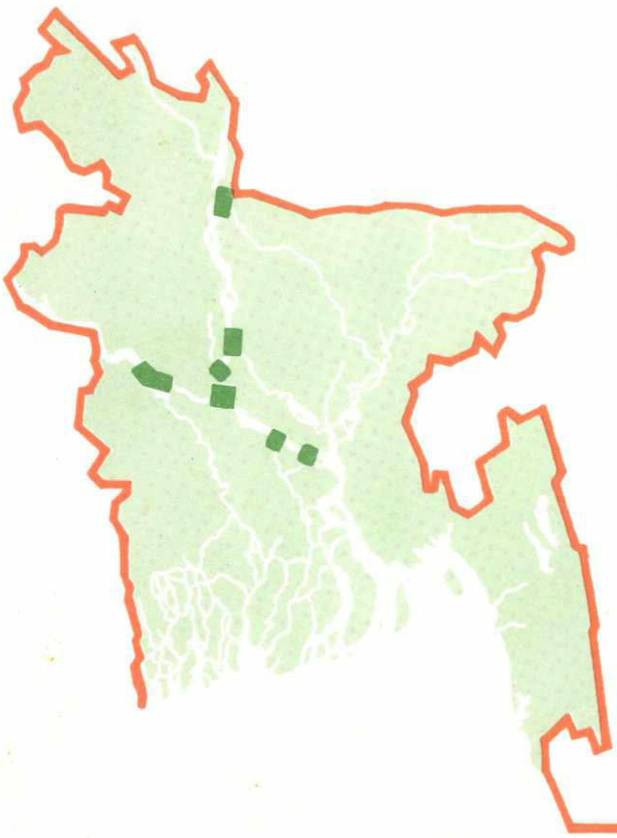
GOVERNMENT OF BANGLADESH
FLOOD PLAN COORDINATION ORGANIZATION

FAP 24 RIVER SURVEY PROJECT

River bathymetry assessment by radar remote sensing



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River bathymetry assessment by radar remote sensing

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1 Introduction

1.1 Background

Remote sensing has proven to be a highly valuable tool for the understanding, the monitoring and the prediction of morphological processes in the major rivers of Bangladesh. Examples in the broadest sense of the term are satellite remote sensing, aerial photography, echosounding and measurements by ADCP, but the operational meaning of the term is usually restricted to gathering information through instruments mounted on aircraft or orbiting space vehicles. Satellite and aircraft remote sensing has major advantages over traditional survey methods on the ground. It provides synoptic information on large areas in a fast and cheap way. The synoptic information allows the recognition of morphological patterns, which is important for the identification of the relevant processes of erosion and sedimentation.

The objective of a morphological assessment determines which type of remotely sensed data is the most useful. Research on underlying mechanisms, short-term predictions for construction works (e.g. Jamuna bridge, FAP 21 test structures) and the positioning of navigation buoys require a high level of detail. Then aerial photography and the high-resolution imagery of SPOT provide the best information. For long-term predictions (e.g. site selection for structures, early anticipation of developments which are to be altered by recurrent measures), images from LANDSAT and MOS are more useful, because the morphological system of the major rivers in Bangladesh exhibits deterministic chaos (Klaassen & al, 1993) and this deterministic chaos implies that the consideration of a sufficiently long river reach (and a probabilistic approach) is more significant for the quality of the predictions than the use of a high level of detail. Sometimes rough indicators are sufficient for even short-term predictions. That is the case when only the general changes of the channel pattern in the river need to be monitored. Examples of such rough indicators are the detection of positions and alignments of main channels and, on the ground, the measurement of water surface slopes at carefully selected locations (Peters, 1981; Peters & Wens, 1991).

The following problems pose limits to the applicability of remote sensing:

- The earth surface can be invisible due to clouds, which are ubiquitous in Bangladesh in the flood season when the major portion of the morphological changes occurs. This is a problem for the traditional optical and infrared remote sensing, but not for radar remote sensing because radar radiation penetrates clouds.
- Sediment concentrations can reduce the visibility of submerged river beds. However, radar backscatter from a water body is not affected by turbidity.
- Aerial photographs and satellite images are basically two-dimensional, whereas river beds are essentially three-dimensional. There are several ways, however, to derive three-dimensional information from photographs or images. Photogrammetry can be used to map the

topography of islands and floodplains from pairs of aerial photographs. Institutional problems, however, severely limit the use of aerial photography in Bangladesh. Another way is to derive elevation contours from inundation boundaries on a series of images, taken at different water levels. Finally, there are special radar remote sensing techniques for bathymetry assessment and topographic mapping.

The analysis of these problems shows that radar remote sensing can be a very powerful tool. It penetrates clouds, is not affected by turbidity and can be used to assess the three-dimensional shape of river beds. Bathymetry assessment and topographic mapping by radar remote sensing are discussed in Sections 1.2 and 1.3 respectively. The discussions lead to the conclusion that bathymetry assessment by radar is most promising for the major rivers in Bangladesh. Based on that, the objective and approach for a project to introduce this technology is formulated in Section 1.4.

1.2 Bathymetry assessment by radar remote sensing

The technique of bathymetry assessment by radar remote sensing is operational for coastal areas and shallow seas (Vogelzang & al, 1992; Hesselmans, 1994; Hesselmans & al, 1994), but could also have a high potential for large rivers like the Jamuna, the Ganges, the Meghna and the Padma in Bangladesh. The technique is based on indirect observation, since radar radiation itself does not reach the river bed. Variations in bed level produce modulations in surface flow velocities. The latter cause variations in the spectrum of water surface waves and hence variations in water surface roughness. Radar backscatter is a function of this surface roughness. This chain of relationships implies that the bathymetry can be assessed by a data assimilation technique, starting from an assumed bathymetry. Numerical models for (1) water flow, (2) generation and advection of waves and (3) radar backscattering are used to compute a corresponding radar image. Evaluation of the differences between this simulated radar image and the real radar image reveals the required adjustments of the assumed bathymetry. A new radar image is computed in the same way from the adjusted bathymetry and this whole procedure is repeated until the differences between the simulated and the real image are smaller than a prescribed accuracy level. The bathymetry thus obtained is approximately equal to the real bathymetry.

River bathymetry assessment by radar remote sensing would greatly enhance two major applications:

- *Optimization of traditional bathymetric surveys:*
  The quick synoptic and relatively cheap survey with remote sensing offers a possibility to optimize a combination of remote sensing and traditional survey methods. The reduction of costs would be valuable in particular because the expensive traditional survey methods are often not sustainable in low-income countries.

- *Study of morphological processes :*
  The synoptic observation of morphological changes during a flood serves the central objectives of the River Survey Project FAP 24.

- *Early warning system for undesired river planform changes:*
  The monitoring of morphological changes during a flood would be a valuable support for the operation of the recurrent measures proposed under FAP 22.

The idea to assess the bathymetry of rivers in Bangladesh with radar remote sensing was explained and discussed within FAP 24 in 1992 and presented during the International Workshop on the Morphological Behaviour of the Major Rivers in Bangladesh, held in Dhaka in November 1993 (Mosselman & Wensink, 1993). It resulted in the decision to carry out a pilot project within the framework of the FAP 24 River Survey Project (topic 9.5 in letter RSP/3.7/998 to FPCO). The radar image of the confluence of the Jamuna and the Ganges in Figure 1.1 shows that backscatter patterns do have a relation with bathymetry. Application to the major rivers in Bangladesh seems hence promising.

Figure 1.1 : ERS-1 image of the confluence of the Jamuna and Ganges Rivers.

1.3 Topographic mapping by radar remote sensing

The topography of islands and floodplains is relevant for morphological assessment, as large floods can inundate and mold those areas as well. Pairs of radar images can be used for topographic mapping through the technique of radar interferometry (Zebker & Goldstein, 1986; Hirosawa & Kobayashi, 1986; Gabriel & al, 1989). There are, however, some problems which make the applicability to islands and floodplains in the rivers of Bangladesh questionable:

- The accuracy depends on vegetation. The effect of vegetation is negligible or absent in mountains and on ocean surfaces, but considerable on the relatively flat islands and floodplains;
- The accuracy is affected by atmospheric perturbations;
- Successful application of the technique requires a high correlation between the two images, which is not ensured when the two images are taken several weeks apart.

No further actions are proposed in this direction.

1.4 Objective and approach

The objective of the pilot project within FAP 24 is

to make the technique of bathymetry assessment by radar remote sensing suited to the major rivers of Bangladesh.

This is not a trivial formulation, because application to rivers is more complicated than application to coastal areas and shallow seas. Hence adaptations are needed in the three numerical models underlying the imaging mechanism. The first step is a campaign with simultaneous measurements of bathymetry, flow field, water surface waves and radar backscatter. This is elaborated in Chapter 2. The measured data are used to adapt the three numerical models. The expected adaptations are analyzed in Chapter 3. The resulting system is tested in a verification study and installed in Bangladesh. The feasibility for Bangladesh is assessed and recommendations are given on the use of radar remote sensing for the optimization of traditional bathymetric surveys and for a morphology early warning system. The verification study and the transfer of technology in Bangladesh are treated in Chapter 4. Chapter 5 comprises the workplan for all these activities.

2 Measurement campaign

2.1 General

The pilot project starts with a measurement campaign in which radar backscatter, bathymetry, flow field and water surface waves are measured simultaneously. Wind speed, wind direction, air temperature and water surface temperature are measured as well, because they govern the generation of waves. The radar backscatter is measured from the ERS-1 and ERS-2 satellites, the other quantities from two FAP 24 survey vessels. Rain is registered in the log if it disturbs the water surface during satellite overpass.

The measurement campaign will take two weeks in July or August 1995. It will cover a 20×10 km^2 area near Bahadurabad, between BTM northings 2770 and 2790, see Figure 2.1.

Data from only a part of the area will be used for the adaptation of the underlying numerical models. The data from the remainder of the area will be used for the verification study.

The radar measurements cover the whole area and recording takes less than a minute. The field measurements are collected along section lines about 200 m apart. By using a DGPS the position of each vessel can be monitored with an accuracy of 5 m.

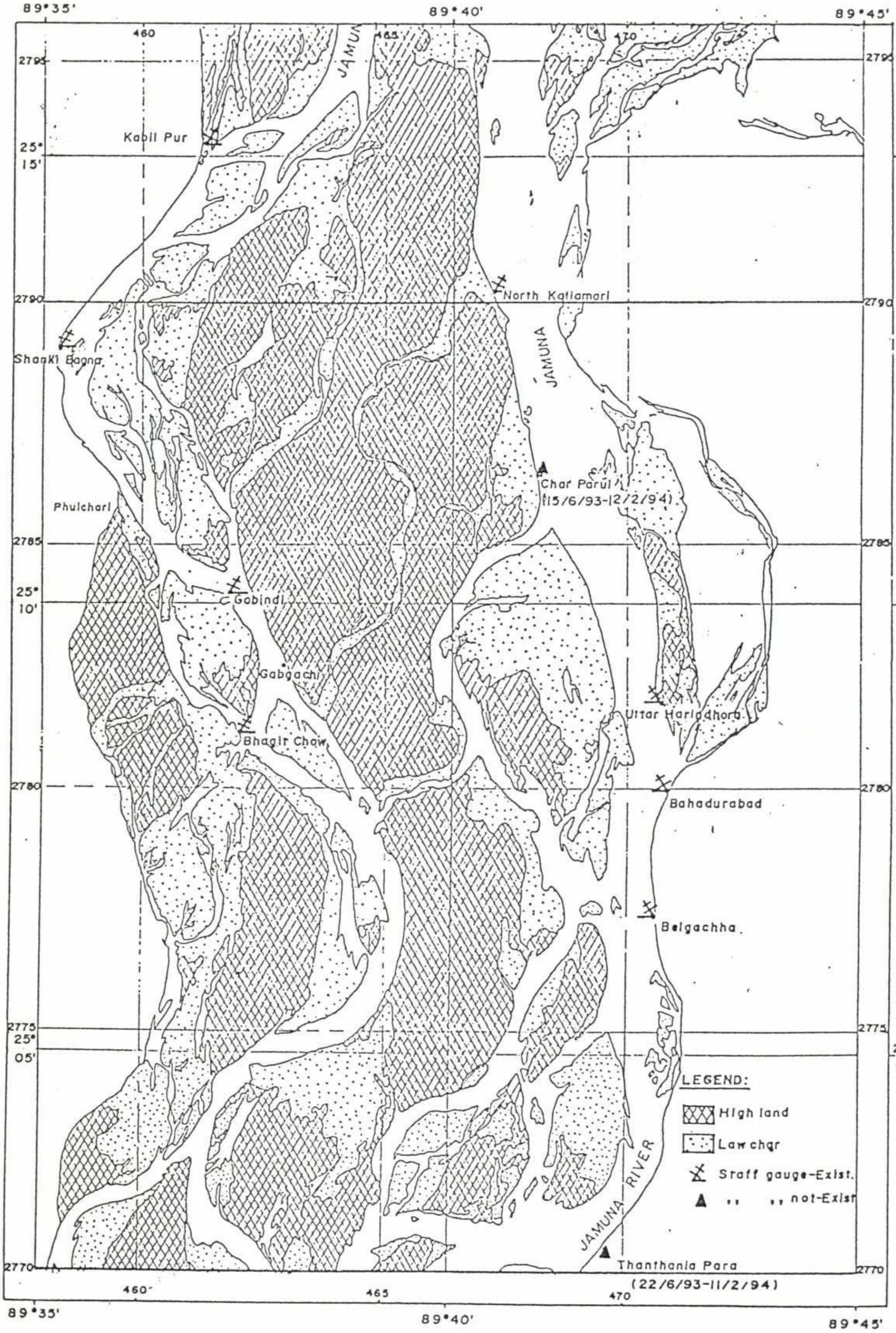

Figure 2.1 : Project area.

2.2 Radar backscatter

Synthetic aperture radar (SAR) images of the project area will be collected during each overpass of an ERS-1 or ERS-2 satellite in the campaign period. In two weeks about 3 to 5 images of the area can be recorded. ERS precision SAR images have a pixel size of 12.5×12.5 m^2, a resolution of 30 m and cover an area of 100×100 km^2.

2.3 Bathymetry

The bathymetry in the area will be measured with an Acoustic Doppler Current Profiler (ADCP) and a dual-frequency echosounder. Depths are sounded once per second. This results in a sampling interval of 1.5 m for a ship velocity of about 3 knots. The depth accuracy is better than 0.20 m. Depth measurements are reduced to Standard Low Water (SLW).

2.4 Flow field

Flow velocities and directions will be measured along each sailed track at intervals of 6 seconds. An Electromagnetic Flow Meter (EMF) is used to measure the flow at a depth of 0.5 m, whereas the ADCP is used to measure the flow at depth intervals of 0.5 m, starting 2.7 m below the surface and ending 1.5 m above the river bed. The measuring accuracy is about 0.1 m/s.

Depth-averaged flow velocities and directions are derived from the measurements.

2.5 Water surface roughness

The water surface roughness is produced by two types of waves, wind waves and waves produced by high flow velocities. The wind waves can be measured directly or be calculated from measured wind and temperature data (see Sections 2.6 and 2.7).

The Bragg waves are the relevant waves on the water surface, because radar backscatter is proportional to the water surface wave energy at the Bragg wave length. They are defined as the waves which have the same wave length as the radar radiation, corrected for the angle of incidence. For a radar wave length of 30 mm and an incidence angle between 17° and 30°, the Bragg wave length varies between 0.05 and 0.25 m. This is hence the range of interest for measurements. There are no generally accepted procedures to measure these short (capillary) waves under varying flow conditions. For wind waves, standard relations hold between the energy densities at different wave lengths, so that the energy near the Bragg wave length can be derived from wave measurements at other wave lengths. As yet, however, no such standard relations are known for flow-driven waves.

Different characteristic wave conditions will be recorded by video. Oral comments indicating time and position are added while recording. A staff gauge with clear elevation marks will be mounted on a cantilevered beam from the vessel. The video must zoom in on the water level at the gauge, but also zoom out to give an overview of the water surface pattern.

2.6 Temperature

The air and water surface temperatures will be measured at the moments when the radar images are recorded. The difference between these temperatures influences the effect of wind on the roughness of the water surface. If the water is warmer than the air, the air-water interface becomes unstable. As a consequence, the water surface becomes rougher than it would be for the same wind speed under normal conditions.

2.7 Wind

Wind speeds and directions will be recorded at five-minute intervals starting one hour before and ending one hour after satellite overpass.

2.8 Rain

Rain is registered in the log if it disturbs the water surface during satellite overpass.

3 Adaptation of system to river conditions

3.1 Introduction

The imaging mechanism is based on three numerical models, which have proven to perform well in shallow seas (Vogelzang & al, 1992), the coastal waters of Belgium and The Netherlands (Hesselmans & al, 1994) and the coastal waters of Germany (Hesselmans, 1994). The major rivers of Bangladesh, however, involve the following additional problems:

- The geometries are more complex. The efficiency of the computations can then be substantially improved by formulating the models in a curvilinear boundary-adapted coordinate system.
- The flow fields are more complex. Hence some of the simplifications used for coastal areas and shallow seas are no longer justified.
- The water surface roughness is not only a result of wind waves. High flow velocities produce waves as well.
- There is no data infrastructure for radar remote sensing in Bangladesh.

The first three problems require adaptations of the numerical models. They are analyzed in the next sections of this chapter. The last problem is adressed in Section 4.3.

3.2 Curvilinear coordinate system

Two-dimensional models for complex geometries are more efficient when they are formulated in a curvilinear boundary-adapted coordinate system. This implies that the model equations must be transformed to the curvilinear coordinates and that a numerical grid generator must be added to the system. Grid generators producing orthogonal and smooth curvilinear grids are available at DELFT HYDRAULICS.

3.3 Flow model

The tidal flows in coastal areas and shallow seas change only gradually from one place to another. They can be modelled well with a one-dimensional mass balance (continuity equation). Even in the coastal waters of Germany where the flow direction along a streamline changes 90°, a locally one-dimensional formulation without curvature correction can be applied (Hesselmans, 1994). The flows in the Jamuna River, however, are much more complicated and require at least a two-dimensional depth-averaged flow model which includes the balance of forces, accelerations and decelerations (momentum equations) as well.

The flow in the Jamuna River is mainly friction-dominated and quasi-steady. Hence, the inertia terms are neglected in the initial approach. This results in a considerable reduction of computation time. The approach leads to the following set of two-dimensional equations in a curvilinear orthogonal coordinate system (s,n):

$$\frac{u\,v}{R_s} - \frac{v^2}{R_n} + g\,\frac{\partial z_w}{\partial s} + \frac{g\,\sqrt{u^2+v^2}}{C^2\,h}\,u = 0$$

$$\frac{u\,v}{R_n} - \frac{u^2}{R_s} + g\,\frac{\partial z_w}{\partial n} + \frac{g\,\sqrt{u^2+v^2}}{C^2\,h}\,v = 0$$

$$\frac{\partial (h\,u)}{\partial s} + \frac{\partial (h\,v)}{\partial n} + \frac{h\,u}{R_n} + \frac{h\,v}{R_s} = 0$$

$$C = C(u,v,h)$$

$$h = z_w - z_b$$

in which u and v are flow velocity components in s and n direction respectively, R_s and R_n are radii of curvature of the s and n coordinate lines, g is the acceleration due to gravity, z_w denotes water level, z_b denotes bed level, h denotes water depth and C is the Chézy coefficient for hydraulic roughness.

The bathymetry data and depth-averaged flow data from the measurements are used to assess whether this model can reproduce the flow field with sufficient accuracy. If necessary, the flow equations are extended with convective terms or with simple relations for three-dimensional effects. The deviation of the surface flow direction due to spiral motions, for instance, can be modelled in a simple way along the lines of Kalkwijk & de Vriend (1980).

3.4 Wave model

The waves in coastal areas and shallow seas are generated by the wind. Modulations in their spectrum due to flow velocity variations can be modelled with the action balance equation, using a relaxation term to simulate the restoring forces of wind input and wave breaking.

In the Jamuna River, high flow velocities generate waves as well. It seems that there is no model for these flow-generated waves. A short literature search of studies on flow-generated waves will be carried out to verify and substantiate this statement. Then an empirical relation between wave data and flow data will be induced from the measurements.

4 Operationalization in Bangladesh

4.1 Verification study

Only data from a part of the project area will be used for the adaptation of the numerical models. The data from the remainder of the area will be used for the verification study in Bangladesh. The verification study will be carried out by image processing specialists of SPARRSO and FAP 19 under the supervision of an expatriate radar remote sensing specialist of FAP 24.

4.2 Technology transfer

The supervised execution of the verification study by image processing specialists of SPARRSO and FAP 19 will serve as an on-the-job training. A broader dissemination of knowledge on the possibilities and limitations of the technique will be pursued within the framework of the FAP 24 training programme.

4.3 Data infrastructure

Operational applications require a fast availability of remotely sensed radar data. This means that a good connection with the ERS ground station of the Thailand Remote Sensing Centre in Bangkok must be established. A possible future alternative is that radar satellite data are received at SPARRSO or at the regional ground station at the Atomic Energy Research Establishment in Savar, Bangladesh.

5 Work plan

5.1 Work break-down

5.1.1 Introduction

The activities of the project are grouped in eight distinct work packages. They are described below. The work packages 2, 3 and 4 are recommended to be executed in the Netherlands for reasons of available computer infrastructure and short communication lines with various specialists in related fields. Execution in Bangladesh is also possible, but requires extra costs for setting up a suitable computer infrastructure (see Annexure A) in Bangladesh and for explicit backstopping by the specialists in related fields.

5.1.2 Work package 1: Measurement campaign

The measurement campaign consists of the following activities:

1.1 Mobilization
1.2 Measurements during survey according to standard procedures of FAP 24, including quality assurance
1.3 Writing of survey report, which includes: description of survey area, positions of measured transects, outline of survey data, description of the digital data format
1.4 Acquisition of ERS SAR images
1.5 Writing of report on the remote sensing data and the hydro-meteorological conditions during image acquisition. The latter bears on the operational feasibility of the method. Hard copies of the relevant part of the satellite image will be included and the quality of the image will be verified.

5.1.3 Work package 2: Model adaptation

The adaptation of the model consists of the following activities:

2.1 Flow model:
- Comparison of flow measurements with model predictions
- Adaptation of the model, if necessary
- Testing, with assessment of effect of simplifications

2.2 Water surface wave model:
- Short literature search of studies on waves produced by high flow velocities
- Induction of an empirical relation between wave data and flow data (flow velocities, flow gradients etc.) from the measurements
- Implementation of empirical model for flow-generated waves

2.3 Interfacing of the models, with adaptation of data assimilation procedure

2.4 Testing, using data from a part of the project area
2.5 Writing of progress report, which includes: description of the bathymetry assessment system, the modifications and the test results.

5.1.4 Work package 3: Testing of model performance

The testing of model performance consists of the following components:

3.1 Channel detection:
- Assessment of the visibility of channels in the SAR imagery. Interpretation ambiguities will be resolved by using SPOT images
- Determination of differences in channel position on subsequent ERS SAR images

3.2 Survey optimization:
- Generation of bathymetric maps based on ERS SAR data and subsets of the survey data
- Assessment of the accuracy of these "limited survey" maps

3.3 Writing of progress report on test results.

5.1.5 Work package 4: Software update

The updating of the software consists of the following activities:

4.1 Adaptation of software for input, output and presentation to the BTM (Bangladesh Transverse Mercator) coordinate system
4.2 Writing and updating of software documentation and user manuals.

5.1.6 Work package 5: Installation of software in Bangladesh

5.1 Selection of the organization and location where the software is to be installed.
5.2 Installation.

5.1.7 Work package 6: Knowledge transfer

Knowledge will be transferred through a six-day course and on-the-job training for about four Bangladeshi experts. The knowledge transfer comprises the following activities:

6.1 Preparations
6.2 Introductory course, comprising:
- background theory
- presentation of survey measurements, SAR data (see work package 1)

- presentation of previous results (see activities 2.4, 3.1 and 3.2)
- introduction to software, manuals and documentation

6.3 On-the-job training and case study

- getting started: reading, writing, plotting, inspecting data, etc.
- reproduction of results obtained in work package 3
- processing of remaining part of survey data.

A broader dissemination of knowledge on the possibilities and limitations of the technique will be pursued within the framework of the FAP 24 training programme.

5.1.8 Work package 7: Verification

A verification is carried out by evaluating the results of the case study.

5.1.9 Work package 8: Final report

This final report will present the results of the project and provide recommendations on the operational use. In particular, a detailed description of the way in which radar remote sensing can be used to optimize traditional bathymetric survey methods will be elaborated.

5.2 Required input and time planning

An overview of the required number of manweeks is given in Table 5.1. The time planning is shown in Figure 5.1. The decision on the precise period of the measurement campaign will be taken in the beginning of 1995 when the final orbits of the ERS-1 and ERS-2 satellites are known, as well as the availability of the survey vessels. An acquisition request will be sent to ESA as soon as the campaign period has been selected, in order to ensure the recording of SAR images. The data will be acquired through the ERS ground station of the Thailand Remote Sensing Centre in Bangkok.

Work package	Description	Country	Manweeks	
			expatriate specialist	local specialist
1	Measurement campaign	Bangladesh	4*	*
2	Model adaptation	The Netherlands	12	
3	Testing of model performance	The Netherlands	8	
4	Software update	The Netherlands	4	
5	Installation of software in Bangladesh	Bangladesh	4	4
6	Knowledge transfer	Bangladesh	4	8
7	Verification	Bangladesh	4	6
8	Final report	Bangladesh	4	

* survey crew not included

Table 5.1 : Required manweeks for work packages.

The available resources of FAP 24 do not allow execution of all these work packages within the framework of the River Survey Project. Additional funding is being sought.

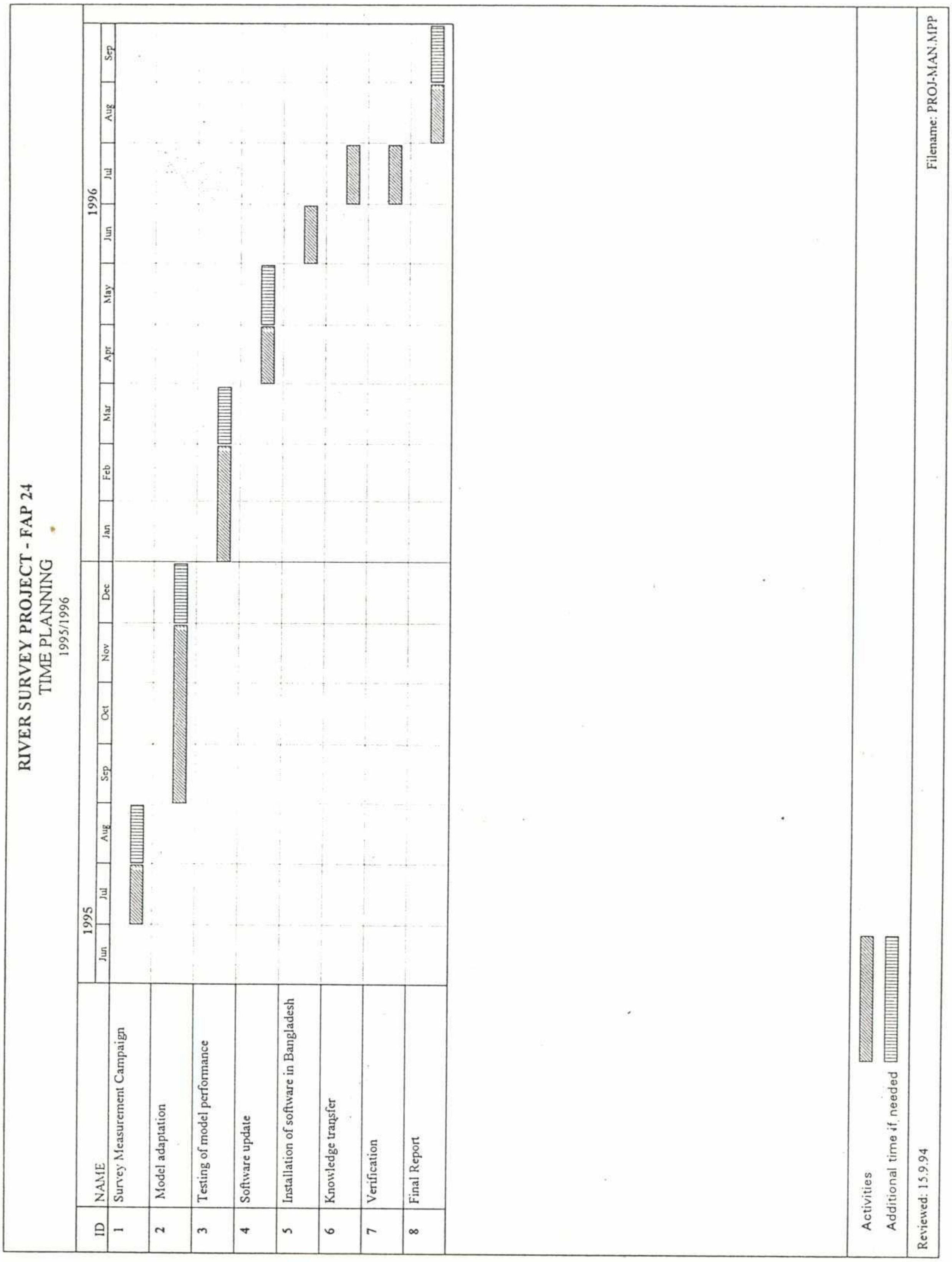

Figure 5.1 : Time planning.

Additional expenses are:

- three to five ERS images, costing about US$ 800,- each
- two SPOT images
- computers
- PC-WAVE licence
- reproduction of reports
- travel and subsistence

5.3 Products

Reports are produced and results and data are made available after each work package. They are specified below.

Work package 1, measurement campaign:

- Survey report, with all measured data, data formats, measurement procedures, weather conditions (wind, rainfall, temperature) and scale 1:20,000 maps showing transects sailed, river banks and bathymetry.
- Survey data in digital format:
  - bathymetry: x,y,z,t
  - flow vector: x,y,z,t,u,v,w
  - wind vector: x,y,z,t,U,φ
  - temperature: x,y,z,t,T_{air},T_{water}
  - river bank: x,y,t
  - water level: x,y,z,t

  where:

  x = easting in BTM
  y = northing in BTM
  z = depth or elevation
  u,v,w = components of flow vector
  U = wind speed
  φ = wind direction
  T_{air} = air temperature
  T_{water} = water temperature

  The river slope, which is about 0.07 m/km, will not be measured. A suitable value will be selected to fit the predictions of the flow model to the measurements (see work package 2).
- Video tape recording of wave conditions.
- Remote sensing report, with description of the acquired SAR images and hard-copies of the relevant part of the images. The hydro-meteorological conditions will be discussed in relation to the conditions in Bangladesh in general.
- Remote sensing data: all the acquired ERS data.

Work package 2, model adaptation:

- Progress report, with a complete description of the different models in the bathymetry assessment system. The adaptations of the models are explained and the results of the test are presented, with an assessment of the accuracy.

Work package 3, testing of model performance:

- Test report, with a discussion of the potential of the system for optimization of traditional bathymetric surveys and channel detection in a morphology early warning system.

Work package 4, software update:

- Software, adjusted to the major rivers in Bangladesh
- Documentation and user manuals

Work package 5, installation of software in Bangladesh:

- Bathymetry assessment system installed on a suitable computer system in Bangladesh. In view of future hardware and software developments it is recommended to postpone the selection of the hardware.

Work package 6, knowledge transfer:

- Introductory course and on-the-job training

Work package 7, verification:

- Case study report

Work package 8, final report:

- Final report, with conclusions on the technical and operational feasibility of the system and recommendations for the optimization of traditional bathymetric survey methods and a morphology early warning system.

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Annexure-A

Hardware and software requirements

Currently the software of the bathymetry assessment system at DELFT HYDRAULICS runs on a HP710 workstation with 32 Mbyte RAM and 1.8 Gbyte harddisk. By means of a local network, the workstation is connected to peripherals, such as a colour printer and a tape reader for the satellite images. The software of the bathymetry assessment system is programmed mainly in a fourth-generation language. This software package is called PV-WAVE. It is available for a number of other workstations as well as for personal computers.

If the software system is implemented on a PC, the system requirements are:

- Windows 3.1 operating system
- 386 processor plus co-processor
- 640×480 8-bit display
- 8 Mbytes RAM
- 20 Mbytes available on hard disk

In addition 1 GByte on hard disk is required to store the remote sensing data and the bathymetric maps. Furthermore, the system should be part of a local area network in order to connect it to peripherals as mentioned above.