BANGLADESH FLOOD ACTION PLAN

Ministry of Water Resources

Flood Plan Coordination Organization (FPCO)

National Digital Elevation Model: A 500 Meter Resolution Land Surface Model of Bangladesh

May 1995

Prepared by

Geographic Information System (GIS)

FAP 19

ISPAN

IRRIGATION SUPPORT PROJECT FOR ASIA AND THE NEAR EAST

Sponsored by the U.S. Agency for International Development

BANGLADESH FLOOD ACTION PLAN

Ministry of Water Resources
Flood Plan Coordination Organization (FPCO)

National Digital Elevation Model: A 500 Meter Resolution Land Surface Model of Bangladesh

May 1995

Prepared by

Geographic Information System (GIS)

FAP 19

ISPAN

IRRIGATION SUPPORT PROJECT FOR ASIA AND THE NEAR EAST

Sponsored by the U.S. Agency for International Development

TABLE OF CONTENTS

8

APPENDICES

FIGURES

TABLES

TEXT BOXES

EQUATIONS

ACKNOWLEDGMENTS

This report is the result of a team effort involving many of the staff of FAP 19. The DEM Project was initiated and coordinated by Timothy Martin, FAP 19 Team Leader. The project was implemented under the management of Shamsuddin Ahmed and Syed Iqbal Khosru. Supervision and technical support was provided by David Savory, Ahmedul Hassan, and Dilruba Aziz. Map interpretation and digitizing was performed by technical assistants Md. Golam Rasul, Syed Afzal Hossain, Sahdat Hossain, and Syed Anower Hossain. The report was written by David Savory and Timothy Martin, edited by Carol Jones, and graphic input was provided by Abdul Malik Faruq.

The DEM Project could not have been possible without the support and coordination of numerous organizations in Bangladesh, particularly that of the Flood Plan Coordination Organization (FPCO). Other organizations include: Bangladesh Water Development Board (BWDB), Surface Water Modeling Center (SWMC), the Northeast Regional Project (FAP 6), and the Water Resource Planning Organization (WARPO).

GLOSSARY

ARC/INFO	-	A vector-based GIS software package
beel	-	Bangla term for an area of open water away from a river
BTM	-	Bangladesh Transverse Mercator
BWDB	-	Bangladesh Water Development Board
DEM	-	Digital Elevation Model
ERDAS	-	A raster-based GIS software package
FAP	-	Flood Action Plan
GIS	-	Geographic Information System
homestead	-	Settlement area
khal	-	Bangla term for a drainage channel or canal either natural or man-made
MIKE 11	-	A hydrodynamic model
MPO	-	Master Plan Organisation (of Ministry of Irrigation Water Development and Flood Control)
PWD	-	Public Works Department
SOB	-	Survey of Bangladesh
SOI	-	Survey of India
SPOT	-	System Pour Observation de la Terre
SWMC	-	Surface Water Modeling Center
TIN	-	Triangular irregular network
WARPO	-	Water Resource Planning Organization

1. Introduction

A digital elevation model (DEM) is a computerized representation of a continuous surface, usually that of the Earth. More specifically, it is an array of digitally stored numbers representing the elevation of discrete points on a surface. This virtual surface can be viewed by displaying the values on a computer monitor with each point represented by one pixel whose brightness corresponds to elevation. Since the elevation points are spatially referenced it is possible to apply mathematical algorithms to them for quantitative characterization of land surfaces. For instance, images of terrain properties such as gradient or aspect can be generated and linear features such as ridges, slope breaks, and watershed boundaries can be delineated. This digital terrain analysis is typically implemented within a geographic information system (GIS).

Another DEM-related spatial analytical technique afforded by GIS is visualization of terrain surfaces via 3-dimensional perspectives. "Wire frame" models of terrain surfaces or "shaded relief" maps can be created and used for land use planning. By far the greatest benefit of DEM analysis within a GIS is the integration of terrain data with other spatial data layers. This function is possible because the intrinsic geo-referencing of GIS data, i.e., the spatial coordinates of these data, are linked to cartographic coordinate systems. Thus, DEMs can be integrated with ancillary spatial data layers, such as satellite imagery, and hydrography, soils, and land cover maps to serve a range of purposes, including a variety of environmental and engineering applications. Of particular importance to the Flood Action Plan (FAP) are water resource-related GIS applications of DEMs, which include flood modeling and mapping, flood forecasting, and floodplain sedimentation modeling. GIS and DEMs also are useful for environmental applications such as soil erosion modeling, watershed analysis, landscape visibility analysis, landscape modeling, and geomorphological studies. In addition, these technologies can help engineers plan the construction of flood control structures, irrigation canals, dams, roads, and utility networks.

Various water resource GIS applications have been implemented by FAP 19. For example, GIS was integrated with the MIKE 11 hydrodynamic model to classify and map flood depths and extent in Bangladesh (FAP 19, 1993c). MIKE 11 output which consists of tabular point data, were transformed to areal representations. GIS was then used to create and integrate DEMs of both the land surface and the flood level surface as derived from MIKE 11 (FAP 19, 1992b). The intersection of the two surfaces defined the potential depth and extent of flooding. The results were used to investigate the environmental impact of flood control structures in the FAP 20 Compartment Pilot Project by modeling various flood scenarios. This was the first time that GIS was integrated with the MIKE 11 model in Bangladesh.

There have been previous efforts to produce regional and national DEMs in Bangladesh. During the 1980s, the Master Planning Organization (MPO) digitized a national level grid of elevation points (not a DEM per se) from Bangladesh Water Development Board (BWDB) topographic map data. The BWDB data consists of a series of topographic maps derived from a grid of spot elevations obtained by ground survey and photogrammetric techniques (100 m - 300 m spacing, 0.1 ft. altitude resolution). The MPO elevation grid is based on interpreted BWDB elevation points and has 1 km horizontal spacing. FAP 19 used ERDAS, a raster GIS (grid-based), to construct several DEMs based on the BWDB data (FAP 19, 1993a, 1993e, 1993f). These DEMs include high resolution regional coverage constructed from the original spot elevation points and a national coverage derived from MPO's interpreted 1 km grid of elevation points. Although the 1 km DEM is useful for regional and national level terrain visualization, the low horizontal resolution limits its usefulness in quantitative terrain analysis. On the other hand, FAP 19's high resolution DEMs proved useful for a variety of GIS application projects (1993b, 1993c, 1995a, 1995b). However, constructing detailed DEMs is time consuming and expensive, and the resulting data are voluminous.

6

Accordingly, FAP 19 initiated this DEM project to produce a medium-resolution (500 m x 500 m), or semi-detailed, DEM based on generalized BWDB spot elevation points. The main objective was to construct regional and national-level DEMs with horizontal resolution suitable for automated terrain analysis and 3-dimensional terrain visualization as required by water resource, environmental, and engineering GIS applications.

2. Data Sources

The source maps for the DEM were BWDB topographic maps compiled between 1952 and 1964 under the authority of the Surveyor General of East Pakistan. These maps contain topographic data as elevation points and contours as well as rivers, *beels,* forests, vegetation, homesteads, roads, and political boundaries. The land elevations points were recorded primarily on agricultural land. Homesteads, forests, dense vegetation, and steep terrain generally were not included in the topographic survey. Areas rendered inaccessible by hydrographic features such as rivers and *beels* also were excluded from the survey.

The maps are derived from several photographic bases and have a variety of cartographic specifications. They are compiled in two scales — 4-in./mi. (1:15,840) and 8-in./mi. (1:7,920) — and have variable areal coverage. Two different datums also are found among the maps: the Public Works Department datum (PWD) and the Survey of Pakistan datum (currently referred to as Survey of Bangladesh, or SOB datum). There is a 1.51 foot differential between the two datum, the PWD being higher. Three companies are responsible for the BWDB topographic surveys: Messrs Air Survey Co. Ltd., Hohlweg-Watts & Associates, Fairey Air Ltd. All maps included a Geographic (latitude/longitude) reference grid which furnished control points for geo-referencing. Table 1 summarizes the specifications for the BWDB topographic maps.

Table 1 - BWDB Topographic Map Specifications

Map Scale	Topographic Survey	Datum	Elevation Grid	Method of Altitude Measurement	Aerial Photo Scale
4"/mile (1:15,840)	Messrs Air Survey Co. Ltd, London, 1952	SOB	100 m x 300 m	Spirit-leveled spot heights	1.6"/mile, (1:39,600)
	- or -				
	Hohlweg-Watts & Associates, 1963/64	PWD	Irregular	Plane table survey	—
8"/mile, (1:7,920)	Fairey Air Ltd, London, 1961/62	PWD	175 m x 175 m	Photogrammetric spot heights	8"/mile, (1:7920)
	- or -				
	Hohlweg-Watts & Associates, 1962/63	PWD	Irregular	Plane table survey	—

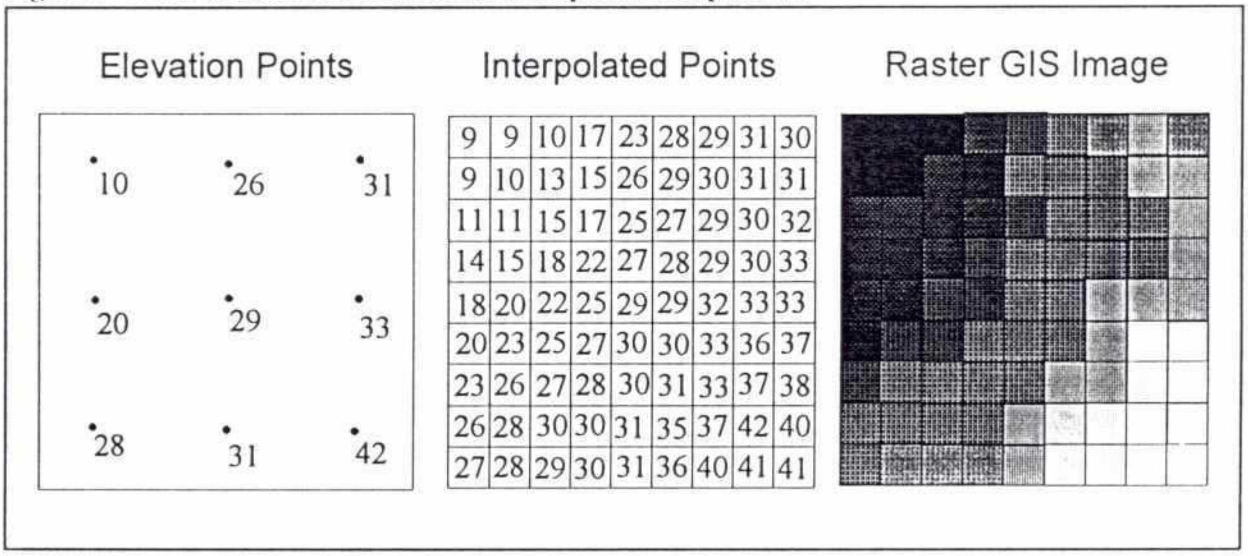
The elevation points are arranged on grids that are roughly 100 m x 300 m for the 4-in./mi. maps and 175 m x 175 m for the 8-in./mi. maps. The 4-in./mi. maps are not as accurate as the 8-in./mi. maps since the scale of the base photography is small (1.6-in./mi.) relative to the map scale. The 8-in./mi. maps contain photogrammetrically derived elevation data and the base photography scale is identical to that of the map. The contours on both maps are generally at one foot intervals and have been derived from the spot heights through manual interpretation or photogrammetric techniques.

Some of the BWDB maps used for this project were previously acquired by FAP 19, while others were borrowed from the following custodians: BWDB, the Surface Water Modeling Center (SWMC), the Northeast Regional Project (FAP 6), and the Water Resource Planning Organization (WARPO). A map indexing system developed by the Survey of India (SOI) was used to catalogue the BWDB maps. Additionally, a nine-digit ID number was devised to identify each data point in the DEM. Refer to Appendix A for the details regarding these indexing systems.

3. Digitizing Methodology

The spot elevation data from the BWDB topographic maps were interpreted and digitized by manually superimposing a transparent 500-m grid template on the maps and recording the elevation point nearest each grid intersection. A total of 432,775 elevation points were digitized from 2106 BWDB maps. Data entry was expedited with an interactive database application program. The data were checked for validity and combined into a single data file with national coverage. After digitizing, these data were converted into GIS file format and using spatial interpolation the elevation points were transformed into a virtual surface, or raster GIS image (Figure 1). Section 4 gives a detailed account of the spatial interpolation procedure and other data processing methods.

Figure 1 - Point to Surface Transformation: Spatial Interpolation



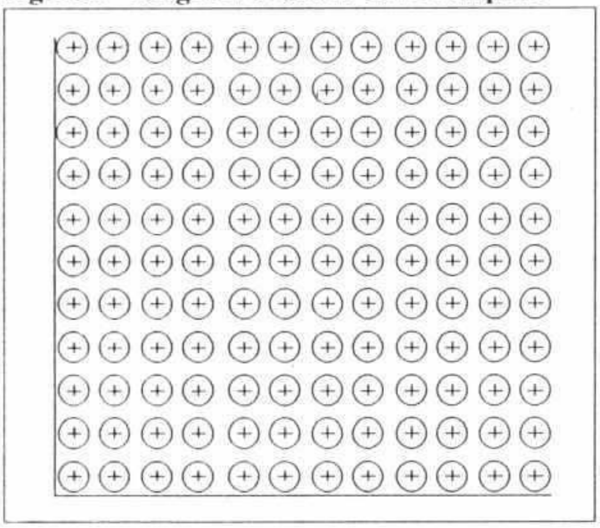
3.1 Map Interpretation

A regular grid with intervals corresponding to 500 m ground distance was encoded in ARC/INFO, a vector-based GIS software package. This grid included circles centered over each grid intersection (Figure 2). The circles had an effective ground radius of 158 m, which is equivalent to 10 mm on the 4-in./mi. maps and 20 mm on the 8-in./mi. maps. Separate grids were designed to cover both the 4-in./mi. and 8-in./mi. map areas. The grids were plotted on clear film (Mylar) to create templates that were manually overlaid on the BWDB maps to acquire elevation point values. The origin of the template coordinate system was the lower left corner of the map, and accordingly, the X and Y axes were plotted on the transparencies to ensure proper alignment of the templates and the maps.

The templates were used to generalize the relatively dense spot elevation arrays on the maps to the 500 m ground spacing selected for the DEM. To accomplish this, for each grid intersection the BWDB elevation value closest to the intersection (i.e., the "nearest neighbor") and within the circle ("selective area") were recorded. More specifically, the algorithm in Text Box 1 was used to select the most reliable elevation value for each template grid intersection.

The encoding of elevation values started from the origin in the lower left corner and moved from east to west within rows, with rows progressing from south to north. The Geographic coordinate (latitude/longitude) for the lower left corner of the map was converted to the Bangladesh Transverse Mercator (BTM) cartographic projection to make the DEMs compatible with other FAP 19 database layers (FAP 19, 1992a). Spot elevations were recorded with 0.1 ft. accuracy and entered directly into a relational database (dBASE IV) using an application program written specifically for this purpose. The program automatically incremented the X and Y coordinates as elevation values were entered. Input parameters for the program were source map scale, datum, the user-id for the grid origin (lower left), map coordinates for the origin, the number of data rows and columns, and the data file name. A total of 323 data points were interpreted for each 4-in./mi. map, and 187 points were recorded for the 8-in./mi. maps. A data entry checklist was maintained by the digitizers to monitor progress.

Figure 2 - Diagram of 500 m Grid Template



Text Box 1 - Map Interpretation Algorithm

1. **IF** elevation points existed in the immediate vicinity of the grid intersection, i.e., within the selective circles,
   THEN - from among these the nearest neighbor was selected.

2. **OTHERWISE, IF** there were contour lines within the selective circle,
   THEN - the value of the nearest neighbor contour line within the circle was selected.

3. **OTHERWISE, IF** there were no elevation points or contours in the circle,
   THEN - no elevation value was recorded.

Land cover attributes were noted and entered in the database if no elevation value could be interpreted from the selective area, but this information was not incorporated into the final DEM products. Further information on the recording and interpretation of the land cover attribute information can be found in Appendix B.

3.2 Data Quality Control

A quality control program was implemented to ensure accuracy during data entry. These measures are outlined below:

- The minimum and maximum elevation values were determined for each digitized map sheet and visually checked for validity. Erroneous values such as 1.1 ft. in the hilly Sylhet region, or 200.9 ft. in coastal areas could easily be detected by this check.
- For each map sheet, five randomly selected database values were checked with corresponding points on the map for validity.
- A primal 3-D view of the elevation data was generated for each map using the ARC/INFO GIS pcTIN program. By viewing this 3-D model, unusual "peaks" or "pits" could easily be detected and subsequently corrected.

4. Data Processing

Following digitizing, it was necessary to adjust the values for datum differences, modify the elevation units, and then convert these data from relational database files to a GIS file format. The final step in DEM construction was to implement a spatial interpolation algorithm for point-to-surface transformation, that is, to transform the point elevation data acquired during digitizing into a virtual surface, or a raster GIS image file. A detailed account of this process follows.

4.1 Pre-Processing

The elevation data interpreted from spot heights and contours required mathematical processing prior to spatial interpolation. As mentioned above, values were adjusted for datum. Additionally, the raw values expressed as feet, were converted into metric units to conform to DEM conventions. The interpreted BWDB elevation data (Z_B) were adjusted to the PWD datum (Z_D) and then converted into decimeter units for DEM input (Z) as shown in Text Box 2.

Text Box 2 - Mathematical Processing of Interpreted Elevation Data

1.	**IF** the datum is SOB, **THEN** convert to PWD datum:	$Z_D = Z_B + 1.51$
2.	Convert to decimeters:	$Z = Z_D * 3.048$

4.2 Data Format Conversion

Following pre-processing, the topographic data existed as 3-D data points geo-referenced with respect to PWD datum. The distance units are meters and decimeters for the horizontal (x, y) and vertical (z) coordinates, respectively. These 3-dimensional points were processed as outlined below to make them amenable to GIS data processing.

- The DBase IV database files containing 3-D map coordinates were appended into regional blocks using a DBase application program.
- The appended DBase files were converted into ERDAS GIS DIG files. DIG files are ASCII encoded files that arrange map coordinates according to their geographic data structure, i.e., point, line, or polygon.
- The DIG files were appended into a single national coverage file using an ERDAS program.

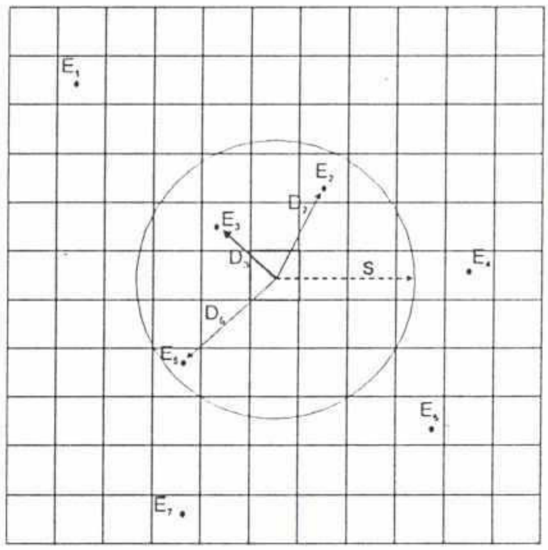
4.3 Point-to-Surface Transformation

The final step in building the DEMs was to create a virtual surface, or raster GIS image from the point data. The product of this GIS processing is a national DEM with 300 m x 300 m pixels and decimeter elevation units.

The existing database files were processed within the ERDAS raster GIS environment using the ERDAS GIS programs SORT and SURFACE. Since topographic data files are often large, the SORT program must be used to divide the DIG file into separate blocks of data points for processing. The SURFACE program then processes the groups of distinct 3-D points and creates a continuous surface stored in ERDAS LAN file format. The surface value for each pixel in the output file is determined via interpolation based on the surrounding points. This calculation involves a *distance weighting factor* based on the distance between the "subject pixel" and the data points in the input file within a specified area, or *search radius*. The search radius is a circle centered on the pixel to be evaluated. Its use ensures that no directional bias is introduced into the calculation (Figure 3). For this operation a search radius of 710 m was used.

Figure 3 - DEM Surface Calculation

DEM Surface Calculation: Distance Weighted Interpolation



E_i = Elevation Point

D_i = Distance From Subject Pixel

S = Search Radius

Weighting Factor (W_i) = $(1 - D/S)^2$

The weighting factor is based on one of the 11 functions supplied by the SURFACE program. It determines the influence a data point has on the computed pixel values. The weighting function chosen as the most appropriate for this project is shown as Equation 1 and graphed in Figure 4.

The value for any given surface pixel was calculated by taking the sum of the weighting factors and the elevation values for all points within the search radius, then dividing by the sum of the weighing factors as shown in Equation 2.

The output image file from this process is an ERDAS LAN file with a 16-bit data range (0 - 65,536). This file can be displayed as a computer image with the brightness of each pixel (gray-scale) representing land elevation. Since the brightness of each pixel is directly proportional to its elevation value, the higher the elevation the brighter (whiter)

D6

the gray-scale. When viewed in this way the discrete elevation values simulate a surface (Cover, Figures 5 and 6). The gray-scale image can be recoded into elevation classes and distinct colors can be assigned to each. Some detail may be lost when viewing in this manner, but absolute elevations can be more easily discerned.

4.3.1 Model Optimization

The transformation of the BWDB-derived point data into an image surface via spatial interpolation is a crucial process when building a DEM. In this operation, there are three input parameters that were chosen deliberately to yield optimal results: weighting function, search radius, and output pixel size. The factors influencing the selection of values for these variables are discussed in the following sections.

Weighing Function: As described above, the surface calculation for any given pixel is determined by using a weighting factor produced by one of the 11 functions supplied by the SURFACE program. The weighting factor is based on the distance between the subject pixel and the elevation points within a specified search radius (Figure 3). Weighting function #5 was chosen as the most appropriate for topographic surface generation. It assigns a relatively high weight to the elevation points close to the subject pixel and then decreases exponentially to zero at the border of the search radius (Figure 4).

Search Radius: To ensure that no directional bias is introduced, only points that are within a circle centered on the pixel to be evaluated are considered in the calculation. One factor which is considered while selecting a radius is the configuration of the terrain to be modeled. For smooth undulating terrains, points relatively far from the subject pixel can be incorporated into the calculation since they are similar (spatially auto-correlated). For steep, hilly landscapes, even points within 100 m can be dissimilar to the subject pixel and should be given little or no weight in the interpolation. Additionally, the potential number of points within a given search radius should be considered. A reliable estimate of the points within the search radius was possible in this

Equation 1 - Weighting Factor Function

$$W = (1 - D/S)^2$$

where,

W = weighting factor
D = the distance from the subject pixel to the input data point,
S = search radius, or the distance from the subject pixel within which to search for data points.

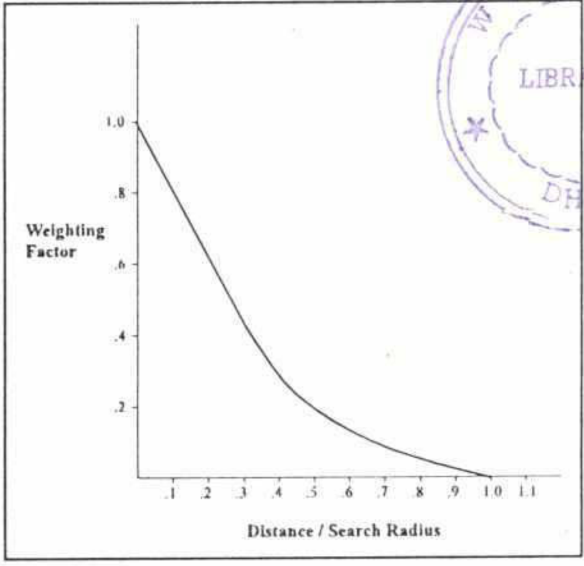
Equation 2 - Calculation of DEM Pixel Values

$$V = \frac{\Sigma(W_i . E_i)}{\sum_{k=i}^{n} W_k}$$

where,

V = the output pixel value,
i = a data point within the search radius,
W_i = the weighing factor of point i,
E_i = elevation of point i, and
n = number data points within the search radius.

Figure 4 - Weighting Function



case because a somewhat regular array of elevation points was being analyzed. Since the points were on a 500-m grid, a 505 m search radius would include up to four points in the calculation. Using the Pythagorean theorem ($c^2 = a^2 + b^2$) it was also determined that with a 710 m search radius, up to eight points would be used to calculate the subject pixel's elevation. Finally, the authenticity of the output DEM surface must be considered. Generally speaking, as the search radius is increased, the terrain surface is smoothed, i.e., the peaks fall and the valleys rise. Excessive smoothing is undesirable when generating DEMs because it results in inaccurate terrain modeling.

In order to determine which search radius, 505 or 710, was optimal for calculating the DEM surface, trials were performed on three sample areas, each with an area of about 280,000 hectares. These areas were in the northeast region of Bangladesh and did not include the elevations of unsurveyed land cover classes (rivers, forests, etc.). The results of the trials are exhibited in Table 2. The trials generally reflect the smoothing trend discussed above, although not markedly.

A search radius of 710 m was ultimately selected for DEM construction, a reasonable value based on the relatively flat terrain dominating the Bangladesh landscape. This distance also ensures that a variety of elevation samples are used in the calculation, thereby avoiding excessive bias. Further, since the trial DEMs indicated smoothing was minimal, the output DEMs had authentic surface morphology. An additional benefit afforded by the relatively larger search radius is that it provided greater coverage of unsurveyed areas.

Pixel Size: A pixel size of 300 m x 300 m was chosen for the DEM generated by this project. It is important to note that the input data were from the 500-m template grid. The accuracy of derived products such as the DEM is dictated by this original data density. The creation of DEMs with 300 m pixels in no way increases the accuracy of the original data. The smaller pixel size created a smoother image "surface," thereby enhancing the appearance and utility of the DEM.

Table 2 - Results of Search Radius Trials

Sample Number	Search Radius	Minimum	Maximum	Mean	Standard Deviation
1	505	93	427	160.5	47.8
	710	96	427	160.7	47.9
2	505	144	301	219.4	29.8
	710	149	301	219.4	28.6
3	505	259	532	386.1	57.4
	710	259	528	386.0	57.4

4.4 Post-Processing

A number of data processing operations were implemented to ensure proper image presentation, enhance its appearance, and improve the authenticity of the data. These processes included converting the ERDAS LAN file to GIS format,"clipping" the data into regions based on previously digitized physiographic boundaries, generating image statistics, and scaling the elevation values to fit the computer display's capability. Finally, the DEM output file may be converted to one of several alternative formats for distribution or analysis.

ERDAS File Format Conversion: The ERDAS LAN file generated during point-to-surface transformation was subsequently converted to ERDAS GIS file format. This format allows the generation of geo-statistics and additional image processing with the ERDAS program GISMO.

Incorporating Regional Boundaries: The boundaries of four broad physiographic regions had previously been digitized by FAP 19. The ERDAS modeling program GISMO, was used to "clip" the regional DEMs according to actual boundaries.

Image Statistics: Elevation data minimum, maximum, mean, standard deviation, and a histogram were generated for each DEM image using the ERDAS program BSTATS. These statistics are used by ERDAS display programs to perform contrast stretching on the images. Contrast stretching allows the user to manipulate the mapping of data values to display values in a manner that optimizes their contrast and brightness. Additionally, these statistics facilitate the generation of area/elevation statistics as described in section 5.2.

Data Scaling: It was also necessary to create scaled DEM data sets for generating easily interpretable computer displays of the DEM image. This involved "compressing" the data into an 8-bit data range (0-255) using the ERDAS program GISMO. GISMO is driven by a script-like programming language that allows the application of mathematical or logical operators to one or more images. The proportionally scaled data was used only for creating computer displays and hard copy output and in no way alters the final DEM products.

Output File Conversion: The primary output from the entire DEM building process is an ERDAS 16-bit GIS file. However, this file may be converted to one of several alternative formats for distribution or analysis. Three application programs were written using a high level programming language (C) to implement these conversions - Erd2Gen, Erd2xyz, and Erd2Surf.

Erd2Gen creates an ASCII file suitable for input to the ARC/INFO GENERATE program which, in turn, produces a point coverage. Erd2xyz creates a comma delimited ASCII file with 3-dimensional point coordinates (x, y, z) for input to a spreadsheet program. Erd2Surf produces a file for use in SURFER, a surface mapping program. Data from the original ERDAS file remains unaltered during these conversions.

5. Results and Discussion

5.1 DEM Products

Five primary DEM products were generated by this project: a national DEM and four with regional coverage. Table 3 provides the specifications for these DEMs as they exist in ERDAS GIS format. Although the files have a 300 m pixel size and a 0.1 m elevation interval, it is important to note that the data resolution of the products is dependant on the data source — 500 m horizontal resolution and 0.1 ft. vertical resolution. The national DEM and the northwest regional DEM are shown in Figures 5 and 6, respectively. Alternative format versions of these DEMs retained their prefixes, but were given ".GEN", ".PRN", and ".GRD" extensions for the ARC/INFO, spreadsheet, and SURFER formats, respectively.

5.2 DEM Statistics

A total of 432,775 digitized elevation points were used to create the national DEM. Table 4 shows the elevation statistics for the regional and national DEMs by region. The minimum, maximum, and mean values reflect the range and central tendency of the relief, while the standard deviation is often an indication of the gross landscape configuration. In other words, smooth undulating landscapes and rugged hilly terrain exhibit relatively low and high standard deviations, respectively. Although the data does seem to reflect this trend, the regions in this project are too vast and heterogenous for the standard deviation to be a reliable indicator of surface roughness. Furthermore, most of the hilly regions of Bangladesh are not included in the data set since they were not topographically surveyed by the BWDB.

Table 3 - DEM ERDAS File Specifications*

DEM Coverage	Digital File Name	Map Coordinate (Upper Left)	Number of Rows, Columns	File Size (MB)
National	BDEM2.GIS	297353, 946825	2196, 1584	6.44
Northwest Region	BDEM2NW.GIS	297353, 946825	1049, 626	1.25
Northeast Region	BDEM2NE.GIS	455419, 876761	1005, 992	1.90
Southwest Region	BDEM2SW.GIS	353835, 685688	1025, 926	0.91
Southeast Region	BDEM2SE.GIS	552178, 676516	1295, 734	1.72

* NOTE - The following specifications are common to all the DEMs: BTM projection, 300 m x 300 m pixels, and 0.1 m elevation units.

Table 4 - Statistics on Regional and National DEMs (Land Elevation in Decimeters)

Elevation Statistic	National	NW Region	NE Region	SW Region	SE Region
Maximum	1035	1035	767	182	614
Minimum	3	54	8	3	4
Mean	129	261	120	40	114
Std Dev	143	157	58	35	164

Figure 5 - National Digital Elevation Model

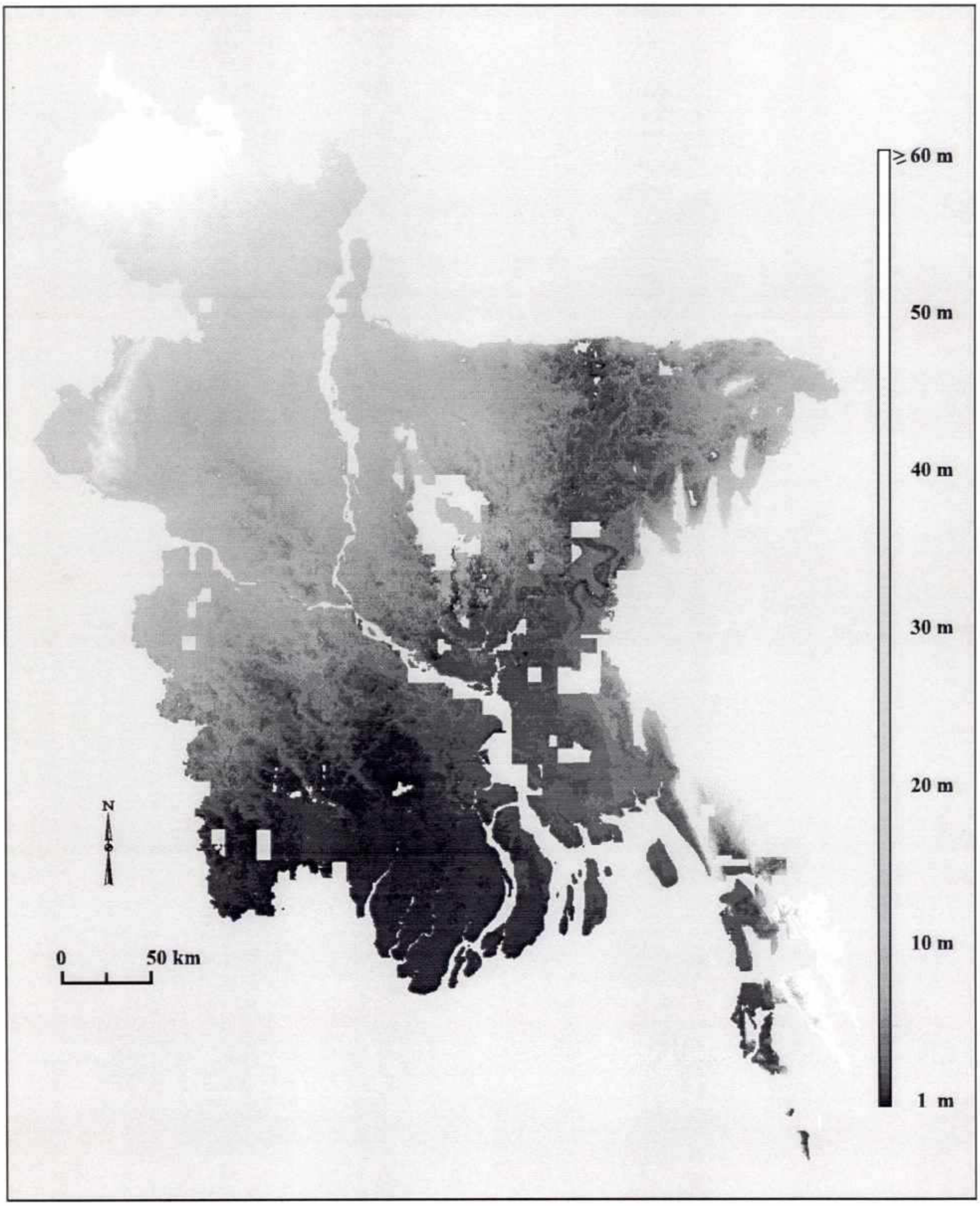
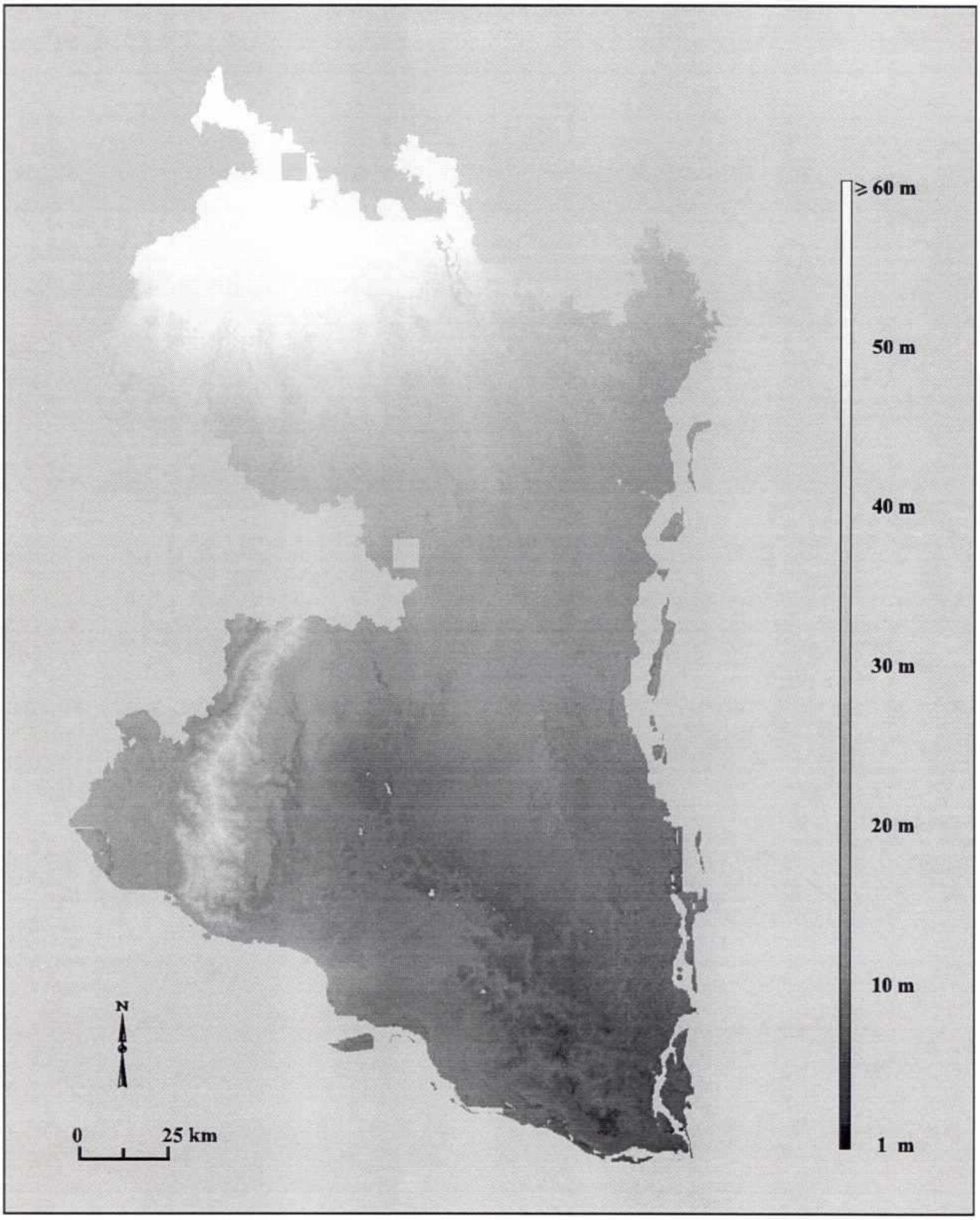
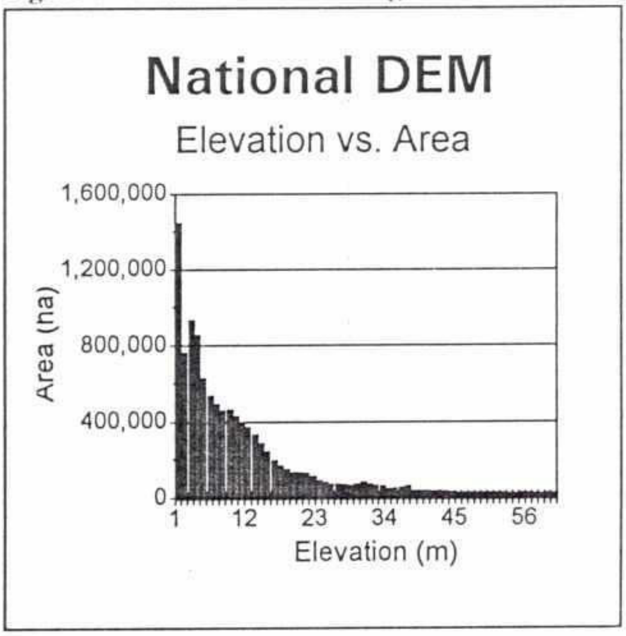


Figure 6 - Northwestern Regional Digital Elevation Model



The relationship between elevation and land area is depicted in the histogram in Figure 7. This figure illustrates that the majority of land in Bangladesh is relatively close to mean sea level. According to the national DEM, 61 percent of the land area topographically mapped by BWDB is 10 m elevation or less, and 92 percent is within 35 m of mean sea level. The tail of the histogram actually extends off the graph from 61 m up to 103 m, but the actual area accounted for at these elevations is less than two percent of the total.

Figure 7 - Area/Elevation Histogram



5.3 Limitations

Although the data set used for this project is the best available with national coverage, it is not ideal since the source maps are old and their coverage incomplete. Thus, there are inevitably some limitations inherent in the DEM products generated and some caveats which should be considered when using these data:

- The products are considered "semi-detailed" because the source data have been re-sampled to a 500-m grid. The process for selecting the values for template grid intersections (section 3.1) had a subtle smoothing effect on the data.
- The approximately 100 BWDB maps covering the essentially flat southwest region of Bangladesh have 5 ft. contour intervals. In this case, the elevation values for the 500-m grid intersections were estimated by visually interpolating between the spots or contours on the maps.
- Some BWDB maps are old and worn, with rips and creases that may have caused some small locational errors. Also, shrunken and desiccated maps may no longer be true to scale, causing minor geometric distortions.
- Some BWDB maps were partitioned into smaller sheet sizes and had to be spliced for data entry. Edge-matching problems may have resulted in small locational errors.
- The topography of Bangladesh is dynamic and, consequently, BWDB maps that were produced 30 years ago depict inaccuracies. When using these maps for the DEM, it follows that there will be local areas where the DEM does not accurately represent existing topography. Rivers have changed course and cut new channels, some chars have washed away while others have formed, new (raised) roads and embankments have been built, and homestead and agricultural areas have shifted. Such changes significantly alter landscape morphology and land elevation.
- The numerous voids in the data set exist for several reasons. The BWDB surveyed mainly agricultural land areas excluding geographic features such as rivers, *beels*, homesteads, forests, and steep terrain. Also, it was not possible to obtain BWDB maps for certain areas because they either were never published, had been misplaced by custodian organizations, or had been purposely made unavailable for national security purposes.
- The international boundary has been approximated in the southwest and southeast coastal regions.

5.4 Recommendations

5.4.1 DEM Applications

The DEM products generated by this undertaking can be used for digital terrain analysis in a variety of environmental, engineering, and urban and rural planning applications. Digital terrain analysis is the spatial processing and graphic simulation of elevation data with the aid of a computerized GIS. GIS applications typically require DEM derivatives generated using digital terrain analysis such as slope, aspect, contour, shaded relief, and 3-D perspective maps.

Slope and aspect maps are color-coded to indicate the terrain's steepness and prevailing direction at each pixel, respectively. These maps are useful for planning and building roads and flood control structures, and environmental and natural resource modeling. Contour maps portray changes in elevation with a series of lines that connect points of equal elevation (as in the BWDB maps) and can be used for graphic representations of topography or incorporated with other GIS data layers for modeling. Shaded relief maps depict variations in elevation based on user-specified sun angles. Map areas in the sunlight appear bright, while areas in shadow are shaded (Figure 8). These maps generally are used only as visualization tools for planning and modeling. Finally, perspective maps provide various 3-D views of landscapes from any number of viewing angles. The surface is generally represented by a "wire-frame" model (Figure 9). Aerial photos, satellite images, or GIS maps can be "draped" over the wire-frame model to enhance visualization.

In turn, these DEM-derived data layers can be integrated with ancillary spatial data layers, such as satellite imagery, hydrography maps, soils maps, and land cover maps, to serve a wide range of purposes. Practical applications of DEMs and their derivatives include:

- Flood modeling and mapping, flood forecasting, and floodplain sedimentation modeling.
- Planning the construction of flood control structures, irrigation canals, dams - cut/fill volume analysis.
- Geomorphological studies - delineating physiographic units such as floodplains, watersheds, etc.
- Soil erosion modeling - e.g., classifying the landscape according to degree of erodibility.
- Crop suitability modeling - e.g., determining areas suitable for wheat cultivation.
- Landscape visibility analysis - assess the visibility of geographic features from various lookout points.
- Road/utility routing - calculating optimal paths.
- Environmental impact assessment - e.g., analyzing the impact of proposed flood control structures.
- Environmental modeling - e.g., simulating the spread of point or non-point source pollution.
- Natural resource modeling - e.g., identifying wildlife habitats associated with elevation, aspect, etc.
- 3-D perspective views showing before/after scenes simulating the effect of proposed development.

5.4.2 Enhancement of the FAP 19 DEM

The utility of the DEMs could be enhanced by incorporating contemporary data or by converting it to other data structures. For example, a spatial data set from the FAP 19 National Database, consisting of 1989 hydrographical data, could be integrated with the DEMs. The water bodies in this data layer are represented as lines for small rivers and canals, and polygons for larger, braided rivers and *beels*. These features could be "overlaid" on the DEMs using GIS operations to "erase" land surfaces that have eroded or otherwise changed since the time the BWDB maps were compiled.

22

Figure 8 - Shaded Relief Map of Northwestern Bangladesh

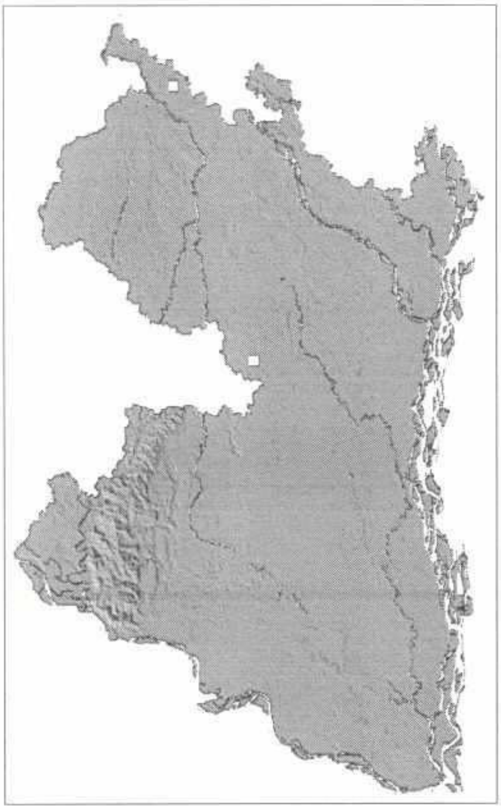
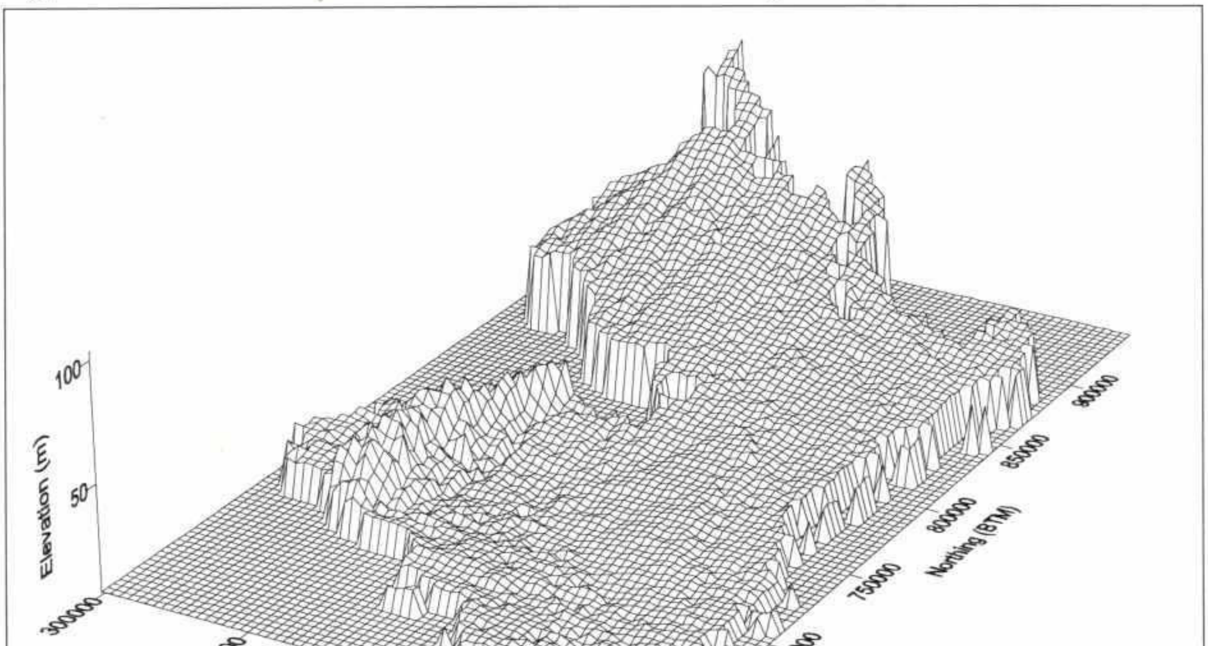


Figure 9 - Wire Frame 3-D Model of Northwestern Bangladesh Generated from a DEM



The raster DEM surface generated in ERDAS for this project also could be improved if land surface breaks could be suitably modeled. This would be an advantage for the Bangladesh DEM because slope breaks such as riverbanks and *beel* shorelines could be demarcated. Such a demarcation would allow *beel* water surfaces to be flat and river surfaces to proceed steadily downhill. A triangular irregular network (TIN) is a data structure that facilitates such surface modeling. A TIN is a virtual 3-D surface consisting of a set of adjacent, non-overlapping triangles connecting 3-D points. Each triangle in the TIN represents a facet of the surface. TIN surface modeling preserves 3-D linear features such as streams, river banks, and ridges (surface breaks). The digitized data is in a TIN-compatible format and a TIN could be constructed to create an alternative representation of the Bangladesh landscape.

5.4.3 Compilation of a "Detailed" DEM

The source data used to create the FAP 19 DEM has been partially generalized, and therefore the products are considered "semi-detailed." In other words, the original BWDB source data was collected on a 300 m x 300 m grid but, was re-sampled to a 500 m x 500 m grid during digitization. Hence, the horizontal resolution of the FAP 19 DEMs are effectively 500 m.

A "full-detail" 300 m resolution DEM could conceivably be compiled from the same source data given adequate funding and resources. Such an endeavor would entail considerably more time and effort during the data acquisition stage than was invested for this project. This is only partially due to the fact that there would be as much as two-thirds more data points to digitize. The workload also would increase because the elevation points would need to be digitized with an electronic digitizing table rather than manually entering numbers into the computer. The reason for this is that the elevation grid on the maps is only approximately spaced at 300 m x 300 m intervals. A slight irregularity in the grid spacing requires that the planar coordinates of each point be acquired explicitly, thereby increasing the time required for data capture. Thus, since data acquisition was the most time consuming phase of this effort, the actual time required may actually double. The data acquisition phase for the semi-detailed DEM required approximately five months with the help of four technical assistants. Regardless, direct digitization of unprocessed BWDB elevation data would yield a detailed DEM with greatly enhanced analytical value.

REFERENCES

FAP 19. 1992a. Technical Note 1 - Bangladesh Transverse Mercator Projection. Dhaka: Flood Plan Coordination Organisation, Ministry of Irrigation, Water Development and Flood Control. (Report prepared by ISPAN).

FAP 19. 1992b. Technical Note 4 - GIS Atlas for Tangail Area Study. Dhaka: Flood Plan Coordination Organisation, Ministry of Irrigation, Water Development and Flood Control. (Report prepared by ISPAN).

FAP 19. 1993a. Technical Note 2 - North Central Region Digital Elevation Model. Dhaka: Flood Plan Coordination Organisation, Ministry of Irrigation, Water Development and Flood Control. (Report prepared by ISPAN).

FAP 19. 1993b. Comparison of Elevation Data from BWDB and FINNMAP. Dhaka: Flood Plan Coordination Organisation, Ministry of Irrigation, Water Development and Flood Control. (Report prepared by ISPAN).

FAP 19. 1993c. Classification of Flood Depth and Extent MIKE 11 and GIS. Dhaka: Flood Plan Coordination Organisation, Ministry of Irrigation, Water Development and Flood Control. (Report prepared by ISPAN).

FAP 19. 1993d. Technical Note 3 - Area Elevation Curves for BWDB Southwest Regional Projects. Dhaka: Flood Plan Coordination Organisation, Ministry of Irrigation, Water Development and Flood Control. (Report prepared by ISPAN).

FAP 19. 1993e. Technical Note 6 - Tangail Area Digital Elevation Model. Dhaka: Flood Plan Coordination Organisation, Ministry of Irrigation, Water Development and Flood Control. (Report prepared by ISPAN).

FAP 19. 1993f. Technical Note 7: Bangladesh National Digital Elevation Model. Dhaka: Flood Plan Coordination Organisation, Ministry of Irrigation, Water Development and Flood Control. (Report prepared by ISPAN).

FAP 19. 1995a. Floodplain Sedimentation Study. Dhaka: Flood Plan Coordination Organisation, Ministry of Irrigation, Water Development and Flood Control. (Report in preparation by ISPAN).

FAP 19. 1995b. Radar Satellite Imagery for Flood Monitoring in Bangladesh. Dhaka: Flood Plan Coordination Organisation, Ministry of Irrigation, Water Development and Flood Control. (Report in preparation by ISPAN).

APPENDIX A - Source Map and Data Point Indexing

A map indexing system developed by the Survey of India (SOI) was used to catalogue the BWDB maps and each data point. The SOI indexing system is based on a primary grid with 4° x 4° (latitude/longitude) cells, a secondary grid within each primary cell consisting of 1° x 1° cells, and a tertiary grid comprised of 15' grid cells. In general, there are nine map sheets per tertiary grid cell for each 4-in./mi. map and 15 sheets per 8-in./mi. map. Figure 10 illustrates the numbering scheme for this system.

Text Box 3 - DEM Data User-ID

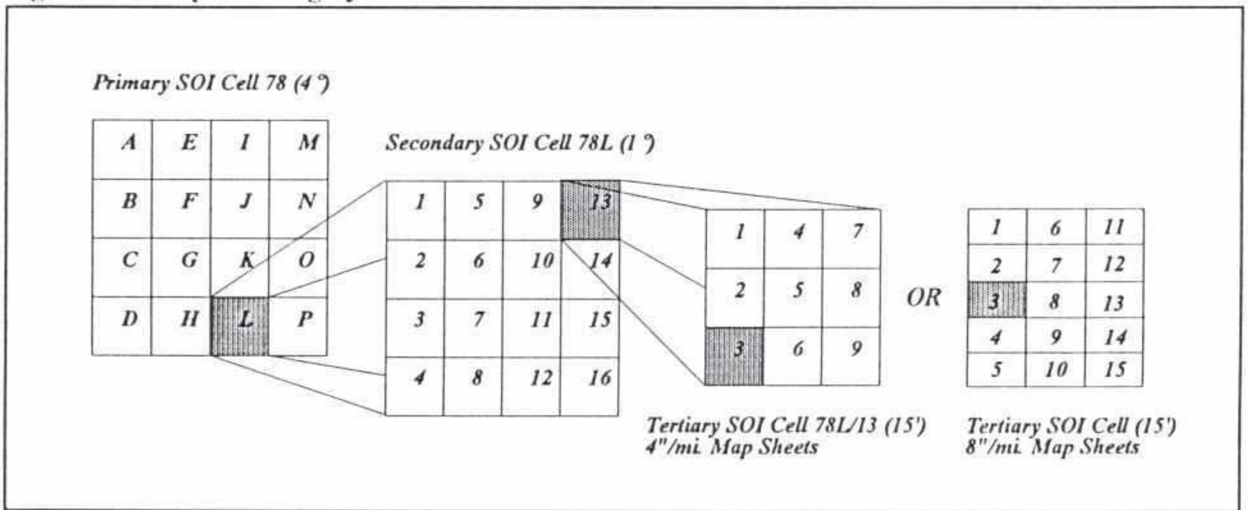
User-ID 26 13 03 010

010 = DEM data point number 10
03 = map sheet number 3
13 = SOI Tertiary Cell
26 = SOI Secondary Cell 78L (see Table 5)

A nine-digit database user-id was devised to identify each source data point in the DEM. For example, for user-id 261303010, the first two digits, 26, represent an alpha-numeric SOI secondary grid identifier, in this case 78L (see User-ID Code in Table 5). The next two digits, 13, refer to the 13th SOI tertiary cell (1°). Next, 03, refers to BWDB map sheet 3 (15') within tertiary cell 13. Finally, the last three digits, 010, refer to a particular digitized elevation data point from the BWDB source maps. Numbering for data points begins in the lower left corner of a map and proceeds east to west (within the row) and south to north by row. This example is summarized in Text Box 3 and depicted in Figure 10.

The file name codes shown in Table 5 were used for data file naming conventions. For example, data files for map 78L/13/3 would have the prefix AL13B3, where AL represents secondary cell 78L, 13 is the tertiary cell, and 3 is the map sheet. The character "B" is merely a joiner for the tertiary cell and map sheet identifiers.

Figure 10 - Map Indexing System: User-ID



28

Table 5 - User ID and File Name Codes

Secondary SOI Index	User ID Code	File Name Code
79A	01	BA
79B	02	BB
79E	05	BE
79F	06	BF
79G	07	BG
79I	09	BI
79J	10	BJ
79K	11	BK
79M	13	BM
79N	14	BN
79O	15	BO
78B	16	AB
78C	17	AC
78D	18	AD
78F	20	AF
78G	21	AG
78H	22	AH
78K	25	AK
78L	26	AL
78O	29	AO
78P	30	AP
83C	31	CC
83D	32	CD
84A	33	DA
84B	34	DB
84C	35	DC
84D	36	DD

Note: Areas within 79G and 84A index were not available for use in this project.

24

APPENDIX B - Land Cover Attribute Interpretation

During map interpretation, land cover attributes were noted and entered in the database if no elevation value could be interpreted from the selective area. Points were classified as homestead, *beel*, river, forest, or unsurveyed if they were coincident with the map symbols for these attributes. Those that did not fall into any of these classes were simply categorized as "land."

Using empirical knowledge about the Bangladesh landscape it was possible to make assumptions about the elevation of template points categorized as one of the land cover classes relative to the surrounding agricultural land. For instance, if a template point fell within a homestead area, but the nearest neighbor elevation point was outside the homestead area, three feet (approximately 1 m) could be added to the mapped elevation value since homesteads are generally higher than the surrounding agricultural land. Similarly, if the template point was in a river but the elevation point was on land, 10 feet could be subtracted from the mapped elevation since the river surface is naturally below the riverbanks. Again, it should be noted that these elevation adjustments were only applied to areas without any elevation points or contours within the selective area (circle).

In addition to the elevation adjustments discussed above, several unusual situations arose which warranted similar approximations.

- For Dhaka City, elevation values were raised six feet above the surrounding agricultural land.
- In the Sundarban Forest Reserve, data points were categorized as either Sundarban or unsurveyed. Much of the unsurveyed area was labeled as classified or unclassified forest on the maps, but this information was not recorded. The elevations in the surveyed areas of the forest reserve were considered to be one foot above sea level.
- Because the terrain in the Chittagong Hill Tracts is steep and relatively unpredictable, only the actual point or contour values were recorded. No approximations or adjustments of mapped elevations were used.
- Elevation point values within *Beel Halti* and *Beel Piprul* of the Atrai basin (northwest region) were decreased three feet since these permanent water bodies are naturally low-lying.

The attribute-driven elevation adjustment values are listed in Table 6.

Table 6 - Altitude Adjustments for Land Cover Attributes (ft.)

River	Homestead	Beel	Forest	Sundarban	Dhaka	Beel Halti and Piprul
-10	+3	-2	+4	+1	+6	-3

Ultimately, these feature-based elevation adjustments were not incorporated into the final DEM products since they did not yield satisfactory results. It proved difficult to make fixed assumptions with regard to the relative heights of each land cover class. Unrealistic values often resulted from the altitude adjustments and the overall visual appearance of the areas subject to the modifications was not authentic. However, a DEM which includes these data has been retained: BDEM2_A.GIS.