DRAFT

BANGLADESH FLOOD ACTION PLAN

TECHNICAL REPORT

CLASSIFICATION OF FLOOD DEPTH AND EXTENT USING GIS AND MIKE 11

GEOGRAPHIC INFORMATION SYSTEM (FAP 19)

Prepared for

The Flood Plan Coordination Organization (FPCO)
of the
Ministry of Irrigation Water Development and Flood Control

February 1993

ISPAN
IRRIGATION SUPPORT PROJECT FOR ASIA AND THE NEAR EAST
Sponsored by the U.S. Agency for International Development

2

DRAFT

BANGLADESH FLOOD ACTION PLAN

TECHNICAL REPORT

CLASSIFICATION OF FLOOD DEPTH AND EXTENT USING GIS AND MIKE 11

GEOGRAPHIC INFORMATION SYSTEM (FAP 19)

Prepared for

The Flood Plan Coordination Organization (FPCO)
of the
Ministry of Irrigation Water Development and Flood Control

February 1993

ISPAN
IRRIGATION SUPPORT PROJECT FOR ASIA AND THE NEAR EAST
Sponsored by the U.S. Agency for International Development

A-12

ISPAN

IRRIGATION SUPPORT PROJECT FOR ASIA
AND THE NEAR EAST

ISPAN Technical Support Center
Room 1001
1611 North Kent Street
Arlington, Virginia 22209-2111
USA
Phone: (703)243-7911
FAX: (703)525-9137
TELEX: 276532 ISPAN UR

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

BWDB Bangladesh Water Development Board

CPP Compartmentalization Pilot Project

DEM Digital Elevation Model

FAP Flood Action Plan

GIS Geographic Information System

MPO Master Plan Organization

TIN Triangular Irregular Network

9

Classification of Flood Depth and Extent Using GIS and MIKE 11

1. Introduction

This study examined the feasibility of using Geographic Information System (GIS) technology and hydrodynamic modelling to classify and map flood depth and extent. This was the first time in Bangladesh that GIS was used to enhance the output of MIKE 11, the hydrodynamic model adopted as the standard by the Flood Action Plan (FAP). In the course of the study, a variety of GIS software, analysis methods, and assumptions were investigated.

1.1 Basic Techniques

Although MIKE 11 data are generally presented in tabular form, by using GIS techniques that same data can be used to develop a spatial model of flooding extent.

Flood depth classifications produced by this method have many applications, among them: resource allocation and optimization modelling, crop suitability studies, environmental impact assessment, and disaster preparedness studies. The flood depth maps and spatial data generated by the methods outlined in this report can be compared with other GIS themes, such as land use and soil type.

This study used GIS surface modelling, a technique in which a DEM is created for both the land surface and the flood level surface (FAP 19 February 1993a). The intersection of the two surfaces defines the potentially flooded area and the depth of flooding. Figure 2 shows a hypothetical vertical section through a floodplain landscape—assuming a horizontal water surface—with depth categories and zones indicated. The GIS models the expected depth of flooding by extending the process to two dimensions from the point data results of MIKE 11. Those results were used to produce flooded area extent-duration-depth curves for "with project" and "without project" scenarios. Assuming there are sufficient data points, this allows the flood depth to be represented over the extent of the area of interest. In all cases the flood depth was mapped using a grid or raster-based DEM. In some cases, however, data structures based on a Triangular Irregular Network (TIN) were used to interpolate water levels onto a grid and create a framework for a raster-based interpolation.

1.2 Land and Water Surface Modelling

Experiments were carried out using data from MIKE 11 regional and subregional models, and Digital Elevation Models (DEMs) created using the two sources of nationwide land surface data: the Master Plan Organization (MPO) 1 km grid and the Bangladesh Water Development Board (BWDB) 4 in. and 8 in. to 1 mi. maps (FAP 19 February 1993a and 1993b). The subregional model was based on the FAP 20 Tangail Compartmentalization Pilot Project (CPP). Regional model outputs were taken from the North Central and Southwest regions. Figure 1 shows the location of the study areas.

MIKE 11 provides water level results at each cross section or flood cell of the model. The location of the cross section, or boundaries of the flood cell, are fixed for the model, providing the only information available to interpret water levels for floodplain mapping. The water level is assumed to be representative of the cross section or flood cell. The validity of this assumption depends on the sophistication and detail of the model. All flooding is assumed to be caused by the modelled drainage network; flooding by drainage congestion is not considered. Thus the flood depth classification may tend to underestimate flooding in some areas.

The accuracy of the flood surface generated by GIS modelling is influenced by assumptions about the nature of flooding. Different modelling options were considered in seeking to generate the most representative flood surface. These were:

- Assuming a sloping water surface versus a level pool in each flood cell.
- Including only flood surfaces contiguous with the main river versus noncontiguous water surfaces.

It is difficult to construct a genuine sloping surface from the one-dimensional MIKE 11 output. The best way to do so would be to construct a TIN based on the exact location and extent of the potential flooded width at each section, but these data are not readily available (Figure 3). An alternative method is to create a sloping water surface from a TIN-structured DEM taken directly from the MIKE 11 water levels, then interpolate the TIN onto a regular grid. The procedure to determine the flooded areas from this potential model is identical to using a grid structured DEM. Contiguity with the main river is difficult to model because of the lack of reliable information. So, for this study, noncontiguous areas of flooding were normally accepted. The exception to this was for known project areas, which in some cases were "masked out" in the flood depth model and designated as poldered areas.

MIKE 11 model scheme plans were digitized from 1:50,000 scale mapping for subregional studies and 1:250,000 scale for regional studies. Although vector data processing methods were used to create DEMs of the water surface, flood depth estimates were made using a raster format. The basic raster size for the subregional studies was 40 m and a 300 m grid spacing was used for the regional studies. To put the grid sizing into perspective, 40 m corresponds to 0.8 mm on the 1:50,000 scale maps and 300 m corresponds to 1.2 mm on the 1:250,000 scale maps.

2. Tangail Subregional Model

The Tangail study area, located in the north central region, comprises 13,000 ha at latitude 24°10' to 24°20' north, and longitude 89°50' to 90°31' east. The area consists of 16 compartments of land subjected to water level control. Each compartment is represented by one or more MIKE 11 flood cells, small components of each compartment, with a total of 45 flood cells.

The Tangail subregional component of this project was carried out for FAP 20 to test the use of GIS in converting DEMs into flood depth classification maps using MIKE 11 outputs. The result was a set of flooded area maps for different flood control interventions for FAP 20 (FAP 19 November 1992).

2.1 Land Surface Modelling

A digital elevation model for the study area was created from spot heights digitized on 200 m by 220 m centers from the BWDB 8 in. to 1 mi. maps. The spot heights were geo-referenced to the Bangladesh Transverse Mercator projection (FAP 19 May 1992). A DEM was generated from the spot heights on a 40 m grid using a procedure that interpolates a value based on the distance weighted average of all points found within a given radius of the interpolated point. The weight function used was:

$$W = \left(1 - \frac{D}{S}\right)^2$$

where D = calculated distance
S = 300 m = search radius.

The interpolated value for each grid cell in the raster array was:

$$\frac{\sum (W_i \times D_i)}{\sum (W_i)}$$

where $_i$ = the ith point found within the search radius.

Compartment and flood cell boundaries, permanent water bodies, and human settlements (homesteads) were digitized from the 1:50,000 scale SPOT image maps with supplementary detail from 1:20,000 aerial photographs. Rivers were classified differently from other water bodies.

2.2 Water Surface Modelling

The MIKE 11 output files give the water levels in each flood cell for each time step of the model. A water surface elevation model was created for selected times in a flood sequence by redefining the flood cells to the output water level for each cell at each selected time. This has the effect of creating a horizontal water level surface in each cell. A simulated perspective view of the potential water surface is illustrated in Figure 4.

2.3 Flood Depth Map

Flooded areas were calculated by determining the flooding depth, if any, at each grid point. Areas classed as homesteads were excluded. Then the data were reclassified into five flood level classes corresponding to depths of flooding: 0-30 cm, 30-90 cm, 90-180 cm, 180-300 cm, and greater than 300 cm. Note that these levels do not classify the land according to the MPO land type classes used for identifying suitable cropping patterns under a flood regime.

2.4 Digitizing and Data Processing

Table 1 shows the resources required to digitize the maps for the Tangail model. Digitizing times include all checking, editing, and joining of individual map sheet information into a single seamless sheet, where appropriate.

Table 2 shows the resources that are required for the different tasks involved in creating a flood depth classification map. The MIKE 11 model results were supplied on an ASCII file of X-Y-Z coordinates that were incorporated into the GIS data base.

Excluding the time to create the land surface DEM and to digitize the compartment data, the time needed to create a flood depth extent map in raster format for a single time step is about one and a half hours. Thus, to create a series for a typical flood season of four months at 10 day intervals would take 18 hours.

2.5 Results

Figure 5 is a typical raster output from the Tangail project showing the extent of flooded area at two different times with and without project intervention. Figure 6 shows how flood extent varies over the season. This was obtained by converting the original raster format into vector format, illustrating the use of alternative formats for presenting results. The vector data can be plotted more economically than the raster format at any scale and with no loss of resolution. It also is compatible with many computer-aided drafting outputs used by engineers, which may be important if the analysis is to be extended or integrated with other information.

Table 3 shows some typical results for flood depth classes, in this case

Table 1
Digitizing Resources, Tangail Model

Source	No. of Sheets	Feature Digitized	Preparation Time (person days)	
			Preparation	Digitizing
1:50,000 SPOT Map	2	Compartment boundaries	1	2
1:20,000 Air Photos	2	Homesteads	1	3
1:50,000 SPOT Map	2	Water bodies	0.5	1
1:50,000 SPOT Map	2	Infra-structure	0.5	1
8 in. to 1 mi.	8	Spot Heights	2	16

Table 2
Resources Required for the Tangail Subregional Study

Task	Time (Hours)
Preparation and Setup	
Converting each vector format overlay onto a raster on a 40 m spacing.	1.0
Creating the land surface DEM by interpolating the spot heights onto a 40 m grid from eight map sheets with 12,000 points, checking the results, and modifying.	24.0
Analysis and Flood Mapping	
Reading MIKE 11 water levels.	0.1
Building the water surface elevation model by recoding the compartment overlay.	0.4
Determining the flooded areas.	0.5
Color map output.	0.5

Table 3
Flood Depth Classes Based on Model Run of July 16, 1991 (hectares)

Subcompartments	Flood Depth Classes 0-30	30-90	90-180	180-300	>300	Net Cultivable Area	Settlements	Water Bodies	River Areas	Total
1	130	144	227	52	0	553	134	1	0	688
3	7	87	292	24	0	410	198	22	0	630
11	285	327	197	12	0	821	290	14	0	1,125
Louhajong Floodplain	608	485	269	9	0	1371	425	7	166	1,969

for the Tangail area without a project for a model run of July 16, 1991. Note how net cultivable area and other land types are separated. This is achieved by using the GIS overlay functions.

3. North Central Regional Model

Figure 7 shows the channel network scheme for the western part of the MIKE 11 North Central regional model. It has been modelled in three sections: old Brahmaputra, western area, and eastern area. This study considered only the 214 flood cells of the western area. The original data was digitized at 1:250,000 scale.

3.1 Land Surface Modelling

The digital elevation model was built on a 300 m grid from both the 4 in. and 8 in. to 1 mi. scale BWDB maps. For the western part alone, spot heights were digitized at either 100 x 300 m (4 in. mapping) or 200 x 220 m centers (8 in. mapping). Flood depth mapping also was performed using a DEM created from the MPO 1 km grid. This model was extracted from the FAP 19 national DEM.

3.2 Water Surface Modelling

Water level information from the North Central regional model was generated for daily conditions between dates May 1989 and November 1991. The identification of each cell and cross section was obtained from the river name and chainage files of MIKE 11, and a map showing the cell and cross section locations. A water surface model was created for the potential flood levels of each cell by attributing the MIKE 11 water level to that cell by simple reclassification.

3.3 Flood Depth Map

The flood depth map was produced by subtracting the land level DEM from the potential flood level surface and coding the depth class in each cell. The newly coded image map shows the flood depth class. It can be used to compute on a cell-by-cell basis, or other basis, the area for each flooding depth. This procedure was performed using both the BWDB and MPO digital elevation models for land surface.

3.4 Digitizing and Data Processing

A DEM was created in 208 person days from digitized spot heights using sixty 4 in. and forty-four 8 in. to 1 mi. maps. The boundaries of some 330 flood cells were digitized from a single 1:250,000 scale map. This took six person days including editing. Rivers, roads, railways, and other embankments were digitized from 1:50,000 scale maps.

It took three days to generate the land surface DEM and about one hour to reclassify the flood cell areas with each set of MIKE 11 water levels. Producing a flooded area map, including raster printing, took 30 minutes. Converting raster data to vectors and plotting (using ARC-INFO) took three hours.

3.5 Results

Figure 8 shows a typical flooded area map for a segment of the regional model comparing results from MIKE 11 for July 13, 1991, for the two different land surface DEMs (MPO and BWDB). Table 4 compares estimates of flooded areas for selected representative flood cells for the two DEMs.

4. Southwest Regional Model

Figure 9 shows the scheme plan of the southwest regional model, a model with imprecise definition of the flood cell locations. Water level information came from the flood period of September 1984. September 20-27 was chosen because satellite images for part of the area were available for those days. A set of X-Y-Z values represents each point on the river network.

4.1 Land and Water Surface Modelling

The land surface was modelled by interpolating the FAP 19 national DEM, which is based on the MPO 1 km grid data, onto a 300 m grid.

Three water surface modelling methods were tested for this area. In the first method, a TIN was constructed from the location of each calculated water level and interpolated linearly onto a regular 300 m grid. In the second method, a weighted average technique with different sets of parameters (FAP 19 February 1993a) was used to interpolate a surface onto the same 300 m grid. A Voronoi or Thiessen diagram was constructed from the TIN in the third method. The resultant Thiessen polygons then were treated as flood cells with their water levels being attribut-

Table 4
Comparison of Flooded Areas of the North Central Model Computed Using Two DEMs (hectares)

	Flood Depth in cm				
	0-30	30-90	90-180	180-300	>300
Area 6					
MPO	3411	801	108		
BWDB	3087	981	252		
Area 12					
MPO	1458	495	1026	63	
BWDB	1062	720	1035	225	
Area 63					
MPO	1746	1782	1782	909	81
BWDB	396	1917	2718	846	423

ed to each polygon. The Theissen diagram is constructed from the TIN by delineating the area that is closest to each spot elevation point. An on-screen interactive comparison of the three basic methods indicated that if the actual definition of the flood cells is not available, the Theissen simulated flood cells provide the best results for representing the flood surface.

4.2 Flood Depth Map

Flood depth maps were produced by subtracting the land DEM from the flood surface and coding for the depth class in each cell, assigning a flood-free code to negative values. The effects of empolderment and embankments were taken into account by recoding apparently flooded areas lying within schemes to a depth code appropriate to the particular scheme.

4.3 Digitizing and Data Processing

The drainage network and polder and embankment boundaries did not have to be digitized in this model as they were provided by the South West Area Water Resources Management Study (FAP 4). The X-Y-Z MIKE 11 water levels were provided by FAP 4 as an ASCII file. The same ASCII file was used for the ERDAS surface interpolation software, then mapped onto a TIN structure, and used to generate the TIN and Theissen diagram.

It took 25 minutes to generate the water surface TIN from some 1,095 points. It took three hours to interpolate it onto a 300 m grid and one hour to construct the Voronoi diagram. It took 30 minutes to generate a 859 x 912 grid of water surface elevations on a 300 m grid using the grid interpolation routines. Producing a flooded area map, including raster printing and masking polders took one hour. Converting rasters to vectors and plotting (using ARC-INFO) took three hours.

4.4 Results

Figure 10a shows flood depth maps with no polders and Figure 10b shows the same with polders and embankments. Note that embankments also have been plotted, but when the flooded surface was processed it was not known if they were actually completed.

Table 5 shows several model areas, ranging from mostly flood-free land to deeply flooded land, by flood class for each interpolation method. These results should not be used for design purposes because they represent only a typical set of flood levels associated with an incomplete calibration of the model, and poldered areas have not been excluded. These data are presented to compare methods, not to present definitive conclusions about flood depth. Most of the values, however, are close enough to one another to indicate that all methods are adequate for prefeasibility studies. The results are most divergent where there is nonflooded land.

5. Conclusions and Recommendations

In general, using GIS technology for post-processing of MIKE 11 outputs was found to be feasible and useful. The benefits are great compared to manual methods of processing. Considerable effort is needed to create the necessary DEMs for regional studies, but once the necessary data sets have been prepared a large number of applications based on the results becomes possible: computing flooded area depth duration curves, identifying beneficiaries of flood protection, evaluating alternative cropping patterns, and assessing impacts on the environment.

Table 5
Area Flooded for a Typical Set of Flood Depth Classes (percent)

Method	Land not Flooded	Flood Depth in cm				
		0-30	30-90	90-180	180-300	>300
Area 13						
TIN	76.8	8.0	10.5	9.2	2.4	
Raster surface	52.1	9.9	17.2	15.7	3.1	
Thiessen	61.4	4.5	6.3	8.8	13.7	3.1
Area 19						
TIN	50.8	7.7	17.9	17.8	3.4	0.1
Raster surface	48.8	5.8	16.6	21.9	4.6	0.1
Thiessen	50.1	7.4	15.2	17.6	7.4	0.1
Area 28						
TIN		0.5	20.5	75.9		
Raster surface		0.5	20.5	75.8		
Thiessen		0.7	22.9	73.2		
Area 217						
TIN			12.8	59.3	23.9	
Raster surface			13.3	73.3	9.4	
Thiessen		0.2	13.5	67.5	12.3	1.9

In terms of software and data structures, it is recommended that raster GIS functions be used for flooded area determination. After necessary format conversion, vector GIS can assist data input and output, while in certain cases, the TIN structure can be used to create the potential flooded water surface.

5.1 Land Surface Modelling

A 40 m raster spacing is recommended for subregional scale modelling, and a 300 m grid spacing is recommended for regional and general scale models.

The land surface DEM should be generated from spot heights taken from the 4 in. or 8 in. to 1 mi. or similar maps for all scales of modelling. Pending the availability of a national DEM generated from the 4 in. and 8 in. mapping, regional model studies can use the 300 m grid generated from the 1 km MPO DEM.

5.2 Water Surface Modelling

For subregional studies, and for quick results, the flooded surface can be represented by a level pool in each flood cell. If more time is available, a sloping surface can be interpolated and sections of water not contiguous with the main river can be altered to better represent actual field condition. The time required to set up a sloping water surface is longer than can be justified for regional studies.

If detailed flood cell locations are not available, and if there is a sufficient density of water levels, the flooded surface can be generated using a Voronoi diagram for each point. The Voronoi diagram can be constructed using the TIN data structure and then be converted to a raster structure. A level pool is assumed in each cell thus constructed.

5.3 Flood Depth Map

For engineering needs, the most satisfactory use of GIS in assessing the impact of flood control interventions at the regional level is to map the areas for which interventions are intended and intersect the MIKE 11 flood cells with the land surface DEM. The area-elevation curves for each cell created then can be generated and evaluated using computed water levels in each cell from MIKE 11, or from the interpolated water surface.

An additional important advantage of using GIS is that the locations and the depths of flooding also are derived. This is valuable when designing engineering scheme layouts and making environmental impact assessments.

5.4 Subregional Modelling

A satisfactory data source for delineating flood management compartments and land class for subregional models is the 1:50,000 scale SPOT image maps. The 4 in. or 8 in. to 1 mi. BWDB maps are sufficient for obtaining spot heights with which to create a DEM, unless more up-to-date large-scale mapping is available.

The Tangail project showed that it is feasible to use GIS MIKE 11 to produce maps for subregional models showing flood depth, extent, and duration.

Data sets generated for flood modelling can be useful for many other activities. For example, Tangail project data are being used for environmental impact assessment (FAP 16) and flood management modelling (FAP 25).

5.5 North Central Model

The cost of producing flood depth mapping once the basic model geometry and DEM has been created is reasonable: one hour per time step or flood event after linking the MIKE 11 results to the GIS. Once the linkage has been established for a particular MIKE 11 format, mapping new results takes about 10 minutes. Therefore, if a reliable DEM is available for a region, GIS flood depth analysis will be cost-effective.

When using the national DEM based on the MPO 1 km grid versus the full-resolution BWDB mapping, at the flood cell level there can be substantial differences in flooded area for each flood depth class. At the regional level, however, as Figure 8 shows, the results are similar. Differences in estimated area of each flood phase are often pronounced for flood cells smaller than 10,000 hectares. These differences do not necessarily translate directly into a difference in benefits from flood control measures, but the disparity between benefit estimates may be significant and should be considered perhaps by means of sensitivity analysis on the benefit calculations.

It was difficult to locate the cross sections and flood cell water elevations from MIKE 11. As the MIKE 11 model for this region was developed, changes were made that were not communicated to the GIS data set. Such problems indicate the need for closer coordination and integration of GIS and MIKE 11 modelling.

5.6 Southwest Regional Model

The location and topology of the flooded cells in the southwest regional model was not definitive, but by collaborating with the modelling team it was possible to transfer MIKE 11 outputs showing each level and its spatial coordinates to the GIS. In the low-lying areas the variation in water level is small, making it acceptable to interpolate water levels between many of the rivers; this is less true for the higher land to the northwest. Incorporating the embankments and polders reduces apparent error in determining flooded areas if the effect of these structures is known. Definition of flood cells in such a flat region is always likely to be a problem. Thus, the accuracy of the model will depend on ancillary information on actual flood patterns.

The differences in flood depth and area for different methods of interpolation were quite small. The most satisfactory method for producing a flooded water level surface when flood cell structures are poorly defined is by a Thiessen polygon interpolation around each flood level. If that method is not available, an acceptable alternative is to use a TIN based on the original MIKE 11 water levels interpolated onto a 300 m grid. The Thiessen polygon method is preferred with the level pool assumption, especially when embankments are considered, because the water level surface is not allowed to slope away from one river to an adjacent river in an unrealistic fashion. The embankments confine the interpolation to the areas outside the embankments.

5.7 Future Extensions

More time is needed to improve the modeling of sloping water surfaces using the TIN data and to more realistically model flooded areas not contiguous with the source of flooding. The current approach does not necessarily indicate which areas are likely to be contiguous with the flood source because minor drainage channels are not represented.

More work also is needed in dealing with surface runoff within polders and embankments, and in main river areas where congestion and drainage problems are caused by high water levels. These problems cannot be solved satisfactorily using GIS modelling techniques; hydrological and hydraulic flood routing methods are needed.

6. References

FAP 19. November 1992. *GIS Atlas for Tangail Area Study.*

FAP 19. May 1992. *Bangladesh Transverse Mercator Projection.*

FAP 19. February 1993a. *Constructing Digital Land and Water Surface Models for Bangladesh.*

FAP 19. February 1993b. *Generation of Area Elevation Curves Using GIS.*

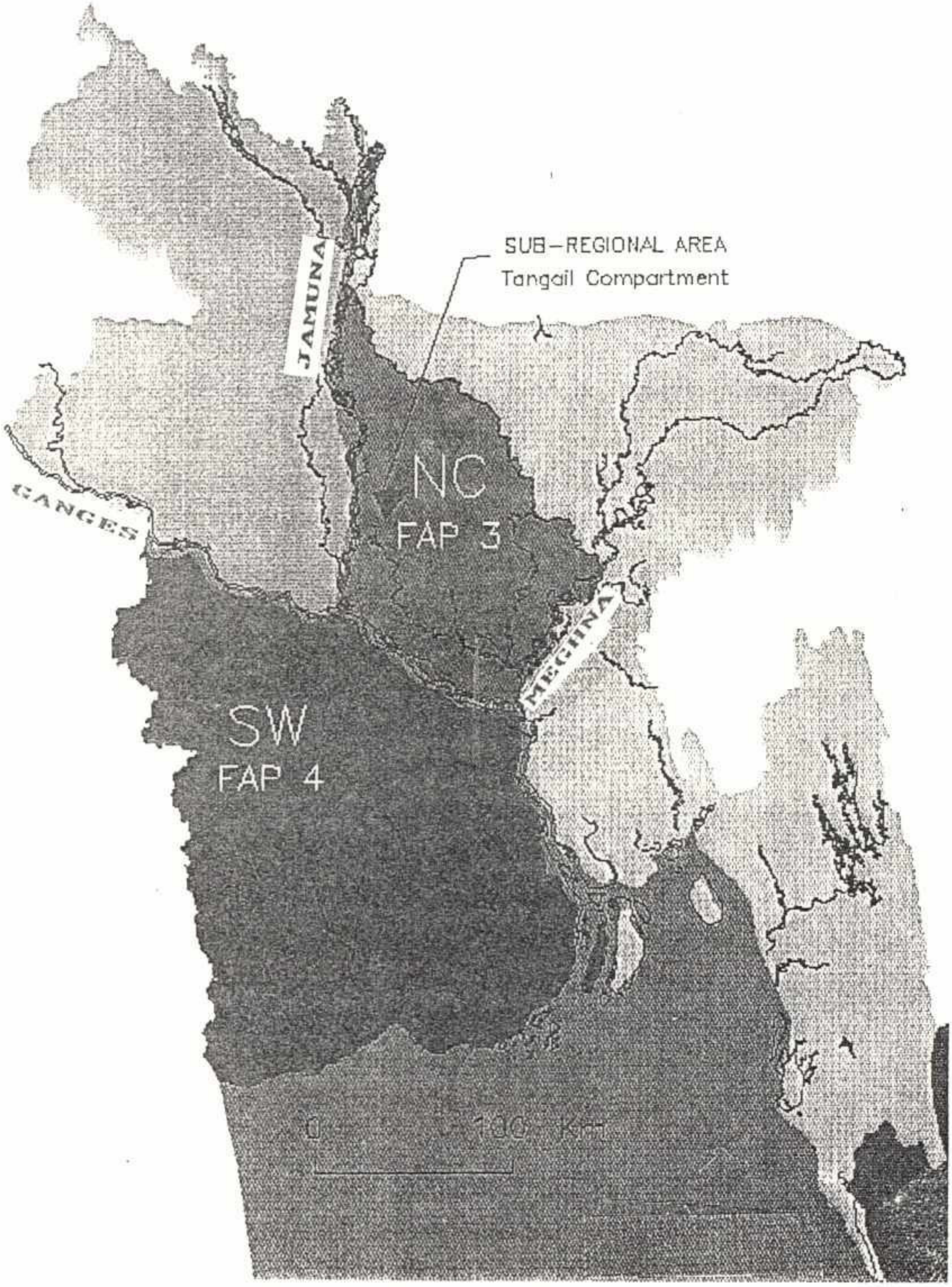

Figure 1: Location of Study Areas

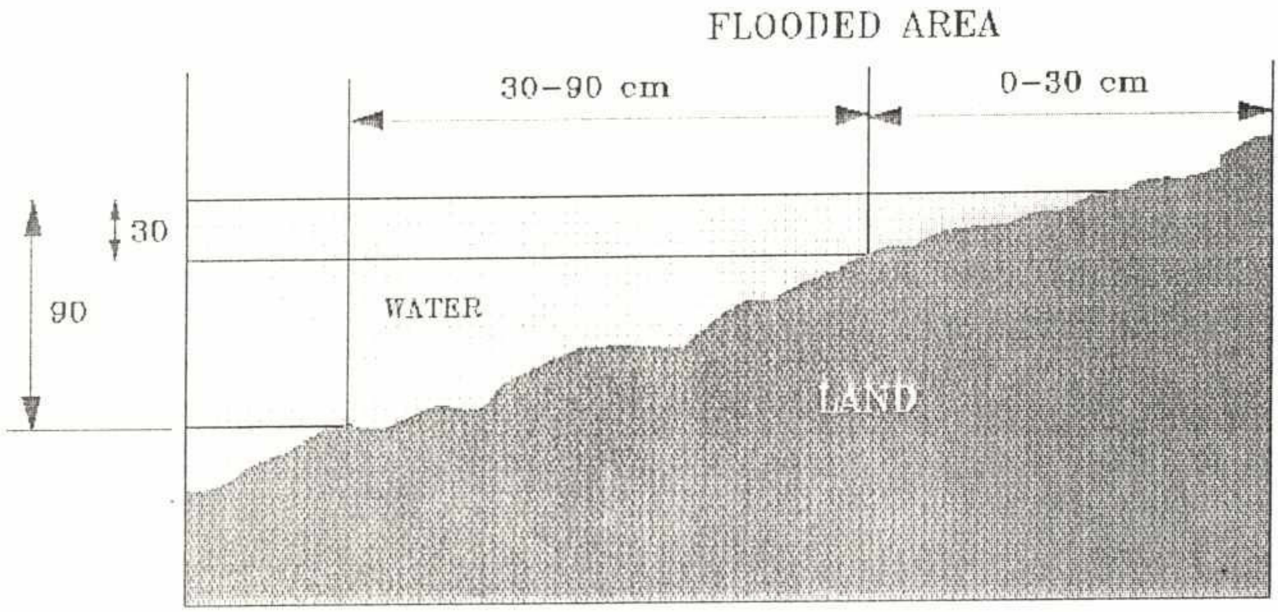

Figure 2: Hypothetical Vertical Section Through a Floodplain Landscape

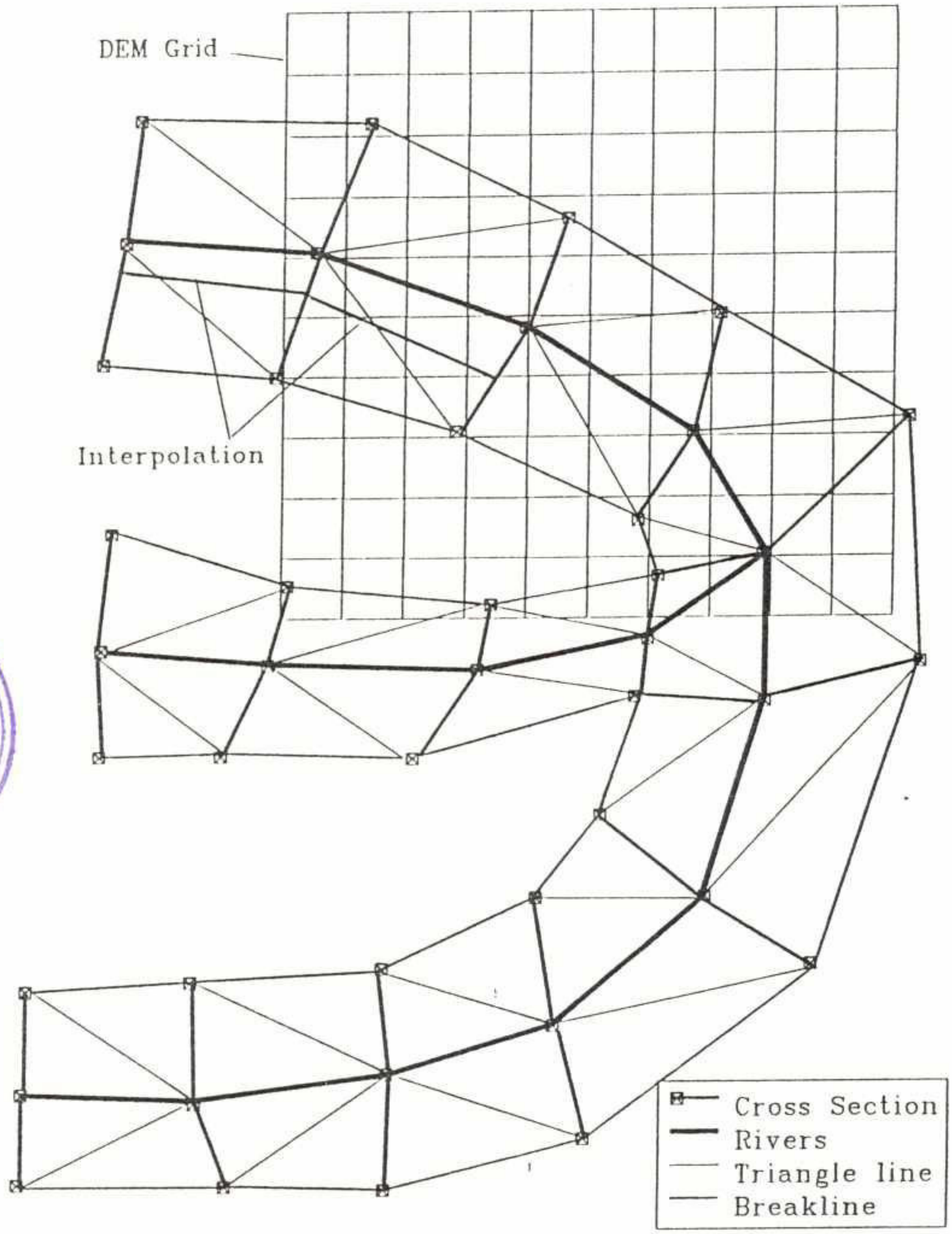

Figure 3: Proposed Method of Creating a Flood Surface by Constructing a TIN Based on the Location and Extent of Potential Flooding at Cross Sections

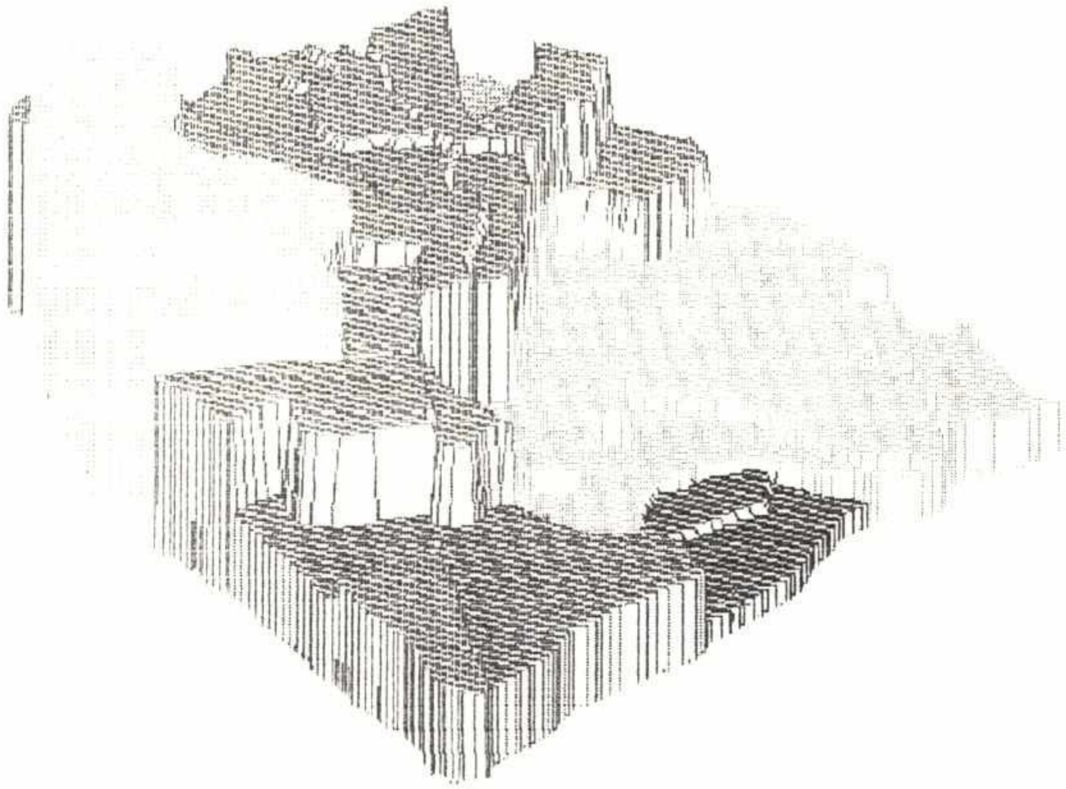

Figure 4: A Simulated Perspective View of the Water Surface from the Tangail Model Results

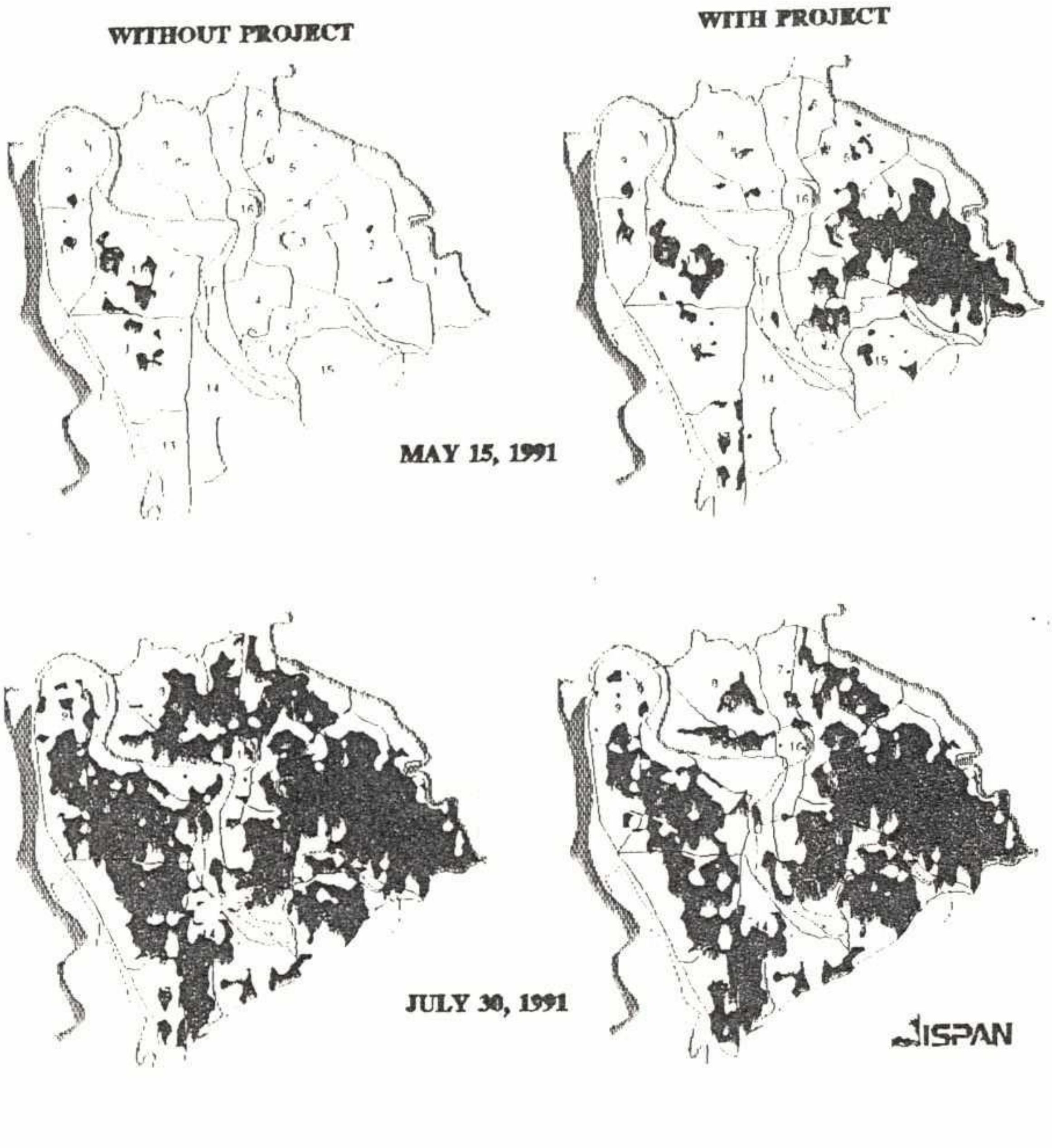

Figure 5: Raster Output from the Tangail Model

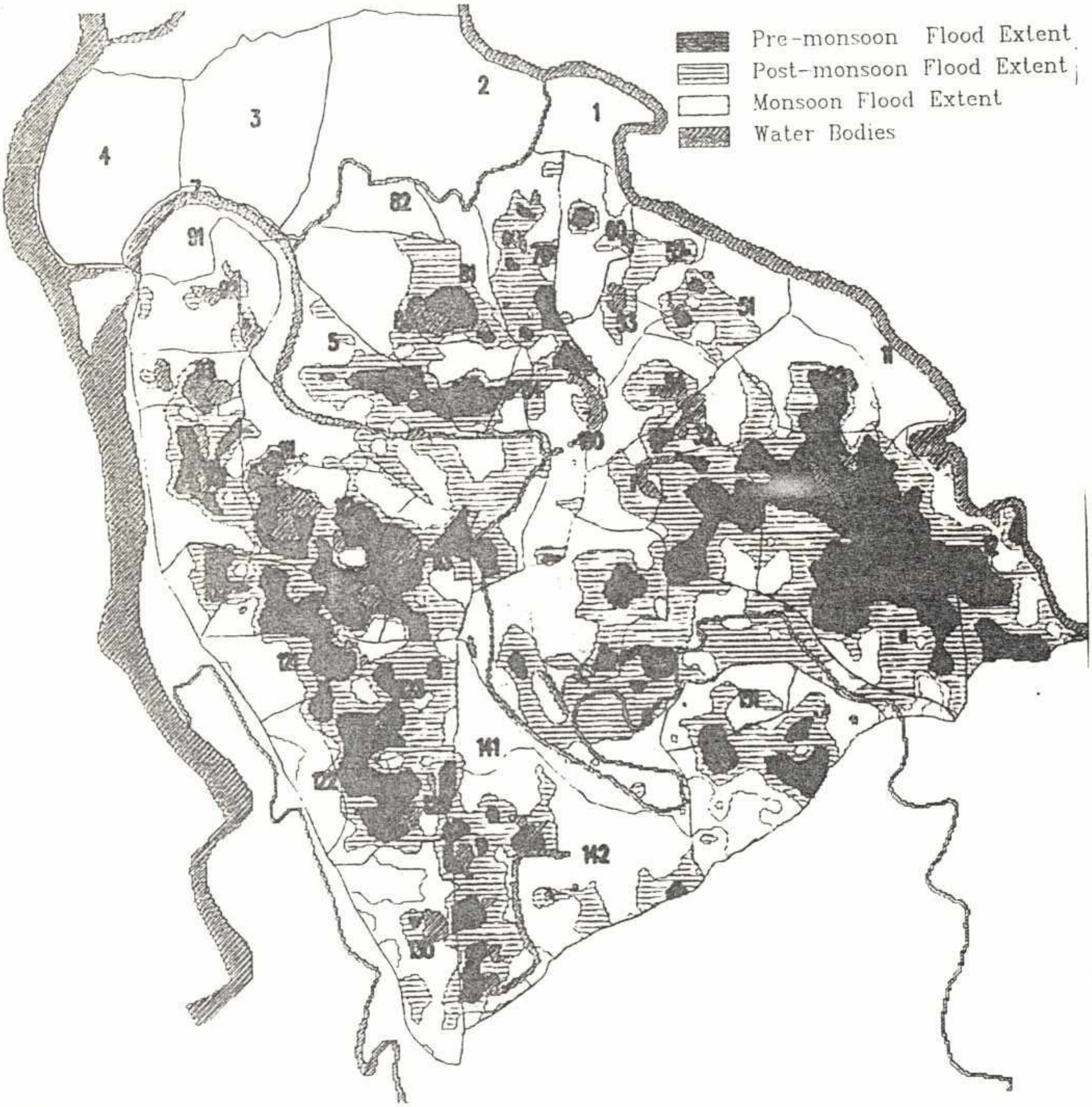

Figure 6: Typical Vector Output from the Tangail Model

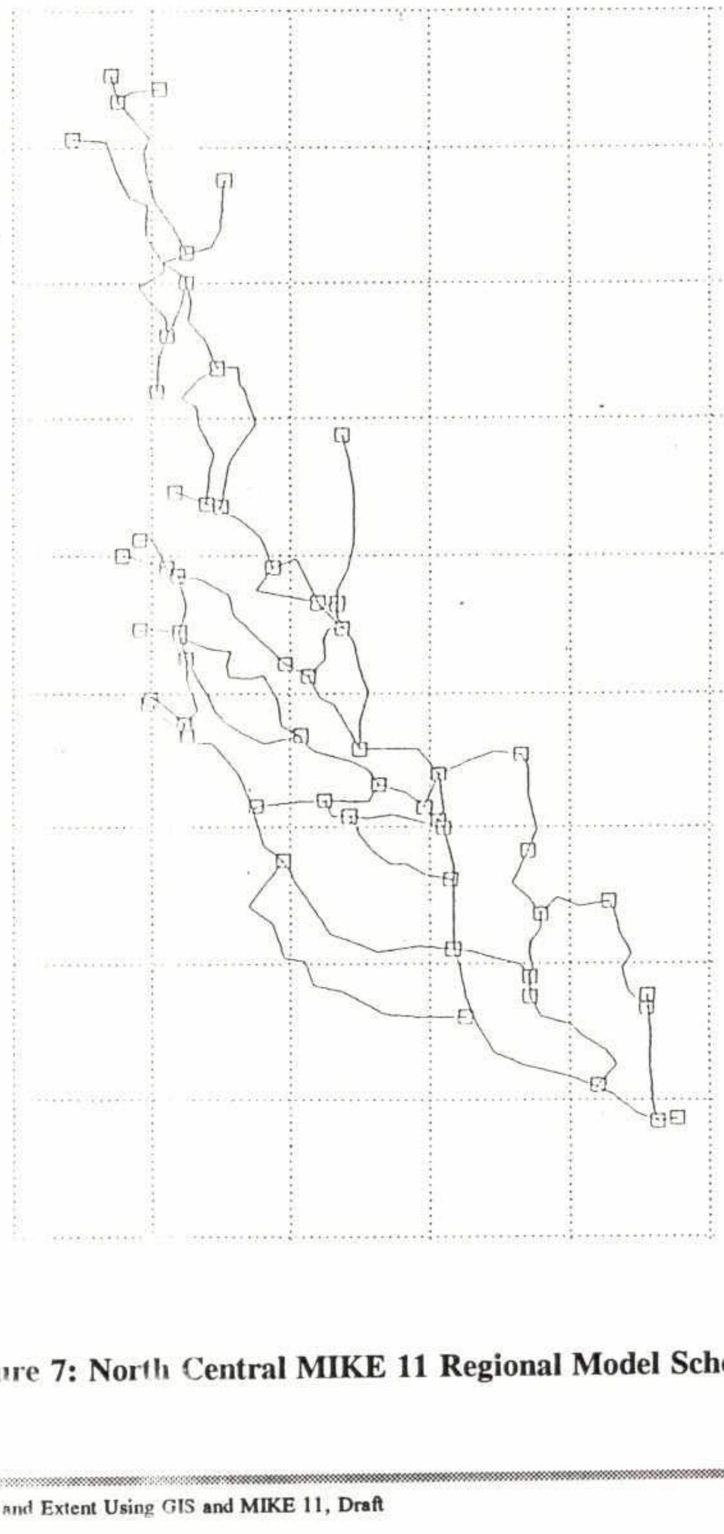

Figure 7: North Central MIKE 11 Regional Model Scheme

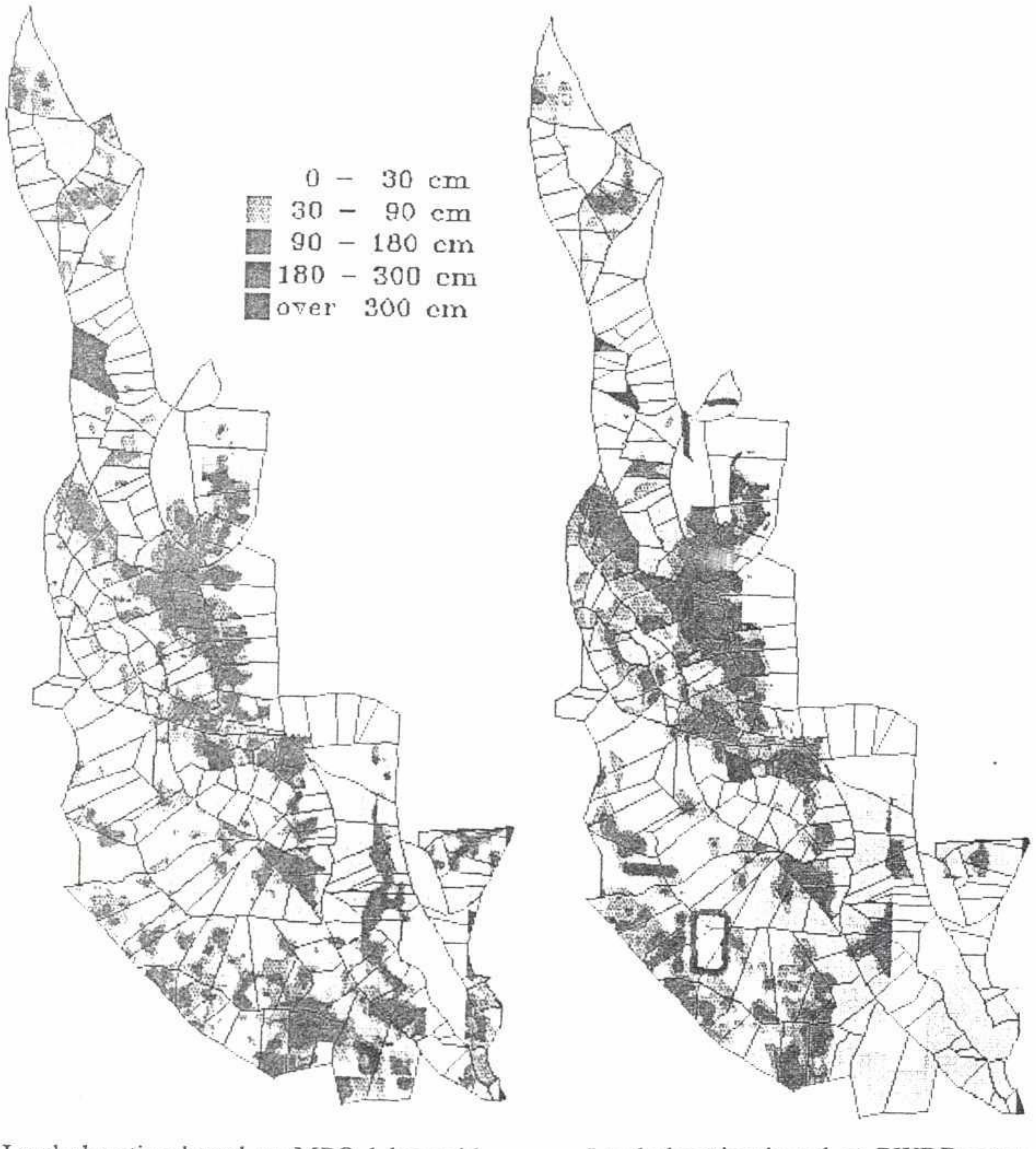

Figure 8: Flood Depth Maps for the North Central Region from MIKE 11 Model Result of July 18, 1991, Using MPO and BWDB Elevation Data

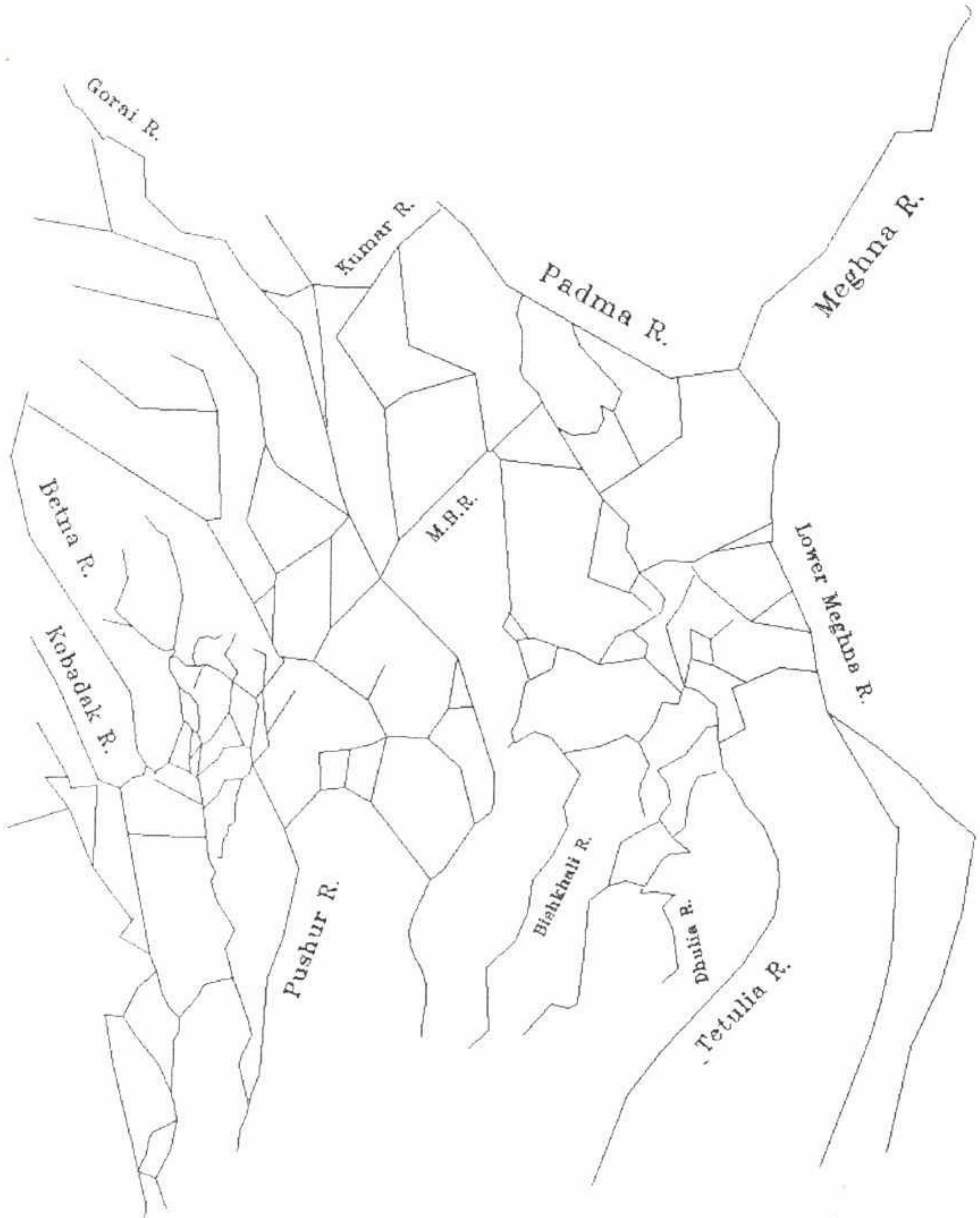

Figure 9: Schematization of the River Network in the Southwest Region

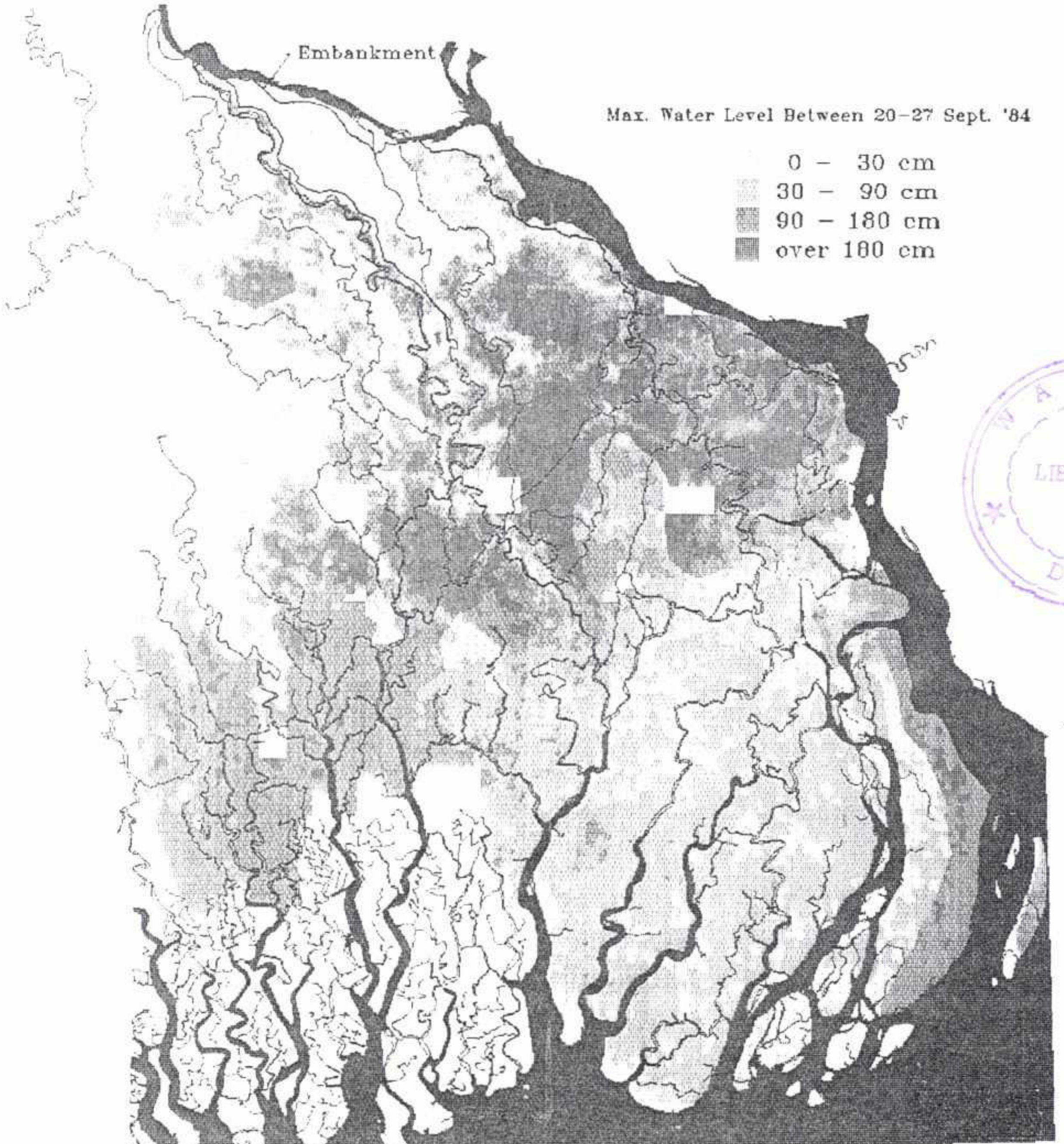

Figure 10a: Flood Depth Map for the Southwest Region without Polders Marked

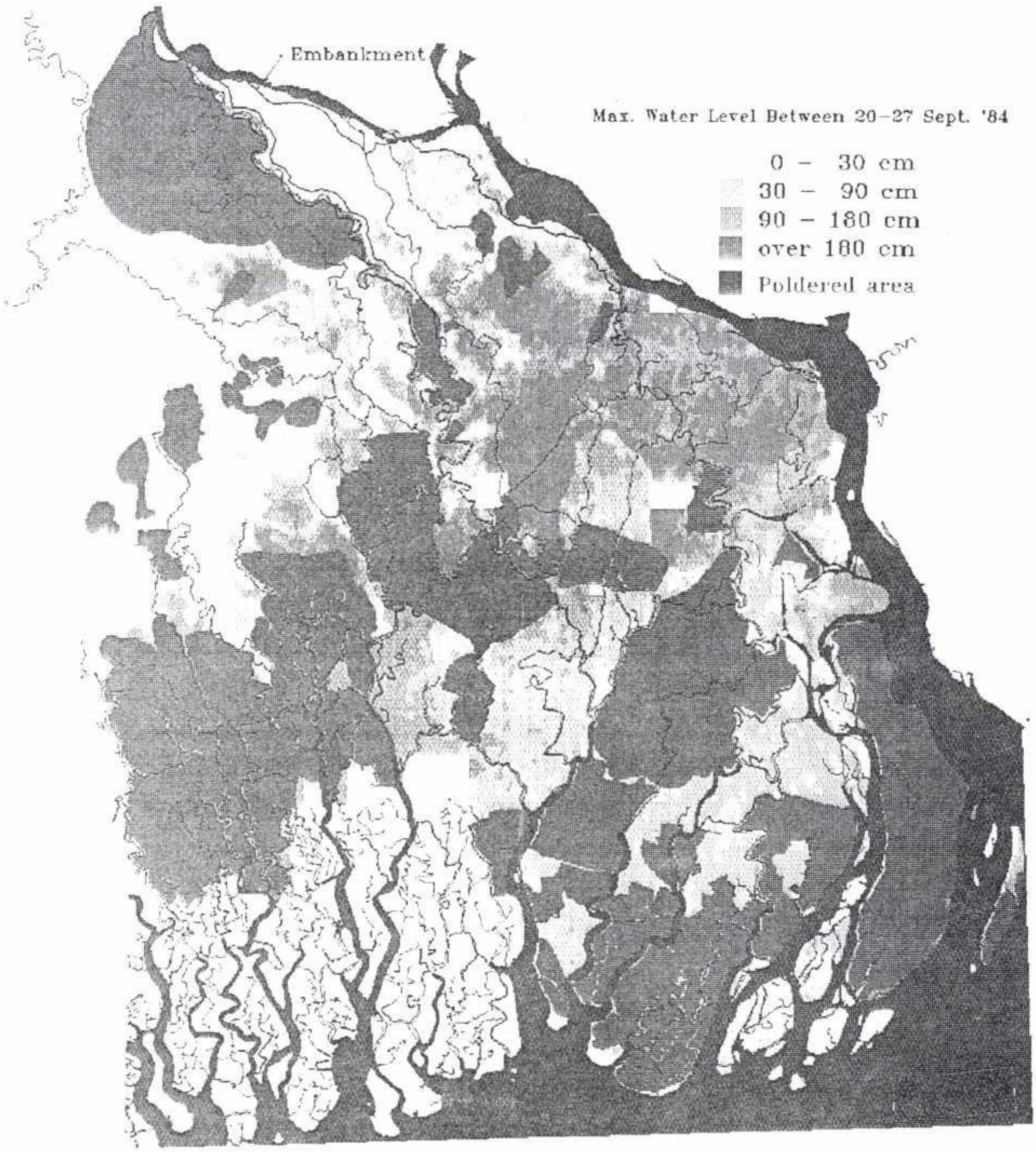

Figure 10b: Flood Depth Map for the Southwest Region with Polders Marked