# GOVERNMENT OF THE PEOPLE'S REPUBLIC OF BANGLADESH

Flood Plan Coordination Organisation



# FAP-25

# FLOOD MODELLING AND MANAGEMENT

COORDINATION ADVISORY TEAM

SIXTH MISSION REPORT

JANUARY 1995



Governments of
Denmark, France,
The Netherlands and
United Kingdom

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# Coordination Advisory Team

## Sixth CAT Mission Report

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| AFPM | Active Flood Plain Management |
| BIWTA | Bangladesh Inland Water Transport Authority |
| BLE | Brahmaputra Left Embankment |
| BWDB | Bangladesh Water Development Board |
| CAT | Coordination Advisory Team |
| CE | Chief Engineer |
| CTA | Chief Technical Advisor |
| DANIDA | Danish International Development Assistance |
| DEM | Digital Elevation Model |
| DHI | Danish Hydraulic Institute |
| EU | European Union |
| EDP | Electronic Data Processing |
| EIA | Environmental Impact Assessment |
| FAP | Flood Action Plan |
| FAPMCC | FAP Modelling Coordination Committee |
| FFM | Flood Forecasting Module |
| FHS | Flood Hydrology Study |
| FMM | Flood Management Model |
| FPCO | Flood Plan Coordination Organisation |
| GIS | Geographic Information System |
| GM | General Model |
| GOB | Government of Bangladesh |
| HME | Hydraulic Modelling Engineer |
| HYMOS | Software Package for Hydrological Data Processing |
| MC | Model Coordinator |
| MIKE 11 | Software Package for 1-D River Modelling |
| MIKE 21 | Software Package for 2-D Estuary and Coastal Area Modelling |
| MOWR | Ministry of Water Resources |
| MPO | Master Plan Organization |
| NAM | Rainfall-runoff Model (Danish abbreviation) |
| NCRM | North Central Regional Model |
| NCRS | North Central Regional Study |
| NERM | North East Regional Model |
| NWRM | North West Regional Model |
| PDM | Planning Design Module |
| PoE | Panel of Experts |
| RMM | River Modelling Module |
| RRI | River Research Institute |
| SAR | Synthetic Aperture Radar |
| SCRM | South Central Regional Model |

| | |
|---|---|
| SERM | South East Regional Model |
| SOB | Survey of Bangladesh |
| SOM | Structures Operation Module |
| SWAM | South West Area Model |
| SWMC | Surface Water Modelling Centre |
| SWRM | South West Regional Model |
| SWSMP | Surface Water Simulation Modelling Centre |
| TOR | Terms of Reference |
| UNDP | United Nations Development Programme |
| WARPO | Water Resources Planning Organization |

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# 1. INTRODUCTION

## 1.1 General

Component 25 of the Bangladesh Flood Action Plan (FAP 25), Flood Modelling and Management, consists of the following three components:

i) A Coordination Advisory Team (CAT)

ii) A Flood Hydrology Study (FHS)

iii) A Flood Management Model (FMM)


The project is executed by the Flood Plan Coordination Organization (FPCO) with the Danish Ministry of Foreign Affairs (DANIDA) as the lead donor. The donor agencies of France, the Netherlands and the United Kingdom also contribute to the project.

The project started in October 1990 with the coordination and the Flood Hydrology Study as the two major activities. The FHS was completed in the course of 1993. The Flood Management component started in October 1992 and has been on going in parallel with the continued coordination activities. FMM will be completed by the end of October 1994, though training activities will be continued to the end of December 1994.

The Team of Short Term Experts of the CAT held their first meeting in Bangladesh in October 1990, producing an Inception Report dated November 1990. Since then there has been four missions in May 1991, December 1991, December 1992 and November 1993. During the last mission it was decided that the sixth mission, being the last mission of the team, should take place in mid October 1994, coinciding with the finalization of the Final FMM report and the third and last FMM workshop.

The overall objectives of the CAT, as stated in the detailed Terms of Reference of the FAP 25, are:

i) To achieve consistency, compatibility and continuity in all related modelling activities;

ii) To coordinate the supply of models as tools to the various FAP projects and the feedback of relevant data and information from various FAP projects to the Surface Water Modelling Centre (SWMC).

Planned activities of the Sixth CAT Mission are contained in Appendix-1.

The Team of Short Term Experts of the CAT on the Sixth Mission are:

| | |
|---|---|
| Dr. Rodney White | UNITED KINGDOM (Team Leader) |
| Dr. Jean Cunge | FRANCE |
| Mr. Johan Grijsen | The NETHERLANDS |

As was the case during the previous missions, the Model Coordinator of the CAT, Mr. Jørn Rasmussen, and the Hydraulic Modelling Engineer, Mr. Emad-uddin Ahmad, worked closely with the Team of Short Term Experts. Whenever the CAT is mentioned in this report, reference is made to the Team of Short Term Experts.

The team worked in Bangladesh in from 14 to 23 October, 1994, and presented its conclusions and recommendations to FPCO on 22 October 1994.

The programme of the mission is included in Appendix 2, and a list of key persons consulted during the mission in Appendix 3.

The CAT would like to express its appreciation to all officials and individuals met for the kind support and valuable information which the team received during its stay in Bangladesh, and which highly facilitated its work.

This report contains the views of the CAT which do not necessarily correspond to the view of the Government of Bangladesh or the four donors. Hence, any proposals presented in the report are subject to approval by the Government of Bangladesh and the donor countries.

## 1.2 Summary of CAT Activities

The four member CAT team carried out its activities through the fielding of six missions, each lasting for about 10-15 days, consulting various modelling related FAPs, FPCO, other GOB offices and donor missions, and reviewing FAP reports. The CAT produced each time draft and thereafter final mission reports. There was a change in the composition of the team. Mr. Marcel Ramette from France attended the first four visits, while Mr. Jean Cunge attended the last two. Mr. Torkil Jonch-Clausen of Denmark attended the first five missions, but could not join the last one. The Model Coordinator, Jorn Rasmussen, attended all visits.

In October 1990, the CAT made the First Mission, reviewed the adequacy of modelling under FAP projects mostly from TORs as none of the studies

had been fielded by that time, and looked closely at the capability and competency of modelling under SWMC. The mission confirmed the suitability of the hydrodynamic 1-D MIKE 11 modelling system of SWMC for FAP projects, but stressed the limitations of 1-D modelling for the prediction of morphological phenomena. The Government was urged to expedite approvals for fielding FAP 25 to coordinate consistency in the modelling works under FAPs and SWMC.

The Second CAT Mission in May 1991 produced an overview of the modelling status of FAPs, a methodology for the Flood Hydrology Study and preliminary guidelines for hydrological studies under regional FAP projects. It also launched an arrangement for coordination between SWMC, FPCO, FAP studies and other relevant studies through informal meetings and through the Flood Action Plan Modelling Coordination Committee (FAPMCC). The CAT, while reviewing the TORs of the FAPs, observed that none of the studies addressed in a comprehensive way the issue of morphological effects in the major rivers of possible FAP interventions. The CAT recommended that such studies be taken up.

The Third CAT Mission in December 1991 stressed the need for giving more attention to the hydrological data quality and early availability of new survey data and maps. Review of modelling technology was continued and CAT provided necessary suggestions to improve the morphological modelling at SWMC. The CAT recommended fielding an international mission on morphology to provide early direction for a morphological study of the main rivers in the country. The CAT observed with satisfaction that the proposed methodology for the Flood Hydrology Study proved to be sound and effective. Finally, the CAT reviewed and prepared new draft TOR for the Flood Management Model component of FAP 25.

The Fourth CAT Mission took place in December 1992 and raised concern that the proposed Morphology Mission had not taken place by that time. With respect to modelling technology, it pointed to the requirement of improving the structure description in the MIKE 11 software. Except for FAP 6, regional studies did not face difficulties with the timely delivery of the regional models by SWMC. The CAT endorsed the recommendations of the Flood Hydrology Study. The mission further gave support to the FMM consultants, who initiated the FMM activity in mid October 1992.

The Fifth CAT Mission in November 1993 was satisfied with the FMM development but was concerned with the institutional hosting of FMM after its development. SWMC was recommended as the logical choice. The CAT was happy to observe that the Morphological Mission was going to take

place. The CAT further recommended updating of the Flood Hydrology study, using an updated General Model.

In addition to these missions, one member of the CAT has visited Bangladesh on three occasions to overview and guide the implementation of the Flood Hydrology Study and to participate in the first FMM Workshop in February 1993, while two members visited Dhaka twice in 1994 to assist and guide the FMM development.

### 1.3 Comments to the Draft report

A draft report containing the views and recommendations of the CAT was submitted a couple of weeks after the mission. Comments have been received from FPCO and Danida and duly considered in the preparation of the final version of this report.

# 2 FINDINGS AND RECOMMENDATIONS

## 2.1 Introduction

The general findings and recommendations of the Sixth CAT Mission are summarised in the following sections. Some of the issues have been recurrent throughout the series of CAT Missions from 1990 onwards; others reflect issues which have become critical in the last twelve months.

Many of the issues which have been highlighted by the CAT have been acted upon and resolved. There are, however, some issues which are unresolved.

Early work by the CAT was at a period when there were many FAP consultants in Dhaka and was predominantly concerned with coordination and consistency activities within FAP. Later on the work included advice and participation within the FHS and FMM components of FAP 25. In parallel with this the CAT identified the need for the consideration of inter-regional effects in general, and a Morphological Study in particular. The CAT was encouraged to give advice on these matters.

In the latter part of its existence several FAP Components were coming to an end and the CAT concerned itself with the issue of sustainability. It is important that the investment in the development of useful technologies and knowledge is not lost to Bangladesh once the current phase of FAP is completed.

## 2.2 Institutional Issues

The sustainability of FAP technology and information is of paramount importance at this time. The CAT stresses that immediate action is required on several specific issues.

* The CAT finds that the arrangements to institutionalise the FMM within the SWMC are, in general, satisfactory. DANIDA and the SWMC need to come to a satisfactory agreement regarding payment of those staff transferred to the SWMC in 1995.

* The CAT remains concerned that there are a number of Government Departments and Projects holding similar hydrological databases. BWDB, WARPO, SWMC, FAPs 1, 6, 19, 24 and 25 all hold databases and the resolution of the question of who should be the ultimate recipient and guardian of these is an urgent question for GOB. The

CAT recommends once again that the findings of the Inter Agency Committee Report of 1991, updated and approved in 1994, are implemented as a matter of urgency.

* It is necessary to take action immediately to safeguard the output from FAP 18, FINNMAP. The CAT recommends that arrangements are made to provide cartographic prints from the mosaics held by FAP 18.

## 2.3 Flood Management Model

* The CAT considers that the development of the FMM system has been carried out in a professional manner by FAP 25. The documentation relating to the system and its use is comprehensive and written in terms which are readily understood. The CAT is satisfied that its own views on this subject have been heeded.

* The FMM system has been demonstrated at National, Regional and Compartment level. The CAT confirms that the system is extremely useful at Compartment level and at Regional level provided that detailed topography and the corresponding DEM are available. Its use at National level is, however, limited.

* One powerful use of the FMM system will be in Impact Assessment with respect to fisheries, land use, agriculture etc, at Compartment, Sub-Regional and Regional levels. For the users outside of SWMC a PC-GIS approach is Advocated. The CAT recommends that FAP 20 further explores this type of application of the system employing sector specialists to aid the interaction between modellers and end-users.

* The CAT endorses the transfer of the FMM system to the SWMC and believes that the workshop and training have developed an awareness of its potential. The CAT advocates the transfer of relevant sections of FAP 19 to SWMC be discussed and agreed by the involved parties, including the need of resources required for an efficient transfer. The transfer should create a solid assistance for PC-GIS users outside of SWMC.

## 2.4 Flood Hydrology Study

* The CAT confirms that the FHS has provided a sound hydrological basis for engineering design criteria along the major rivers of Bangladesh. The methodology has been used, in some cases with

minor modifications, by FAPs 1, 2, 4, 5 and 6. FAP 20 plans to use the methodology shortly.

* When the GM is next updated in early 1995 the SWMC has agreed to repeat the long-term simulations for the existing conditions and for protection scenario No. 3 carried out under the FHS and to update the hydrological design conditions.

* The CAT further recommends that FAP 24 is consulted at the time of the next GM runs for the FHS concerning the possible effects of future morphological developments on design levels for FAP projects.

* Once the FAP 25 FHS report is finally approved by GOB, the CAT urges GOB/FPCO to ensure that the guidelines and methodology for establishing hydrological design conditions are followed in future FAP and water related studies.

## 2.5 Model Coordination

* The CAT believes that the coordination role offered by FAP 25 has been essential in achieving consistency and compatibility in the modelling work carried out within the FAP studies.

* The CAT has attended FAPMCC meetings and believes that a similar forum must be established for the future. The CAT recommends that SWMC establishes a SWMC Models Users Group for the discussion of new developments, practical experience and problems related to the application of SWMC models. Membership of the Group would comprise SWMC personnel plus a varying community of end-users.

## 2.6 Morphology Study

* The CAT considers that the important Outputs from the Morphological Study are the predictions of the likely changes to the physical features and plan location of the major rivers of Bangladesh over the next 30 years with and without manmade interventions. The CAT recommends that Outputs 5 and 6 of the TOR are expanded and made more positive. The study should determine, for each of the designated rivers, whether their size will increase or diminish, whether their plan position will change and, if so, to what extent, in which direction and how quickly.

* The CAT recommends that the TOR are expanded to show clear linkages between the proposed Techniques and Analyses, on the one hand, and the Objectives and Outputs on the other.

* The CAT maintains its long held view that the Morphology Study should only consider morphology, hydrology and river hydraulics. Socio-economic and environmental investigations are best carried out on a Regional basis.

* The Morphology Study, as defined by the Mission, is extensive and the cost estimate is commensurate with the importance of the study. However, the CAT recommends that the study should be extended over a longer period (up to 42 months) to allow for a more efficient work programme.

* The CAT endorses the view that the consultant should be free to use models other than those available from SWMC because of the need to introduce new ideas and techniques to help solve the difficult issues inherent in morphological studies. However, the CAT recommends the use of SWMC as local consultants where its modelling expertise is applicable.

* The Study has many aspects and needs a wide range of skills. The CAT recommends the setting up of a small International Panel of Experts (IPoE) comprising local and expatriate experts to oversee the study on a six monthly basis.

## 2.7 Summary of Unresolved Issues

This Section presents a concise summary of those issues which are mentioned elsewhere in this report but, as yet, remain unresolved

* Flood Hydrology Study Methodology and Guidelines, including also Safety Margins, to be implemented in future FAP and related activities.

**ACTION: FPCO**

* Steps to be taken to ensure that HYMOS is available to the SWMC for the updating of the Flood Hydrology Study.

**ACTION: FPCO**

* Finding a solution to the problems associated with the Bhanadurabad rating curves and discharges for the period 1988 to 1993.

**ACTION: FPCO, BWDB Hydrology, SWMC and FAP 24**

* Updating of the BWDB Hydrometric Data using the results of the FAP 18 levelling of 50 - 60 temporary benchmarks.

**ACTION: BWDB Hydrology**

* Follow up actions based on the recommendations of the Inter Agency Committee on the Improvement of Water Resources Data.

**ACTION: Ministry of Water Resources**

* Production of Cartographic Maps based on the FINNMAP photomosaics for Jamalpur, Tangail and Sirajganj.

**ACTION: FPCO**

* Production of new Topographic Maps based on the comprehensive second order levelling data for the different regions.

**ACTION: FPCO**

# 3. BACKGROUND

## 3.1 Flood Action Plan

The Bangladesh Flood Action Plan (FAP) has been prepared by the Government of Bangladesh in close cooperation with the World Bank. Several studies undertaken in the wake of the disastrous floods hitting Bangladesh in 1987 and 1988 provided the basis for the FAP.

The Action Plan aims at the identification, planning, design and construction of high priority flood control projects, which are technically, economically, environmentally and socially feasible.

It has been decided by the GOB that the river models being developed in the Surface Water Simulation Modelling Programme (SWSMP), including rainfall-runoff, hydrodynamic, sediment transport and salinity modules should be used in the FAP studies.

## 3.2 The Surface Water Simulation Modelling Programme

The SWSMP was established in 1986 because of the widespread recognition that the effective control and utilization of water resources in Bangladesh is vital to the economic and social development of the country. Mathematical models of the complex river system are in this respect indispensable tools for an integrated approach to planning and design.

The first phase (SWSMP-I) of the programme was financed by UNDP and finished at the end of 1988. It had the objectives i) to develop the local capability in surface water simulation modelling, including a sustainable institutional setup within a permanent Master Plan Organisation (MPO), later renamed the Water Resources Planning Organisation (WARPO), and ii) to develop a structured approach to modelling with a General Model covering the whole country and a regional model for the South-east.

The second phase (SWSMP-II), financed by DANIDA, had a duration of four years and finished in December 1993. This phase produced five new regional models, introduced new software and modelling capabilities for sediment transport, 1-D morphology and salinity intrusion and, finally, established the Surface Water Modelling Centre (SWMC) as a permanent institution, first under WARPO and now under the River Research Institute (RRI).

The third phase (SWSMP-III) started in January 1994. It has a duration of three years and is also financed by Danida. This phase will introduce

environmental and two dimensional modelling. It will emphasise the attainment of sustainability of the SWMC.

### 3.3 Flood Modelling and Management

With the launching of the Flood Action Plan in 1990 many of its 26 components were to start simultaneously and were assigned to use the mathematical models of the SWMC, where models were at various stages of development.

The FAP 25 component was therefore established with the dual purposes of coordinating i) the supply of models, being developed under SWSMP-II, to the FAP projects and ii) model applications within the FAP.

During the detailed project formulation the needs of a Flood Hydrology Study and a Flood Management Model became evident. The former should provide the hydrological basis and methodology for establishing unified engineering design criteria for the FAP, while the latter should enhance capabilities of the SWMC models with respect to modelling of flood plain inundations.

# 4. FLOOD MANAGEMENT MODEL

## 4.1 Introduction

Flood management concerns the policy based decision making, reflecting the needs of communities and the environment. Management decision components are numerous, such as land use, environment, infrastructure, agriculture, fisheries, flood preparedness and others. GIS is a decision-aid tool often applied to such complex situations where compromises are sought. Such software allows thematic mapping of impacts of various actions and decisions taken. Thus the use of modelling results, i.e. the results of simulations representing future or hypothetical physical situations, as an input to a GIS for mapping of impacts is a logical approach to the solution of flood management problems.

The modelling tool generally used in Bangladesh for flood simulation is the MIKE 11 software, which does not produce results in a form easy to use for flood impact assessment.

FMM is essentially a system for flood modelling and management, which integrates MIKE 11 modelling software and the ARC/INFO Geographical Information System. It also provides an interface with a DEM (Digital Elevation Model). While all the components of the system had been operational before the inception of FAP 25, their integration asked for further developments. Some of the work concerned the components themselves, but most of the work consisted of the development of the software necessary to create one consistent, documented and tested tool.

The TOR for the FMM defined two stages. Stage 1 is the System Development Phase comprising: system analysis, interfacing MIKE 11 and DEM, enhancement of graphics and postprocessing facilities (interfacing with ARC/INFO), enhancements of MIKE 11 itself, and additional data collection. Stage 2 is the Application and Demonstration Phase comprising the setting up and demonstration of bespoke (tailored) models at compartment, regional and national levels. These two stages ran in parallel.

## 4.2 System Development

Work on the FMM started in October 1992, following approvals by GOB and the donor agencies. The Consultant (from DHI, BCEOM and Euroconsult) and local staff were recruited and computer hardware and software were procured and installed in the FAP 25 Office.

The system development has been carried out according to the TOR. The development has been closely followed by CAT missions, which reviewed draft reports (Inception Report, Interim Report I and II, and Final Report) and attended demonstrations in April and August 1994. The CAT found that the FMM development progressed satisfactorily. There was a delay (about 1.5 month) in the completion of Interim Report I, but otherwise the project was implemented on schedule.

The CAT is satisfied with the spirit of cooperation of the FMM team and particularly with the attention given by the team to the CAT's remarks and suggestions. The FMM Draft Final Report was reviewed by the CAT and the FMM team in August 1994. The FPCO comments on the FMM Draft Final Report have been discussed by the sixth CAT mission and the FMM team in October 1994. Modifications in the report considering FPCO comments have been agreed to.

The FMM is a tool for the preparation of input data for modelling and also for the provision of graphical output, which enhances our understanding of inundation phenomena. The FMM allows also for the production of GIS thematic maps according to specifications made by the users. This point is further developed in Section 4.5.

The FMM system has been demonstrated on the applications described below. The applications are not real-life studies but demonstration cases.

## 4.3 System Applications

Stage 2 of the TOR, the Application and Demonstration Phase, is completed. Relevant issues concerning various project components were discussed in detail in the FMM Review Mission of August 1994 and are summarised below.

a) Bespoke Compartmental FMM

The main objective of this part of the project was to demonstrate the FMM concepts at compartment level. The pilot FAP 20 Tangail Compartment Model has been used as the basis for the development of a more detailed model. The network lay-out was checked and refined where appropriate for the demonstration of the FMM capabilities. Topographic data have been completed, the compartment representation was enhanced and the model has been calibrated for 1993 flood. A number of demonstration runs were carried out and comparative result maps (impact of the project on flood levels, on flood phase, on crop damage, duration depths, and impact of

structure operations) are shown in the FMM Draft Final Report, Volume II.

FAP 20 uses the overall Tangail Compartment Model and detailed sub-compartment models for design purposes and for structure operation studies. Detailed models still need to be developed for several sub-compartments, while structure operation studies need to be continued and the potential of using the FAP 20 - FMM for flood impact (damage) assessment has been recognized. Consequently, FAP 20 is requesting an extension of its modelling and FMM related activities until the end of 1995. The CAT fully supports this and, now that the FAP 20 - FMM has become operational, strongly recommends that the interaction between modellers, designers and other sector specialists in the FAP 20 project team be intensified for the benefit of the project.

b) Bespoke Regional FMM

FAP 25 built a regional FMM for the North Central Region (NCR-FMM) and carried out demonstration runs, as shown in the FMM Draft Final Report, Volumes I and II. The primary purpose of this task was not to develop a complete FMM which could be used as such by future projects (e.g. FAP 3.1 or FAP 3.2) but only to demonstrate the use of FMM at regional level.

The FMM team modified the original NCRM supplied to them by SWMC. In implementing the modifications, the FMM team followed the CAT suggestions to focus on the demonstration of the capabilities of FMM rather than on further improvement of the existing NCRM accuracy.

The CAT recommended that FAP 25 should supply SWMC with a minimum technical documentation concerning the modifications and changes of the original NCRM, as well as with the results of the runs carried out by FAP 25. It is not necessary that such documentation be edited and approved as other project reports.

The CAT concluded that the NCR-FMM represents an applicable tool for regional planning where an overview of flood characteristics is required.

c) Bespoke General Model FMM

FAP 25 has developed and tested the GM-FMM based on the GM of the SWMC. As shown in the FMM Draft Final Report, GM-FMM is functional, but limited in its accuracy. As could be expected, due to the simplified schematisation of flood plains in this model, FMM cannot be used with confidence for inundation mapping except for very high floods.

CAT concluded that while fulfilling the demonstration purpose, the main role of the national level model remains its use for flood forecasting and for providing boundary conditions to regional models.

## 4.4 Impact Assessment

Impact assessment studies must be carried out by specialised agencies and are not within normal activities of modellers. Thus the inundation duration and extension impacts on fisheries, land use, agriculture, or on operation rules for regulation structures should be carried out by respective competent professionals or agencies. Such agencies can nowadays more easily be equipped with PC-based GIS thematic mapping technology, which allows them not only to consider separately impacts of various phenomena or activities but to cross and superimpose information and then derive rapidly more complete and reliable conclusions. This activity cannot be carried out by flood modellers who obviously lack the necessary qualifications. On the other hand, the end-users of model results, i.e. the agencies capable of assessing impacts, lack the qualifications and means necessary to model the floods and inundations.

The FMM System allows for a more efficient and user-friendly modelling set-up and produces results in cartographic form (inundation maps). The latter can be printed but are also available in ARC/INFO-GIS standard files form. Hence the maps can be exported towards other GIS compatible systems. As a consequence the SWMC may become a supplier of basic material for planners and impact assessment agencies. The latter should quickly realise the advantages of this new type of data and it is expected that they would ask SWMC to produce new maps corresponding to new hypotheses, thus initiating a client/customer permanent relationship. It is extremely important that real-life first applications be successful and useful in order to initiate the process. FAP 20 is a good example of such supplier/end-user relation.

Though flood inundation maps are most useful, multi-sectoral flood impact assessments are even more valuable for the development of optimal flood management practices.

The CAT recommends that FAP 20 further explores and uses the GIS functionality of FMM during the remainder of the project. This work may be undertaken in the project office at Tangail in order to facilitate the use of the FMM by various sector specialists and to intensify the interaction between modellers and these end-users. The non-modelling end-users of the project staff should take the lead in these activities, where necessary supported by modellers, whose main role would be to provide required flood maps. A PC-

based GIS and GIS expertise is already available with FAP 20 in its Tangail project office. Flood maps can be exported from the FMM-workstation in the FAP 25/SWMC office in Dhaka to the PC-GIS in the FAP 20 Tangail office.

Advantages of such procedures would in general be:

- immediate enhancement of the results and productivity of FAP 20 project,
- "live" demonstration of the usefulness and applicability of efficient supplier/end-user relationships between modellers and impact assessment specialists, and
- validation and "live" demonstration of the export of FMM - GIS files to PC-GIS, the latter being more popular, cheap and better accepted than workstations.

## 4.5 Sustainability

For sustainability, the FMM system developed by FAP 25 will have to be maintained, used and kept alive in Bangladesh. One condition for sustainability concerns institutionalisation, including availability of trained and qualified personnel, software maintenance, software licences and ownership, etc. Another concerns the "market" required to sustain any activity, i.e. the development of a group of end-users for FMM products.

a) Transfer to the SWMC

The CAT believes that the FMM development in FAP 25, associated with workshop and training sessions, has generated considerable local awareness of the usefulness and expertise necessary for continuation of FMM activities in Bangladesh. The potential is here, but it is essential that a proper institutional framework exists for this expertise to be retained and further developed.

The CAT expressed several times in its mission reports its concern about institutional sustainability of the FMM system. The logical institutional host for FMM is SWMC, provided SWMC remains to be located in Dhaka. FMM is a logical addition to the products of SWMC, which should maintain, distribute, and improve the software. The FMM system should, like the surface water models at SWMC, be maintained, improved and upgraded over time through the integration of user experiences and demands and also with new technologies. While new users will need introductory training before applying the tool and certainly some support and assistance during the application, it is essential that the experience of the users be documented and fed back to the custodians of the FMM who would make

it available to subsequent users.

b) Software Licences

Environmental Systems Research Institute (ESRI) has the proprietary rights of the ARC/INFO GIS software package. FAP 25 has purchased a three-user full licence, which is transferable to SWMC. ESRI has also provided three training licenses for training on the MIKE 11-GIS and agreed that they are transferable to GOB for the same purpose.

UNEP/GRID - Bangkok Office has provided four PC-ARC/INFO training licenses free of charge to FPCO for use during the FAP 25 training courses. The same office has also arranged for the provision to GOB of additional full user licences for MIKE 11-GIS applications at a greatly reduced cost (5% of list price), should the need arise.

The SWMC holds a MIKE 11 licence and service agreement with DHI. The expiry dates are 2002 and 1996 respectively.

In conclusion, workable arrangements for the future use of FMM technology are (soon) in place.

c) Creation of an FMM market

The first condition to the sustainability of the FMM is the long-term financial sustainability of the SWMC. It seems at this stage that SWMC functioning is financially ensured until the end of 1996. Beyond that date it can only be ensured by demand for SWMC services - i.e. by the creation of a "market". One part of the demand can stem from the GOB institutions. Another part should be commercial demand by consultants, engineering companies, etc.

Section 4.4 explains how the services of SWMC and specifically FMM results can be made useful for the GOB agencies. The CAT highlights the need to initiate such services as soon as possible because it takes a long time to create habits and permanent supplier/end-user relationships. It is suggested that FAP 19 - GIS capabilities could be used to that end. Indeed, it should be possible within a few months to implement PC-GIS at a few GOB agencies and initiate simple procedures allowing for the export of FMM inundation maps to the PCs as well as a simple, user-friendly manual allowing the employees of these agencies to create in their offices, on their PCs, GIS maps which suit their purposes. This implementation could then be used as demonstrations to create more interest.

As for commercial demands, there would be some demand from FAPs (e.g. FAP 3.1) and other donors-financed projects. But it is essential, in order to create a commercial approach and state of mind in SWMC, that it also finds a local market. The same PC-GIS approach as above should be used.

In view of the above the CAT feels that a small part of the FAP 19 capabilities should be transferred to SWMC, following agreement between the involved parties as to the resources required and keeping in mind that SWMC can absorb only those which are necessary to its activities. Such a transfer should start with closer cooperation (e.g. on procedures of the export of FMM results towards PCs).

The CAT believes that the SWMC needs a period of time before becoming "commercial" and financially sustainable. The CAT recommends that during the transition period governmental agencies should ensure SWMC a decreasing percentage of turnover. GOB should ensure SWMC a stable and guaranteed income for maintaining and updating the General Model and the six Regional Models. The rest of the turnover should be ensured by marketing of SWMC products. The CAT mission feels that the creation of this market is a long and difficult process, for which SWMC should be given ample time.

# 5. FLOOD HYDROLOGY STUDY

## 5.1 Methodology

The Flood Hydrology Study (FHS), one of the three major components of FAP 25, started early 1991 and was completed in December 1992. The objective of FHS was to establish the hydrological basis for engineering design criteria along the major and regional rivers of Bangladesh, which would be implemented by regional and other FAP studies. The CAT produced a detailed FHS methodology during its second mission in May 1991, which is summarized in this Section.

Due to the complexity of the Delta of Bangladesh and the interaction of the various flood causing factors, a joint probability analysis of these causes and the definition of design events of a given return period in terms of standardized boundary conditions is impracticable. Hence, extensive simulations with the General Model (GM) and regional models of SWMC were considered the only feasible option to generate long-term hydrographs for regional and main rivers, both for current and possible future conditions, on the basis of which hydrological design conditions can be derived. Consequently, the adopted methodology for the FHS consisted of three main activities:

* base line statistical and correlation analysis of historic water level and flow data with the aim to (i) establish reliable boundary and validation data for the GM, (ii) determine the statistical representativeness of the period 1965-1989 for the full century, and (iii) recommend suitable probability distributions for various hydrological variables;

* a validation of the GM for the full period 1965-1989, statistical analysis of model output including design statistics, determination of associated safety margins, supply of regional model boundary conditions to the regional consultants, and outline of a methodology for deriving design statistics at a regional level as well as for comparison of alternative protection schemes; and

* runs with the GM for the period 1985-1989 for alternative future country-wide flood protection schemes and for the full period 1965-89 for the most likely future protection scheme, including the analysis of results and supply of boundary conditions to regional consultants.

The CAT wishes again to emphasize the importance of the FHS, since decisions on very large investments must rely on a reliable set of hydrological

design conditions.

## 5.2 Findings and Recommendations

FHS submitted its Final Report in three volumes, i.e. the Main Report (June 1992), Annex 1 with supporting Appendices and Annex 2 with an analysis of country-wide protection schemes (February, 1993). The report is still with the Technical Committee for approval, following endorsement by the Review Committee in its meeting of 28 August 1994.

The basic approach of the FHS, relying for a great deal on the validation of the GM for a historic period of 25 years, has proved to be sound and justified. SWMC has cordially cooperated in this exercise, assisting the FHS team with the recalibration of the model as required. Proper steps were undertaken to reduce the computation times of the GM to a feasible level for the FHS.

FHS has established guidelines for the selection of probability distributions for various hydrological variables, in particular the 3-parameter log-normal distribution for annual maximum water levels, average annual or seasonal discharges (flood volumes), and annual or seasonal rainfall data. The Gumbel and EV-2 distributions appeared to be appropriate for the analysis of extreme daily discharges. However, probability analysis is very much a matter of judgement and these recommendations should, therefore, never be applied rigidly.

The simulation period 1965-1989 proved to be representative for the century, though designs made on the basis of the hydrological conditions for this 25-year period may be slightly conservative.

FHS has investigated a number of potential FAP development scenarios through long-term simulations with the GM (Annex 2 of FHS Report). These simulations have provided useful insight into the possible range of water level changes in the entire river system in response to various FAP interventions, though not yet taking into account possible implications of project-induced morphological developments (see below). If the GM performance is significantly improved through the next update (see Section 5.4), the CAT *recommends* that SWMC considers to repeat the long-term simulations for protection scenario nr. 3, carried out under FHS.

FHS has provided hydrological design criteria as well as boundary conditions for regional models based on output from the GM, to be used by regional and other relevant FAPs. It has further established guidelines for review and

correction of hydrological data, for determination of safety margins for design along the regional and national river network, and for taking into account the effects of possible long-term morphological development on design water levels. The recommended concept of safety margins on peak design water levels takes into account the effects of random morphological processes, model errors and shortness of hydrological records, which should be considered within the overall safety requirements including freeboard for wave run-up.

Because of the importance of a unified approach throughout the FAP for the assessment of design criteria, the CAT *recommends* that GoB/FPCO take steps to ensure that these guidelines and the mentioned methodology for establishing hydrological design conditions be followed in future FAP and related studies. The CAT learnt that a committee has been formed and a unit will be established in the Design Directorate in BWDB to produce design standards and to develop hydraulic designs following international standards. This provides a direct opportunity to incorporate the FHS methodology and guidelines in the design practises to be adopted within BWDB.

FAP 24 has presented a 'Qualitative Impact Assessment of FAP Implementation' (March 1994), pointing out the limitations in the use of the fixed bed GM under FHS vis à vis the morphological changes likely to occur due to large scale FAP projects. Indeed, results produced with the fixed bed GM are only valid immediately upon implementation of projects, whereafter induced morphological developments will gradually alter the hydraulic conditions to some extent. However, the 100-year flood could occur just upon completion of a project, which justifies the fixed-bed modelling approach. If project-induced morphological developments which may alter design conditions are of concern, the exercise should be repeated with a fixed bed model representing the situation expected to exist after, for example, 25 years. Design conditions need to be selected taking simulation results for both situations into account.

The CAT *recommends* that at the time of the next GM model runs for the FHS exchange of information is sought with FAP 24 concerning the possible effects of future morphological developments on design levels for FAP projects.

## 5.3 Application within Regional and other FAP Projects

The rationale for the adopted methodology for estimating design water levels for the main rivers in Bangladesh applies also for the regions. Long-term simulations with regional or sub-regional models and statistical analysis of

results should, therefore, be adopted by regional and other FAPs for establishing hydrological design conditions. FAP 25 provided for this purpose relevant FAPs with 25 years of boundary conditions for the regional models, both for the present and for possible future situations.

FAP 1, 2 and FAP 5 consultants have closely followed the proposed methodology and have undertaken 25-year simulations for the present conditions and "with project" scenarios.

FAP 3 could not follow the proposed methodology due to the late initiation of the NCRM development, but it is expected this will be done during future studies.

Though complicated due to tidal boundary conditions of the models, FAP 4 has also managed to complete a 25-year simulation for the existing hydraulic situation, on the basis of which design statistics have been established.

The major constraint for FAP 6 to undertake long-term simulations is to establish adequate (3-hourly) boundary conditions through NAM rainfall-runoff modelling because of limited rainfall data from India and difficulties with NAM model calibration for catchments in India. Instead, it is now proposed that simulations would cover a nine-year period, from 1985 to 1993, using three-hourly 'observed' discharges as boundary input to the model. A 24-hour resolution of rainfall data and historic water level/-discharge data is not considered adequate to characterize the flood potential in the flashy border streams. A nine-year period is very short for statistical analysis and FAP 6 should at least demonstrate that statistical rainfall characteristics for this short period are indeed representative for a longer historical period. The CAT further *recommends* that FAP 6 considers to undertake simulations using daily rainfall data to generate NAM inflow from the Indian watersheds, and to compare the results with those of the proposed simulations based on three-hourly cross-border flow data derived from water levels. Comparison of simulation results could shed some light on the potential of long-term simulations.

FAP 20 still plans to undertake 25-year simulation runs with the Tangail Compartment Model, as soon as reliable boundary conditions can be derived from the NCRM or NCR-FMM. In order to make long-term simulations feasible, FAP 25 restructured the NCRM to include parts of the Jamuna and other rivers. A comparison of simulation results with those derived from the GM revealed discrepancies with respect to the distribution of flow in the Jamuna and the left bank flood plain. Once SWMC has solved this problem as part of the next updating of the GM, long-term simulations should still be

made with restructured NCRM and subsequently with the TCM. Meanwhile, the 1987, 1989 and 1991 have been identified as covering a wide range of flooding conditions and simulations were carried out for these years.

Thus, it may be concluded that the methodology proposed by the FHS for establishing hydrological design conditions, in general, is adhered to. Results achieved have proved that the methodology is justified and beneficial.

## 5.4 Outstanding Issues

a) Transfer of FHS to SWMC

As part of the transfer of FAP 25 software and hardware, the data bases and models developed under the FHS will also be transferred to SWMC for possible future updating of the FHS. This enables further model runs for possible future country-wide flood protection scenarios to be made as the need arises. Preservation of these data bases and models would also appear to be very relevant for the proposed Morphological Impact Assessment project (see Chapter 10).

User licence to the HYMOS software package, used for hydrological analysis in the FHS, was issued to BWDB - Hydrology as the expected end-user. The CAT recommends that this package is also made available to SWMC.

b) Updating of the General Model

The main role of the GM is its use for flood forecasting and providing boundary conditions for the regional models. As mentioned above, simulations with an enhanced NCRM, including the Jamuna river and a refined schematization of spill channels towards the North Central Region, have shown discrepancies with results of the GM. This implies that the calibration of the regional and GM models needs to be improved iteratively. SWMC will take up this matter during the next updating of the GM, expected early 1995. SWMC will at that time also incorporate several approved changes in benchmark levels and preliminary conclusions concerning the problems with the rating curves at Bhahadurabad for the years 1988 and afterwards.

SWMC has agreed to undertake upon completion of the next updating a simulation with the GM for the period 1965 - 1993, to compare the performance of the model for the period 1965 - 1989 with previous long-term simulations and to revise, using the period 1965 - 1993, the main results as contained in the Tables 1 and 2 of the Executive Summary of the FHS Main Report.

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# 6. MODEL COORDINATION

## 6.1 General

The model coordination activities of the FAP were undertaken with the objectives to:

i) achieve consistency, compatibility and continuity in all related modelling activities;

ii) coordinate the supply of models as tools to the various FAP projects and the feedback of relevant data and information from various FAP projects to the Surface Water Modelling Centre

The coordination has been undertaken by the Model Coordinator and the Hydraulic Modelling Engineer (HME) of FAP 25, supported by the CAT. Initially, the Model Coordinator was residing in Dhaka. However, from mid-1992, with the gradually decreasing need of coordination, the day-to-day coordination was left with the HME.

The day-to-day contacts between the SWMC and the various FAP consultants have been numerous since the start of the FAP, not least on the detailed technicalities of modelling and the MIKE 11 software. During the initial periods of model development modellers from the regional FAP studies were housed at the SWMC and this greatly facilitated a cooperation of mutual benefit.

However, the CAT believes that the coordination forum established under the umbrella of FAP 25 has offered a significant contribution to coordination of modelling and modelling related activities, which would not have been achieved otherwise and which has created exactly the results expressed in the objectives of the coordination, cf. above.

The coordination structure has comprised:

* day-to-day contacts between FAP 25, SWMC and relevant FAP projects;

* informal coordination meetings called by the Model Coordinator, especially during the period 1991-92 when coordination demands were considerable

* the FAP Modelling Coordination Committee (FAPMCC), see 6.2.

The coordination activities have included a number of issues:

* distribution of hydrological data for the main rivers to interested FAP projects following approval of BWDB;

* promotion of and support to the various FAP projects in implementation of the methodology developed in the Flood Hydrology Study, see Chapter 5;

* facilitating of overall discussion on the importance of quality data for river modelling, advocating successfully the need for supplementary primary data collection in SWMC, and arranging, after a lengthy process, for provision of data to FAP consultants free of charge, see section 8.1;

* arranging for speeding up delivery of topographic data from FAP 18 - Topographic Mapping, see section 8.2;

* keeping track of schedule for model developments at SWMC vis à vis FAP requirements with respect to delivery of models and arranging to the extent possible for necessary modifications or changes in model development schedules, see section 9.1;

* facilitating the preparation of commonly agreed procedures for updating of SWMC models, see section 9.1;

* conducting a discussion among FAP modellers of model accuracy requirements, see section 9.2;

* on the request of FPCO, reviewing and commenting on FAP consultants' reports on hydrological analysis and modelling;

* conducting a user requirement survey and drawing up final TOR for the Flood Management Model study,

## 6.2 FAP Modelling Coordination Committee

The FAP Modelling Coordination Committee (FAPMCC) has been the superior body for model coordination under the Flood Action Plan. Members of the FAPMCC are representatives of GOB authorities involved in hydrologic data collection and modelling related activities and team leaders of the FAP studies using the SWMC models. Initially, the FAPMCC was chaired by the Director General of WARPO and later by the Director General of the River

Research Institute (RRI), when SWMC was transferred to RRI.

The FAPMCC has held a total of nine meetings since May 1991. The committee has been addressing most of the coordination issues mentioned in section 6.1. It has been instrumental in achieving progress especially on the issues requiring action within and among GOB authorities, notably on:

* obtaining permission for free exchange of data and models between FAP studies

* reimbursement of FAP consultants on payment made for data

* speeding up the delivery of topographic data from FAP 18

* validation of SOB datum based on FINNMAP surveys across Jamuna

All the above issues have now been solved, most of them unfortunately too late to be of direct benefit to the FAP studies which finished in 1993 or earlier. However, procedures are in place and data available for ongoing and future FAP activities.

One important outstanding issue is concerned with the FAP 24 observed shift in BWDB rating curves at Bhahadurabad after 1988 flood. The FAPMCC established a committee to resolve the issue. In its report the committee was not able to provide a definite answer and recommended joint measurements by FAP 24 and BWDB during 1994 monsoon season. While joint measurements have been carried out, the CAT notes that this exercise is of benefit for future discharge data but it would not resolve the observed discrepancy between FAP 24 and BWDB discharge data in the period 1989-1992.

The CAT urges the relevant parties, i.e. BWDB Hydrology, SWMC and FAP 24 to reach a joint decision on official GOB discharge data for Bhahadurabad for the period 1989-92 based on an agreement of the most likely causes of observed discrepancies. The CAT is of the opinion that the General Model of SWMC could prove very useful in identifying the most likely rating curve(s) for this period.

## 6.3 Future Model Coordination

FAP 25 will finish by the end of 1994 and, thus, so will the coordination activities undertaken under the umbrella of FAP 25. During the first two years of the FAP (1990-92) there was a considerable need for coordination

of modelling activities, not least because model development activities did coincide with a huge demand for practical applications of the models, notably created by the regional FAP studies. Over the last two years the coordination need has diminished, because the number of model users has gone down and because the models have reached a stage where teething problems have been overcome and where they can be applied for the purpose they are intended too. With the development phase being completed, the CAT recommends that SWMC in the future will undertake the required day-to-day coordination, which has hitherto been undertaken by FAP 25.

The CAT recommends that SWMC establishes a SWMC Models Users Group as an informal forum for discussion of new developments, practical experience and problems related to the application of SWMC models. It may also be considered to setup a standing committee on surface water modelling with members from relevant GOB institutions. The role of such committee could be i) to enhance the awareness among senior professionals on the possible use of modelling technology including FMM within their institutions' mandate, ii) to address issues of importance for sustaining the modelling technology and iii) to identify possible new fields of model development and application.

# 7 Modelling Technology

## 7.1 General

In its Inception Report the CAT has reviewed the MIKE 11 River Modelling System, to identify its strengths and limitations. The CAT has expressed its opinion that as such the hydrodynamic modelling system is appropriate to the needs of the regional studies and several of the supporting studies. It can provide the overall description of the general hydraulic behaviour of the river system and flood plains in Bangladesh, including effects of proposed human interventions, as demonstrated in a series of case studies within Bangladesh. Nevertheless, the CAT identified a number of issues and problems faced by model users, which required enhancement of the hydrodynamic modelling system. These enhancements have gradually been implemented to the satisfaction of the model users and the CAT during the course of FAP 25.

As concerns morphological modelling, one needs to be aware of the inherent limitations in a one-dimensional description of sedimentation and erosion processes. The MIKE 11 system, like any other available 1-dimensional model, cannot account for morphological changes in the river environment caused by river bank erosion, char development, etc.

## 7.2 Documentation

Initially, the scientific documentation for MIKE 11 appeared somewhat dated. This was improved to suit the needs of the various users of the modelling system under FAP. It was further agreed with SWMC to announce changes in the coding of MIKE 11 and the release of a new version by newsletter to all users in Bangladesh.

## 7.3 Time Step

Initially the need to use small time steps (20 minutes to 1 hour) in simulations with the models put severe constraints on their use for the regional studies, and prohibited the use of the GM for long-term simulations for the purpose of the Flood Hydrology Study. The CAT has requested SWMC/DHI several times to investigate and remedy this problem, for the benefit of regional FAPs, who would wish to investigate with their models numerous engineering options for flood defence measures. A solution to this problem was also a prerequisite for the implementation of the FHS - methodology for estimating design water levels in the regional FAP projects. Though the need to use small time steps was never remedied, an acceptable

situation was achieved with the introduction of MIKE 11 version 3.01. When using a PC 486 instead of a PC 386, an improvement in run time with a factor 3 could be achieved.

## 7.4 Description of Structures and Drying Channels

For quite some time certain FAP-users of MIKE 11 experienced problems with the functioning of structures in their models, though part of these problems were due to inexperience of the users. MIKE 11 allowed initially the users only a limited range of hydraulic structure descriptions. This was considered as a serious issue by the CAT and SWMC/DHI was urged to give high priority to this issue. To remedy the situation, SWMC/DHI provided advice and satisfactory modifications of the software and documentation to model users.

For the benefit of FAP 20 a multiple structure facility was included. In October 1994 DHI developed a new dedicated structure operation function for the Tangail Compartment Model, in which gates can be operated on upstream and downstream minimum and maximum water levels with a variable operation time step, to better reflect the actual or improved practise of structure operations under field conditions.

Shallow flows in drying channels tend to create stability problems. These problems are addressed by introducing a narrow artificial slot in cross-sections. Following the problems faced by FAP 5 and FAP 6, DHI has worked on an improvement of the slot description. It is expected that this modification will be introduced in the next MIKE 11 release (3.10), due by the end of 1994. This release is also expected to be significantly improved with respect to the modelling of hydraulic structures.

## 7.5 1-D Morphological Modelling

The CAT has addressed the issue of morphological modelling at various occasions and made several observations:

* The applicability of the Cohesive Sediment Transport Module of MIKE 11 for the study of erosion/sedimentation problems in tidal reaches of Bangladeshi rivers may be doubtful in situations where (i) the effects of salinity gradients or fresh/salt water interfaces on the flocculation/sedimentation in fresh/saline or brackish environments may be important, or (ii) adjustment of bed levels due to sedimentation or erosion of cohesive sediments are necessary.

* There is evidence that vertical salinity gradients are not pronounced in the tidal river stretches discharging into the Bay of Bengal. In the event, significant vertical gradients would occur in certain areas, Consultants may have to use a more sophisticated tool than provided by a 1D - one layer model to solve specific problems.

* The sediment transport theories used within MIKE 11 are general theories and can be regarded as well proven over a range of conditions. The subject is not, however, cast in stone and amendments and additions are desirable as knowledge increases.

* MIKE 11, like other 1-D models, is not designed to simulate bank erosion, local scour, changes in channel cross-sectional shape due to sediment movement, or changes in the plan geometry of channels.

* One-dimensional sediment transport modelling represents a major simplification of the natural processes. In particular, such modelling does not take into account and cannot predict changes in channel width, cross-sectional shape and channel pattern, nor lateral movements of channels. This is particularly so in wide sand bed channels such as the Jamuna, which are inherently two-dimensional and dynamic. Nevertheless, useful results may be obtained, which will throw some light on the possible changes in longitudinal bed profiles resulting from proposed engineering works.

* It is generally agreed that the development of regional morphological models is too ambitious at this stage. It is now recognized that "morphological" models can only be set-up for relatively simple networks with a small number of branches and that the channel topography has to be subjected to further schematization before a useful model could be built.

Further reference is made to Chapter 10 concerning the Morphological Impact Assessment study.

# 8. HYDROMETRIC AND TOPOGRAPHIC DATA

## 8.1 Provision of Hydrometric Data

The importance of having good quality data as the basis for development and application of the SWMC models is appreciated by all involved parties and has been stressed by the CAT continuously.

Based on the experience from SWSMP-I, it was realised that there was a need to strengthen the primary data collection of BWDB to support the development of reliable regional models in SWSMP-II. This should not considered a criticism of BWDB Hydrology. Rather it reflects that they have been underfunded for a considerable period of time and that its resources of man and material were not sufficient to carry out the large extra burden placed on it by SWSMP-II. Thus, SWSMP-II had provision for strengthening of the data collection of BWDB Hydrology in the form of training, manpower, equipment and transport. In addition, more specialised surveys were undertaken by SWMC itself.

Following the first year of the SWSMP-II the quality issues took on even greater importance and the SWMC realised that a further, additional effort was required. The objective was to maintain a permanent presence in the field both as an incentive for good performance by field staff and as evidence for the importance given by SWSMP-II to data quality. The CAT strongly supported this proposal, and DANIDA accepted to provide extra funds to SWSMP-II during the monsoon seasons of 1991 and 1992 to the benefit of the programme and the FAP.

Timely provision of hydrological data, free of charge is another important issue addressed by the CAT from the beginning and which represented a bottleneck for the performance of the different studies in the first years of the FAP. Based on the recommendations of a ministerial committee, an approved set of procedures was finally reached in 1993 along the following lines:

* that FAP studies, as a matter of urgency, be reimbursed for payments made for data and models;

* that FAP studies, in the need of data and models, would make a detailed request to FPCO with a copy to the concerned GOB agency;

* that FPCO, with a minimum of delay, request the concerned GOB agency to handover the requested data to the consultant;

* that any payment required for such data and models be settled directly between FPCO and the concerned agency;

* that FAP studies, for the sake of convenience, should be allowed to collect data from other FAPs after having properly informed FPCO and the concerned GOB agency;

* that MIKE 11 software and MIKE 11 based models can only be obtained from the SWMC, and following the procedures above.

To the knowledge of the CAT FAP 24 and FAP 25 have been reimbursed the payments made for data. To which extent other FAPs have requested reimbursement is not known.

## 8.2 Topographic Information

Topographical maps in the scale of 1:50,000 (corrected in 1983) and SPOT images for 90-91 dry season were available from the beginning of FAP.

FAP 18 (FINNMAP) initiated its works in the Brahmaputra corridor and around with second order levelling and contour mozaic for three priority areas. Six copies of mozaics ( for Jamalpur area in scale 1:20,000, for Tangail and Sirajganj areas in scale 1:10,000) will be delivered to FPCO before the end of 1994. These copies are positive, photographic copies which are fragile and may easily deteriorate when used in the field. The CAT recommends that topographic maps at 1:20,000 and 1:10,000 scales be printed, while the facilities to do so are still available (FINNMAP).

FAP 6 had also survey programmes in the North East Region through SOB. Some regional studies took steps to make additional levelling in priority areas of the regions, including checking of water level benchmarks to allow precise flood modelling.

The Second CAT Mission stressed the importance of FPCO giving high priority for acquiring the FAP 18 levelling output at an early date to ensure that its output could still benefit to some extent the FAP studies. This was materialised only in December '93 after SOB checking when many FAPs had completed its studies.

In parallel, FINNMAP carried out second order levelling in the coastal areas. This survey has now been completed but are awaiting SOB check. During the Third CAT Mission it was recommended that FPCO should take action to obtain a release of preliminary FINNMAP data from this coastal survey in

batches, similar to the arrangement made in FAP 18 for the Jamuna area pending SOB checking. This has not taken place. Furthermore, it appears that FINNMAP has fund constraint to carry out the remaining field level contour survey and development of final maps with 25 cm contours.

FINNMAP has levelled 50-60 BWDB temporary benchmarks in the Jamuna area. The CAT and the FAPMCC have recommended BWDB to make correction as required in their hydrometric data. This has not yet taken place.

In conclusion, second order levelling data are now available for most of the regions and the CAT recommends that actions be taken to develop updated topographic maps for the benefit of follow up activites of the FAP, including also modelling and the potential that has been established with the development of FMM under FAP 25.

## 8.3 Data-base Harmonisation

The third CAT report (March 1992) addressed the question of flow of data and information between the FAP projects, SWMC and various GOB institutions and the possible proliferation of data bases and data processing software. It was recommended that FAP 25, as part of its coordination, made recommendations to MIWDFC on data base and processing software and formats.

An Inter-Agency Committee on Improvement of Water Resources Data submitted in January 1991 a report addressing inter alia the above issues. It contains an overview of type of data being collected by different agencies, of problems and constraints related to data collection, processing and data exchange. It suggests steps for improvement, including short term steps that could be taken within the existing resources of the agencies and long term steps within a 3-5 year time frame and, finally, a comprehensive list of recommendations. Among its recommendations the committee proposed:

* to establish a Central Data Register Office at MPO (now WARPO) for all water related data;

* to introduce standard format diskettes in all data collection and data user agencies to allow easy entry and retrieval of data;

* to let WARPO prepare specifications for necessary hardware/software to be gradually procured by all relevant data agencies.

In August, 1992 FAP 25 proposed to FPCO that WARPO be requested to initiate follow-up actions on the above recommendations.

In the Fourth and Fifth Mission reports the CAT observed that only little progress had taken place. In May 1993 it was decided to update the 1991 report and include the recommendations of the Committee on Data and Model Exchange within the FAP. The updated report was submitted in draft in February 1994 and has been approved in May 1994. It contains no major changes as compared to the 1991 report.

The CAT remains concerned about the lack of progress on this issue, but is obviously not in a position to resolve it. There are a number of Government Departments and Projects holding similar hydrological databases. BWDB, WARPO, SWMC, FAPs 1, 19, 24 and 25 all hold databases and the resolution of the question of who should be the ultimate recipient and guardian of these is an urgent question for GOB. Furthermore, the considerable work undertaken by various FAP studies in checking and correcting data should be considered by the recipients with a view to possible updating of their databases.

# 9. MODELLING UNDER FAP

## 9.1 Model Development at SWMC

The model development strategy pursued at SWMC includes a structured approach implemented through a staged development.

The structured approach comprises three levels:

* a General Model covering the entire country (except Chittagong and the Hill Tracts) including the major river system, but excluding secondary river networks;

* six Regional Models, each describing the secondary river network within each region in some detail;

* Subregional models, receiving boundary conditions from the General and Regional Models and providing more comprehensive details at subregional level not least with respect to flood plain flow and inundations;

The General Model and the South-East Region Model were developed during SWSMP-I and refined during SWSMP-II. The five remaining Regional Models were successfully developed during SWSMP-II.

The possible areas of application of these models have been modified over the years considering the considerable experience gained during model development at SWMC and applications, notably in the FAP.

In general, the General and Regional Models have an appropriate level of detail for developing regional water management plans and would in many cases also be applicable to feasibility studies. Subregional models would normally be required for detailed design of flood control and drainage projects and in some cases also to support feasibility studies.

Originally, a three-stage model development was envisaged, but this was later modified to two stages:

* first stage - the Pilot Model based on and calibrated from one season of data and describing the key characteristics of surface water distribution and drainage in the area;

* second stage - the Full Model based on the second season of data

and adding more drainage characteristics. When a new set of data is used to verify the two years of calibration the Full Model becomes verified (the original third stage).

Each of the Regional Models and the General Model have been thoroughly documented during their various stages of development, see Table 9.1.

| Model | Title of Report | Year |
|---|---|---|
| GM | Verification Report | 1991 |
| GM | Verification Report | 1992 |
| GM | General Model Update and Verification Report | 1993 |
| SERM | NAM Calibration Report | 1991 |
| SERM | Verification Report | 1991 |
| SERM | NAM Calibration Report | 1992 |
| SERM | NAM Calibration Report | 1993 |
| SERM | Verification Report | 1993 |
| NWRM | Pilot Model Calibration Report | 1991 |
| NWRM | NAM Final Calibration and Verification Report | 1993 |
| NWRM | Full Model Calibration Report | 1993 |
| NWRM | Model Verification Report | 1993 |
| SWRM | Pilot Model Calibration Report | 1991 |
| SWRM | Full Model Calibration Report | 1993 |
| SWRM/SCRM | NAM Model Calibration Report | 1993 |
| SCRM | Pilot Model Calibration Report | 1993 |
| SCRM | Full Model Calibration Report | 1994 |
| NERM | Pilot Calibration Report | 1992 |
| NERM | NAM Final Calibration Report | 1993 |
| NERM | Full Model Calibration and Verification Report | 1993 |
| NCRM | Pilot Model Calibration report | 1992 |
| NCRM | Full Model Calibration Report | 1993 |

## 9.2 Modelling within FAP Projects

The SWMC models have been very important tools and supported general analyses and recommendations of approximately half of the projects under the FAP, notably the regional studies but also FAP 1, FAP 3.1, FAP 9A, FAP 10, FAP 16, FAP 20, FAP 21/22, and FAP 25.

The models being used have mostly been the Pilot Models and, hence, the use has not been without problems and in some cases even involved major problems. Most problems were overcome and as of today all the SWMC models are available as Full Models. The future use of these models is thus expected to run much more smoothly and is further enhanced through the FMM development under FAP 25.

The development of models at the SWMC has faced delays during SWSMP-II, notably because the assumptions made about data quality were overly optimistic. The timely development and delivery of these models from the SWMC to the regional FAP studies have been on the critical paths of these studies. However, through the dedicated and joint efforts of the SWMC and the regional FAP studies these delays have been minimised.

The decision of the GOB to prescribe the use of only one general river modelling system (i.e. MIKE 11) in FAP projects and the creation of a modelling coordinating framework under the FAP have led to an overall consistency and compatibility in modelling and planning approach which greatly facilitate the synthesis of FAP projects recommendations and the continuation of recommended projects into feasibility and detailed design phases.

Through model updating, refinement and the application of the FMM technology the SWMC models would be further enhanced and allow feasibility studies and detailed design to be more solidly founded than it would have been otherwise possible. The CAT *recommends* that this be appreciated by FPCO and BWDB in the preparation of Terms of References for these activities. Encouraging in TORs when relevant, the use of SWMC as model consultant would contribute to the capacity building and sustainability of the Centre.

## 9.3 Model Accuracy Requirements

Model accuracy requirements have been discussed throughout the FAP and latterly in connection with the establishment of the FMM. In 1992 FAP 25 prepared a note on the issue based on input from the regional FAP studies

indicating levels of accuracy, which are acceptable for users of the model results in the various phases of project planning, feasibility and design. The note was discussed at the 5th FAPMCC meeting in October 1992.

As stated previously, the CAT finds the proposed levels reasonable and realistic from a modelling point-of-view. The issue of possible improvement in model accuracy through a more comprehensive data collection has been brought up by members of the PoE. This issue touches upon the question of the economic value of reliable hydrological data. While appreciating the importance hereof, the CAT is not in a position, within its limited resources, to address this very complicated issue. Undoubtedly, however, the additional effort of the SWMC to improve the data collection of BWDB in 1990, 1991 and 1992 has been a worthwhile effort.

The level of detail to be included in a regional model is a trade-off between the need for accuracy and the advantage of a simplified model, and this of course depends on the complexity of drainage conditions in the area under consideration. While it is not possible for the CAT to assess in detail, it is the impression that the present regional models strike a balance in this respect. Ultimately, it is of course up to the individual model users to assess whether a particular regional model meets the accuracy requirements or a more detailed subregional model needs to be developed.

## 9.4 Model Updating Procedures

On the initiative of FAP 25 the SWMC in early 1992 prepared a set of procedures for regular updating of the SWMC models. These procedures were discussed at various occasions in the FAPMCC. The issue was also discussed during the Fourth and Fifth CAT Missions in December 1992 and November 1993 respectively.

The agreed procedure will include an annual verification based on the data from the preceding year. Updating will only be undertaken if this verification provides unsatisfactory results, or in the case of implementation of major new schemes, which could affect river flow and inundation patterns. Originally, it was the intention to do the verification during the winter period based on data for the period November through October, which allows updated models, based on the latest monsoon season, to be available in due course for forecasting in the next monsoon season.

However, as pointed to by the CAT in its Fourth Mission report, this may not be possible because BWDB normally makes data available only for hydrological years i.e. from April through March. This has been confirmed

during the present Mission. Thus model verification will be carried out based on data from the preceding hydrological year. As an example, the verification to be done in the SWMC during the winter 1994/95 will be carried out using 1993/94 data. The CAT considers this to be acceptable provided no major changes are likely to have occurred in the latest monsoon season. In those cases a special effort should be done to acquire the latest monsoon data for model verification.

The CAT recommends that the above procedure be published in the next SWMC Newsletter and also that SWMC, as previously recommended, establishes a clear nomenclature for updated releases of the General Model and the regional models.

For the purpose of model verification and updating the SWMC has requested BWDB to include some additional stations in their routine data collection programme. According to the Chief Technical Advisor of the ongoing UNDP support programme in BWDB Hydrology a general revision of the BWDB hydrometric network is presently under consideration. Recommendations are expected before the end of the year. The CAT recommends that the utmost be done to accommodate the wishes of the SWMC.

## 9.5 General Model Use and Model Storage, including Special Versions

The SWMC has been charged with hosting all MIKE 11 based river models, including special versions developed under the FAP. Also the SWMC is supposed to host models based on other software, including two-dimensional models.

SWMC has established standard procedures for receiving and archiving models developed or applied by users outside the SWMC. Finished FAP studies have returned their models to the Centre in accordance with these procedures.

The Inception Report of the SWSMP-III, dated July 1994 contains in Appendix E an agreement regarding the use of DHI software in projects for Government of Bangladesh. According to this agreement the MIKE 11 software package, including the MIKE 11-GIS, developed under FAP 25 is available for project work for GOB under a special license agreement free of royalties until January 1, 2000. Beyond 1996 (upon completion of SWSMP-III) a regular updating and service from DHI can be obtained, provided that a Service Agreement is established with DHI. Signing of this agreement is pending the signing of the government to government agreement of SWSMP-III.

# 10 MORPHOLOGICAL AND INTER-REGIONAL STUDIES

## 10.1 Introduction

In May 1991, on its second mission, the CAT raised the question of the "missing component" in FAP, namely a study to look at the overall morphological and hydrological effects of proposed and potential FAP projects.

The Third CAT Mission in December 1991 proposed a river morphology study as a key component of this (missing) inter-regional study. The CAT further proposed that a mission of international experts should be assembled in Dhaka to formulate details of the study.

The Fourth CAT Mission in December 1992 reiterated the request for the mission suggesting that it would carry out a preliminary morphological study to be followed by a more comprehensive study, identified by the mission, within the inter-regional study. Outline Terms of Reference for the mission were formulated and were included as an appendix to the fourth CAT report dated April 1993.

Two members of the CAT team attended the International Workshop on the Morphological Behaviour of the Major Rivers of Bangladesh held at the Sheraton Hotel, Dhaka, on 6 and 8 November 1993. At that meeting FPCO announced the formulation of a new study entitled "Morphological Study of the Major Rivers of Bangladesh". A first draft of the Terms of Reference for this study was being developed by GOB and preliminary comments were requested from the CAT.

The Fifth CAT Mission in November 1993 noted that the issue of a nationwide morphological study was being taken up by GOB. The CAT gave guidance to FPCO and made general recommendations as follows:-

- River morphology is a complex and difficult subject. The CAT, therefore, recommended the involvement of top world experts in the field of river morphology who would formulate, monitor and supervise the study.

- The CAT recommended that the study should be self contained and should not venture into those issues which are best dealt with on a regional basis.

- The CAT recommended that the study should be restricted to

morphological and hydrology/hydraulic issues and that social, economic, environmental and other aspects should be studied at regional level.

- The CAT urged rapid processing of the proposals because of the importance and urgency of the study. It also suggested phasing of the study such that early results would be available to support investment decisions.

- Finally the CAT recommended that the study should be initiated by fielding an expert mission. This subsequently took place in September 1994.

## 10.2 Expert Mission of September 1994

A high level, multi-disciplinary, international team of experts undertook the Mission in September 1994. Their brief was to draft a Project Document and Terms of Reference for the Morphological Study.

The draft Project Document, dated September 1994, includes a literature review, a report on the mission's field trip, a discussion of the key issues identified in consultation with the GOB and briefing notes to donors.

The draft Terms of Reference, of the same date, gives comprehensive guidance on aims, objectives, data, methodologies, connectivities with other projects, institutional aspects and anticipated outputs.

The CAT has general comments on the reports as follows:-

- One very general comment from the CAT is that the Morphology Study must not be side-tracked into studying detailed issues such as the sediment transport patterns in local areas. The study should be a top-down study which concentrates, at least initially, on the major issues of the anticipated changes to channel characteristics and patterns over the next 30 years or so.

- The TOR lists 12 anticipated Outputs. Predictions of future changes to the defined major rivers are discussed in Outputs 5 and 6. The CAT believes that these future changes to the rivers are important Outputs of the study and amplification of these Outputs is required. The CAT suggests that the predictions should cover the period to the year 2025. The CAT also suggests that the nature of the changes should be defined. It is desirable to know, for each of the designated

rivers, whether their size will increase or diminish, whether their plan position will change and, if so, to what extent, in which direction and how quickly.

- The TOR lists Techniques of Analysis to be used by the consultant and also the Objectives and Outputs. The CAT firmly believes that the linkages between the proposed methods and the desired outputs should be made clearer in the TOR.

- There is one deviation from previous CAT recommendations in the Mission's TOR. The Mission recommends limited socio-economic and environmental investigations as part of the morphological study. The CAT argues that the expertise required by these associated studies rests with Regional Consultants who have already done extensive work in this area and have reported their findings. The TOR provides for minimal inputs for these associated studies and appears to pay lip-service to the subject. The CAT maintains its long held view it study should only consider morphology, hydrology and river hydraulics.

- The morphology study, as defined by the mission, is quite extensive and the estimated cost of the study is commensurate with its importance. However, the spend rate is high and the CAT feels that the studies should be extended to about 42 months instead of the proposed 30 months to facilitate efficient working.



- The Mission Report Document states that the appointed consultant may use models other than those available at the SWMC where applicable. The CAT endorses this approach because of the need to introduce new ideas and techniques to help solve the difficult issues inherent in morphological studies. The CAT, however, recommends the use of SWMC as local consultants where its modelling expertise is applicable.

- The CAT endorses the idea that the use of FAP 24, or an extension thereof, should be considered for any additional data collection requiring the expertise and equipment held by FAP 24.

- With so many people involved in the study and so many aspects to investigate it will be difficult to strike the correct balance of effort in the various sectors. The CAT recommends the setting up of a small independent review panel of international experts comprising local and expatriate experts, who will meet in Bangladesh every six months or so to cast an independent eye on progress.

APPENDIX-1

**Planned Activities**

**for**

**Sixth Mission of Short-term Experts**
**on the Coordination Advisory Team (CAT)**

## 1. BACKGROUND

Component 25 of the Bangladesh Flood Action Plan (FAP 25), Flood Modelling and Management consists of the following three components:

i) A Coordination Advisory Team (CAT)

ii) A Flood Hydrology Study (FHS)

iii) A Flood Management Model (FMM)

The project is executed by the Flood Plan Coordination Organisation (FPCO), with the Danish Ministry of Foreign Affairs (Danida) as the lead donor. The donor agencies of France, the Netherlands and the United Kingdom also contribute to the project.

The CAT component has been ongoing since October 1990, while the FHS was completed in December 1992. The FMM, the last component, started in mid October, 1992 and is expected to continue to mid October 1994.

The Team of Short-term Experts of the CAT held their first meeting in Bangladesh in October 1990, producing an Inception Report dated November 1990. The following visits of the team took place in May 1991, December 1991,

December 1992 and November 1993. During the fifth visit, it was decided that the sixth visit of the team should take place in October 1994.

## 2. OBJECTIVES

The overall objectives of the CAT, as stated in the detailed Terms of

Reference for FAP 25, are:

i) to achieve consistency, compatibility and continuity in all related modelling activities;

ii) to coordinate the supply of models as tools to the various FAP projects and the feedback of relevant data and information from various FAP projects to the Surface Water Modelling Centre (SWMC)

The specific objectives of the Sixth CAT Mission are:

- review of the final outcome of FAP 25 in general and the future of the FMM in particular;

- review follow-up on recommendations of the Fifth CAT Mission report;

- advice to FPCO on any necessary steps to be taken in the continued coordination of modelling activities under the FAP;

## 3. ACTIVITIES

In pursuance of the provisions of clause 4.1 of the Terms of Reference of FAP 25, the work of the team will include the following activities:

a) Liaise with FPCO, SWMC and the PoE on the general progress and development of modelling activities within the FAP;

b) Attend a meeting of the FAP Modelling Coordination Committee (FAPMCC);

c) Review actions taken by FPCO, the Model Coordinator/Hydraulic Modelling Engineer, SWMC and the FAP components in the light of the report of the Fifth CAT Mission;

d) Participate in Third FMM workshop under FAP 25;

e) Review the general outcome of the FMM development and make recommendations for possible further development and applications;

f) Review actions taken on the institutional responsibility for maintenance, updating and operation of Flood Management Models considering possible developments and recommendations of FAP 26-

the Institutional Development Programme;

g) Report to FPCO.

## 4. COMPOSITION OF THE TEAM

The expatriate advisory Team of Short-Term Experts will be composed as follows:

- Dr. Rodney White (the United Kingdom)
- Mr. Johan Grijsen (the Netherlands)
- Dr. Jean Cunge (France)
- Dr. Torkil Jønch-Clausen, Team Leader (Denmark)

The Team will be supported by the Hydraulic Modelling Engineer, Mr. Emaduddin Ahmed and the Model Coordinator, Mr. Jørn Rasmussen of FAP 25 throughout their visit.

## 5. PROGRAMME OF THE VISIT

The team will work in Bangladesh in a 10-day period in late October/early November 1994.

Prior to leaving for Bangladesh, the Team will study available recent FAP reports of relevance for the CAT activities, notably the Final FMM Report if available. The Team will work closely with FPCO and hold discussions with the relevant government agencies, FAP consultants and donor agencies.

The Team will present its findings to FPCO, the PoE and the local donor representatives before its departure from Bangladesh.

## 6. REPORTING

The Team will submit a draft report within two weeks after their departure. The final report will be submitted to FPCO, with copies to the World Bank and the donor agencies of Denmark, France, the Netherlands and the U.K. before December 31, 1994.

## Programme of Sixth CAT Mission

| Day | Date | Time | Activities |
|---|---|---|---|
| Friday | 14 October | 1540 | Dr. Jean Cunge and<br>Dr. Rodney White arrive<br>(Mr Johan Grijsen arrives earlier) |
| Saturday | 15 October | 0900 | Visit FAP 25 office<br>Review Draft Final FMM Report<br>CAT internal |
| Sunday | 16 October | 0830 | FAP 20 |
| | | 1230 | Mr. Jorn Rasmussen arrives |
| | | 1400 | Embassies/Missions |
| Monday | 17 October | 1000 | Meet FPCO |
| | | 1530 | FAP 24 |
| Tuesday | 18 October | 0930 | FAP 19 |
| | | 1100 | Meeting Director General, WARPO |
| | | 1430 | World Bank |
| | | 1600 | FAP 6 |
| Wednesday | 19 October | 0930 | SWMC |
| | | 1130 | Meeting Additional Secretary, MOWR |
| | | 1400 | FAP 18 |
| Thursday | 20 October | 0900 | Meeting Chief Engineer, Planning, BWDB |
| | | 1030 | Mr. Karoly Futaky (BGD/88/054) |
| | | 1100 | Draft FMM Final Report Review at FPCO |
| Friday | 21 October | | CAT internal |
| Saturday | 22 October | 0900 | Debriefing FPCO |
| | | 1030 | 9th FAPMCC meeting at FPCO |
| | | 1230 | Mr. Johan Grijsen departure |
| Sunday | 23 October | 1100 | Dr. Jean Cunge at CFD |
| | | 1200 | Dr. Jean Cunge and Jorn Rasmussen departure |
| Monday | 24 October | 1800 | Dr. Rodney White departure |

**List of Key Persons Consulted**

MOWR
Mr. S.M. Afazuddin, Additional Secretary
Mr. A.S.M. Mobaidul Islam, Joint Secretary
Mr. Md. Shahjahan Ali, Deputy Secretary
Mr. M.A. Khaleque, Deputy Chief(Planning)

FPCO
Mr. M.H. Siddiqi, Chief Engineer
Mr. Ashfaqui Azam, Superintending Engineer

Panel of Experts
Mr. Md. Nurul Huda, Chairman
Prof. Jahiruddin Chowdhury

WARPO
Mr. Liaquat Hussain, Director General

BWDB
Mr. Anwar Yusuf, Chief Engineer, Planning

UNDP/BWDB Hydrology
Mr. Karoly Futaki, Chief Technical Advisor (BGD/88/054)

SWMC
Mr. A.S.M.A. Abdul Khaleque, Superintending Engineer
Dr. Ranjit Galappatti, Chief Technical Advisor
Mr. Anders Malgren Hansen, Environmental Modellor
Mr. Jalaluddin Md. A. Hye, Executive Engineer
Mr. Sharifuzzaman Chowdhury, Senior Consultant

Royal Danish Embassy
Mr. K. Kjaer Nielsen, Chargé d'Affaires
Mr. Erik Sjorslev Jensen, Counsellor

Caisse Francaise de Developpement (CFD)
Mr. Pin Yathy, Head of Delegation
Mr. Khawajah Ahmad

British High Commission
Dr. Harry Potter, First Secretary, Natural Resources

Royal Netherland Embassy
Mr. Bert Diphoorn, First Secretary Development (Water Sector)

World Bank
Mr. Ross Wallace, Resident FAP Coordinator

FAP 6
Dr. Harry King, Team Leader
Mr. Larry Bodnaruk, Modelling Specialist
Mr. Saifuddin Ahmed, Modeller
Mr. Mujibul Haq, Agriculturist Expert

FAP 18
Mr. Heikki Perennius, Team Leader, FINNMAP

FAP 19
Mr. Darrell L. Deppert, Chief of Party
Mr. Timothy Martin, Team Leader

FAP 20
Mr. Hans Visser, Team Leader

FAP 24
Mr. Pieter van Groen, Team Leader
Mr. Hans Hoyer, Chief Surveyor

FAP 25
Dr. Guna Paudyal, Team Leader
Mr. Bill Syme, Computational Hydraulic Engineer

Mr. Johan Crebas, Flood Control Engineer II