineated based on this map. A number of problems were identified, and corresponding solutions have been established based on the study. Most of the suggestions related to irrigation and drainage have already been implemented, and the results are found very much satisfactory. These are definitely positive indications of the successful utilization of modeling tool for better management of water resources projects. Computer-based interactive information system (IIS) for the whole project area and decision support system (DSS) for a pilot area have been developed for better management of the project.

Keywords Command area development · Irrigation · Drainage · Groundwater · Hydraulic modeling technique · Scenario

1 Introduction

The economy of Bangladesh predominantly depends upon agriculture. In Bangladesh, potential cultivable area is about 8.3 Million hectares (Mha) of which 7.7 Mha are considered irrigable as per NWMP [1]. About 70 % of the population is dependent on agriculture. In the next 25 years, the population of the country is expected to increase by 40 %. The agricultural land will be reduced by about 4.4 % (Technical Report # 7, National Water Management Plan [1]. This increase of population will increase the rice demand in the next 25 years about 29 %. The changes in the agricultural area have important implications for food production as the reduced area implies an increase in cropping intensity on the remaining land.

Development of agriculture through irrigation, drainage, and flood control has got priority in the national development plans to attain food adequacy. The central strategy for the water resources development would be expansion coverage and proper utilization of water resources conjunctively to increase area under effective cultivation for the improvement in agricultural productivity [2]. Water management for the following issues needs to be considered to attain food adequacy.

- Increase irrigation coverage up to the potential;
- Achieve full potential benefit of irrigation;
- Minimize crop damage by flooding;
- Minimize crop damage by drought forecasting;
- Crop diversification based on available resource; and
- Increase cropping intensity.

In Bangladesh, total irrigated area has been estimated to be 4.11 Mha as per BADC [3] and NWMP [1] and the remaining 3.6 Mha area is available for irrigation. With existing easily accessible water resources, a major source of irrigation is groundwater available in the northern parts of the country, major portion of which is already now being used. About 2.7 Mha areas are solely dependent on surface water for irrigation. Moreover, there is scope of diversifying crops with irrigation, which may accrue more benefit [4].

Planned utilization and efficient management of water resources for irrigation is one of the most crucial elements for achieving desired changes in agricultural production which calls for the application of an integrated hydrological modeling tool. Most of the irrigation projects in Bangladesh were implemented 30–40 years ago when planning, and the design of the projects had been done based on the then available conventional methods. Those methods were based on many assumptions and limitations where analysis of project was not possible in a holistic approach considering all the project parameters at a time. Nowadays, lots of infrastructural changes have been occurred. The irrigation canal command area conceived earlier has been changed, and many drainage routes have been blocked. As the hydraulic events are dynamic and changes occur every year, it is very difficult to provide solution of these complex situations for the normal prevailing method without modeling technique. Modeling is such an approach by which it is possible to investigate the whole project in a holistic way considering all the project parameters at a time. In this approach, the impact of different option scenario is also possible to visualize beforehand. As such, the modeling technique can provide sustainable solution in water management problems for irrigation and drainage improvement.

IWM began its journey in 1990 with the commitment to provide scientifically based analytical tools, models, and decision support services that would help planners, designers, engineers, and scientists to understand, describe and manage the complex water resources and ecosystem which would ultimately contribute to:

- Minimize losses of lives, crops, and properties;
- Enhance and protect quality of life; and
- Sustainable economic development toward poverty alleviation.

Since 1996 IWM has been providing modeling support in irrigation, drainage, and flood management. It has been observed that in many irrigation and drainage projects, benefits have been achieved after the implementation of IWM's suggestions. This credit also goes to the design cell of BWDB and project-level implementation. The hydrological modeling has become now a proven tool in the water resources management aspects such as irrigation, drainage, and flood management.

The committed role of IWM and benefit using the modeling tools for irrigation management of command area development project and flood management projects have been discussed in this paper.

1.1 Application of Mathematical Model in Command Area Development Project

1. Teesta Barrage Project Phase-I

The Teesta Barrage Project (TBP) has been planned to provide primarily supplementary irrigation for transplanted Aman. In addition, irrigation to Rabi and Aus crops may also be possible in a limited scale depending on the availability of surface water resources. The Phase-I of TBP has been completed in June 1998 covering a gross benefited area of 154,250 ha and a net irrigable area of 111,406 ha. Study area is shown in Fig. 1.

The main objective of this project is to increase the productivity of the land by achieving the full potential benefit of irrigation in the project area. But after the completion of TBP Phase-I, the project experienced water-logging problems at several locations coupled with the fact that the potential irrigable areas did not get irrigation. The project authority tried their best at micro-level to solve the problems. They dealt discretely with individual problems using available conventional methods. But as they had no such tool like mathematical model to investigate the whole project in an integrated way, they could not find the complete solution. Solution of one problematic area would create new problem to another area, and as such problems were persistent [5].

A. To attain the objectives of TBP by overcoming the problems, mathematical model study was identified to review and evaluate the performance of the existing irrigation and drainage systems thus to find out problems and suggest remedial measures. IWM developed mathematical models of the irrigation and drainage systems by incorporating all the rivers, canals, road networks, and hydraulic structures within the project area, topographic and hydro-meteorological data, cropping pattern, crop water requirements, and all other project elements necessary to describe the real situation.

IWM carried out a comprehensive modeling study of the Command Area of TBP Phase-I. The study includes seven major components, which are as follows.

- Survey and mapping;
- Irrigation study;
- Drainage study;
- Groundwater study [6];
- Development of a decision support system (DSS) for a pilot area;
- Development of interactive information system (IIS); and
- Development of structure operation rule curves.

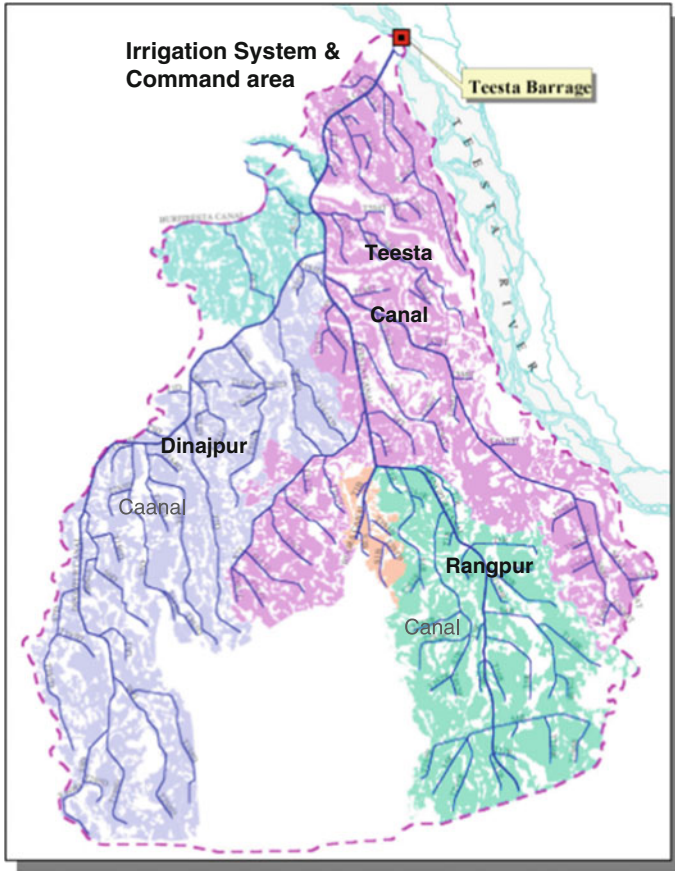


Fig. 1 Command area development of Teesta Barrage project

1.2 Survey and Mapping

Survey and data collection work started at the very beginning of the study. Data collection includes water level and discharge observation in the drainage channel and irrigation system, topographic survey for an area of 1542 km², inventory of existing structure on irrigation and drainage channels, groundwater-level observation, and soil testing. Detailed topographic survey work comprised of benchmark establishment, land-level survey and plotting of contours, delineation of homestead area, water bodies, alignment of roads, embankments, railway lines, irrigation canals, and drainage channels. The survey works have been carried out by using

sophisticated satellite-based survey equipment, digital total station, and conventional optical levels. The collected data have been organized in a relational database, and an interactive information system (IIS) has been developed.

1.3 Irrigation Study

The four main irrigation system of the project are as follows:

- (i) Teesta irrigation system, (ii) Dinajpur irrigation system, (iii) Rangpur irrigation system, and (iv) Bogra irrigation system

As Bogra system is not fully developed, here only the performance of the existing three irrigation systems has been evaluated integrating tertiary, secondary, and main canal systems applying hydraulic modeling. During both Kharif-I and Kharif-II, it has been observed that in the Teesta and Rangpur main canals, full supply level cannot be achieved in a dynamic head for the required flow of Phase-I. The reason behind the fact is that these canals were designed for larger flow to cover the areas of both phases (Phase-I and II). A number of bottlenecks have been identified in the Teesta, Rangpur, and Dinajpur canal systems, i.e., less flow into the secondary and tertiary canal at optimum gate operation of main canal, improper size, vent and sill level of structures, and insufficient tertiary canal length to cover full command area. A number of improvement scenarios have been developed and studied in consultation with the field officials and Design VI of BWDB to find optimum solution. The model study reveals the need of some interventions to achieve full supply level and required flow in the canal system. On the basis of detail hydraulic model study and interactions with local people, officials of TBP and Design VI, remedial measures have been suggested for improving the irrigation canal systems to bring potential irrigable area under irrigation. Figure 2 shows that FSL is not achieved at the dynamic head in the existing system of S7T canal. The study-suggested solution is shown in Fig. 3 where FSL is achieved with two additional check structures and optimized operation of structures.

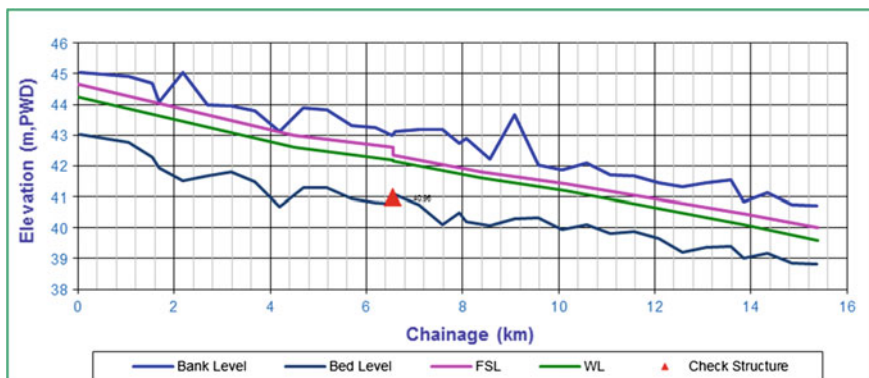


Fig. 2 Comparison of FSL and WL at S7T canal in the existing condition

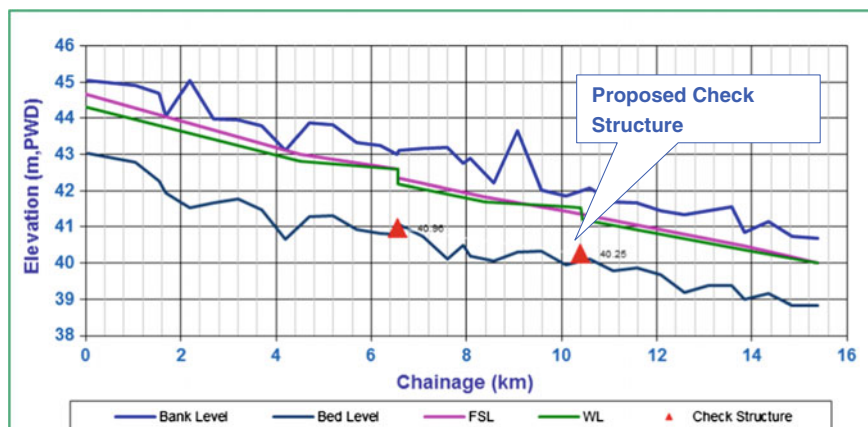


Fig. 3 Comparison of FSL and WL at S7T canal at the optimized condition

1.4 Post-Project Evaluation of Irrigation

Most of the recommendations related to problems associated with the irrigation system have already been implemented by BWDB. A field visit was made by IWM professional along with BWDB officials to evaluate the performances of the recommendations. Interactions with local people were also made in this regard. Summary of the overall field observation is given in the table below.

Sites visited	Previous problem	IWM’s recommendation	Status of implementation	Improvement obtained
CKD1S4T	Insufficient flow to the downstream	Addition of two pipes	Implemented and operated	Enough flow to the downstream
S6T bypass canal	Insufficient flow into the canal	Bypass canal from u/s of R3T	Implemented but not operated yet	Required flow and FSL are expected in the canal
S8Tcanal at 14.1 km	FSL is not achieved	Construction of new check structure	Implemented except vertical gates	FSL is expected to be achieved by operating the gates
T2R bypass canal	No flow in the canal	Bypass canal from u/s of R2R	Implemented and operated	Enough flow in the canal
Offtake of T4T	Higher sill level, no flow into the canal	Lowering of sill by 70 cm	Implemented and operated	Enough flow in the canal
T1D bypass canal	No flow in the canal	Bypass from u/s of R3D	Implemented and problem removed	Enough flow in the canal

1.5 Drainage Study

The river systems that drain the project area are as follows:

(i) Buriteesta–Naotara–Dhum System, (ii) Aulikhana–Ghagot System, (iii) Deonai–Charalkata–Jamuneswari System, (iv) Dhaijan–Bullai–Jamuneswari System, (v) Burikhora–Old Jamuneswari–Chickly System, and (vi) Kharkharia–Ichmati Jamuna System.

The irrigation canals cross the natural rivers at many locations. The cross-drainage structures have been provided at the meeting point of river and canal. The irrigation canal dyke interrupts the natural overland drainage. For smooth overland flow, siphons under the irrigation canal bed were provided at the flood plain. These siphons do not have defined drainage channel at the upstream or downstream. No proper annual maintenance is being practiced to clean and flush the siphons for functioning with full capacity, which results in blockage of the siphons to some extent such as Naotara siphon.

The design drainage coefficient was calculated on the basis of 5-day accumulated rainfall of 5-year return period considering three-day submergence [7]. In the Teesta Barrage Project area, most of the homesteads are only at 0.3 m or 0.45 m above the ground level. So in a number of places, homesteads get inundated at water level of 3-day duration such as Hajarihat. There are many areas of drainage congestions, which are localized problems.

1. *The major identified drainage congestion areas within TBP Phase-I are as follows:*
2. *(i) Naotara siphon, (ii) Dhodrar River, (iii) T6S7T at Hajarihat, (iv) Mirkabeel area, and (v) Ghugumari River at Kaimari*

A comprehensive modeling study has been carried out to investigate the drainage problems and suggests solution in an integrated way. A set of drainage options has been developed in consultation with officials of Design VI and Teesta Barrage Project, BWDB. Flood management model study to assess the impact of all options was carried out. The results of the options have been consulted with design engineers and field officials of TBP. It has been revealed from this study that all major drainage structures are adequate for 5-year flow with 3-day submergence. But nowadays, the project people expects one-day submergence. It has been also observed that siphon gets siltation in each year. Annual flushing is essential for smooth functioning of the siphon with its full capacity.

Drainage congestion along Dhodrar River was a common phenomenon in the past. There are eight water control structures and ten culverts over its 20-km length most of which are not adequate to drain u/s area. Different local government agencies built all the culverts; out of these, the culverts at changes 19.3 and 20.45 km are found quite inadequate to accommodate u/s flow generated from a drainage area of 5500 ha. Figure 4 shows newly constructed 2-vent box culvert (left side) as per the recommendation of IWM along with the existing inadequate one

(right side) on Dhodrar River at 19.3 km. It has been reported that there is no more drainage congestion at this location after the construction of the new culvert.

To identify the drainage problems and to find the probable optimal solutions, six scenarios have been developed. Hydraulic model simulations were made for each option to generate and analyze information on water level, inundation depth, discharge, and flow velocity. The final option for implementation has been selected on the basis of draining the runoff within 1 day causing no drainage congestion.

Figure 5 shows the flood map of existing condition at Dhodrar River [8] and study-suggested solution where drainage congestion is removed with design



Fig. 4 Drainage improvement of Dhodrar River at 18.0 km

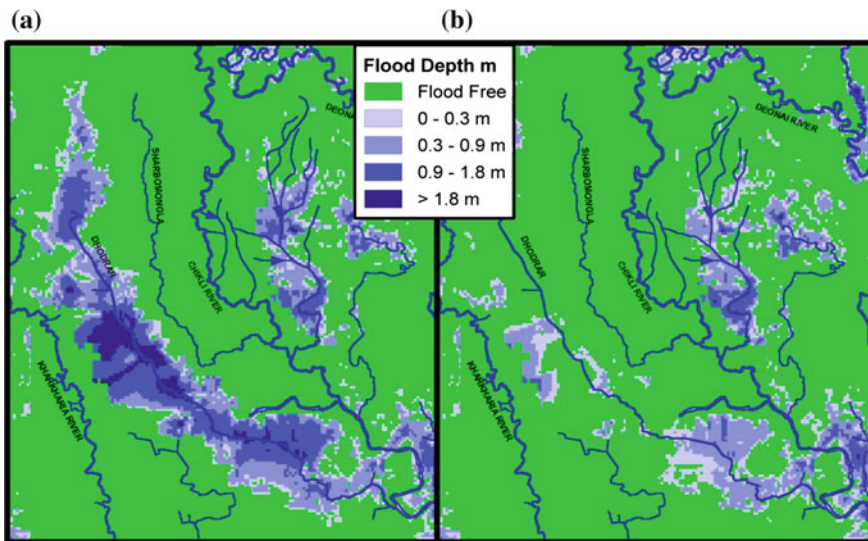


Fig. 5 a and b Flood map for the existing condition and suggested option

cross-section and additional one vent at 4.1 km, two additional vents at 10, 10.9, 12.68, 13.8, 18, 19.3, and 20.45 km, and three additional vents at 15.3 km.

Similarly, several improvement options were carried out for the existing drainage problem of each area. Merits and demerits of each option were analyzed, and findings were shown in a local workshop in Dalia. Views of beneficiaries project officials and concerned design cell were considered, and finally, hydraulic parameters for optimum option were suggested.

2 Post-Project Evaluation of Drainage

Most of the IWM's recommendations related to drainage problem have also been implemented by BWDB. Professionals from IWM and BWDB visited several sites to evaluate the effectiveness of the recommendations, which have been implemented. The visiting team also collects opinion of the local people. Summary of the findings of field visit is given in the table below.

Sites visited	Previous problem	IWM's recommendation	Status of implementation	Improvement obtained
Drainage siphon at 12.5 km of S8T canal (Kaimari)	Drainage congestion at u/s of Siphon	Addition of 2-vent box siphon	Implemented	No congestion observed in monsoon of 2004
Dhodrar River at 15.3 km and 18 km	Drainage congestion	Addition of 3 vents at 15.3 km and 2 vents at 18 km	Implemented	No congestion observed in monsoon of 2004
Mirkabeel Siphon at 0.41 km of S6R	Drainage congestion at u/s of Siphon	Addition of 1 vent box siphon	Implemented	No congestion observed in monsoon of 2004

3 Conclusions

Application of mathematical modeling in water resources project is very beneficial for the decision makers to observe the impact of any intervention or modification in the project infrastructure at different stages of the project, e.g., prefeasibility, feasibility, implementation as well as rehabilitation stages.

The application of modeling tool in TBP phase-I opens up a new dimension of models as a very useful tool in Command Area Development Project, which may be replicated in other CAD projects, e.g., G-K CAD, Barisal, Manu CAD, and

WMIP projects. The effectiveness of modeling tool has been proven to be convenient, cost effective, and quantitative with regard to the aspects on assessments.

Models can be used effectively for people's participatory-based irrigation and drainage management studies. It was observed that through adopting a series of options and demonstrating their effective outcome to the beneficiaries save lot of efforts in resolving conflicting issues and complex situations regarding water management problems.

Groundwater model study will provide Thana (Sub-district) wise available water resources, recharge mechanism, zoning plan, and indication of future expansion.

Surface water and groundwater are interlinked, sometimes withdraw from one source has an impact on the other. An integrated model study can give an overall picture on the water resources availability and management considering total demand from different sources.

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