DECISION SUPPORT SYSTEM FOR ASSESSING RICE YIELD LOSSES FROM ANNUAL FLOODING IN BANGLADESH

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I dedicate this work to my wife Rima, and my daughter Prova

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ABSTRACT

In one out of every two years, 20 percent of Bangladesh is inundated. Floods that occur at frequencies of one in 5, 10, 20 and 50 years inundate 30, 37, 43, and 52 percent of the country, respectively. The nation pays a heavy price in human sufferings and property from these floods.

The purpose of this research is to assemble a prototype decision support system that could enable extension agents to search for alternative ways to minimize flood damage to agricultural crops and policy makers to assess yield losses and prepare for food shortages.

The prototype system consists of a crop simulation model for rice, a rule-based system for assessing rice yield loss from flooding and a geographic information system for aggregating site-specific flood damage into yield loss for the entire nation. The system is designed to accommodate more than one crop, but this study was restricted to the rice crop. It is able to simulate the growth, development and grain yield of rice varieties cultivated by Bangladeshi farmers in any location and season under a wide range of management options. Simulated rice yields for a flood-free crop is used as a basis for computing yield loss from floods of varying severity.

A rule-based system called FLOODEX was developed to compute yield loss from flooding which is expressed as a percent of the simulated non-flooded grain yield and computed on the bases of yield loss from depth of submergence, duration of submergence, growth stage and clarity of water. The expected yield is a fraction of the

simulated yield, and production for a homogeneous area is the product of yield and area. The geographic information system enables yield loss and production levels to be displayed spatially.

A major constraint to early application of the system was the lack of site-specific input data to operate the crop simulation models. These data include a minimum set of crop, soil, and weather data for benchmark locations in the country. The immediate value of this system may lie in its capacity to serve as a framework for organizing interdisciplinary research and prioritizing resource allocation.

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LIST OF ABBREVIATIONS AND ACRONYMS

AEZ	Agro-Ecological Zones
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BRRI	Bangladesh Rice Research Institute
DAT	Days After Transplanting
DAS	Days After Sowing
DSSAT	Decision Support System for Agrotechnology Transfer
FAO	Food and Agriculture Organization
GIS	Geographic Information System
HYV	High Yielding Variety
IBSNAT	International Benchmark Sites Network for Agrotechnology Transfer
IRRI	International Rice Research Institute
MOA	Ministry of Agriculture
NVI	Normalized Vegetative Index
NOAA-AVHRR	National Organization and Atmospheric Agency-Advanced Very High Resolution Radiometer
PAT	Polygon Attribute Table
UNDP	United Nations Development Program
WSTA	Weather Station

I. PROBLEM AND SETTING

Bangladesh occupies an area of 144,863 km^2 lying astride the Tropic of Cancer between latitudes 20° 25′ and 26° 38′ N and longitudes 88° 01′ and 92° 40′ E. The country is bounded by India to the north and west, to the east by India and Myanmar (Burma) and to the south by the Bay of Bengal. Bangladesh can be divided into five political regions consisting of Dhaka, Khulna, Chittagong, Rajshahi, and Barisal Divisions. These five divisions have 65 Districts. Further, each district is composed of several Thanas. The total number of Thanas in the country is 489 of which 29 are metropolitan.

The country consists of an array of varying agro-ecological regions. These offer a wide range of opportunities and constraints to agricultural development. Diversity of environmental conditions not only occurs at the national and regional levels, but also at Thana and village levels. In actuality, micro-level complexity of soil and hydrological conditions is an important characteristic of the Bangladeshi environment. Considerable year to year variability in rainfall, soil moisture availability, air temperature and flooding creates major problems for designing site-specific agricultural research and extension programs for sustainable agricultural production.

It is, however, the risks and uncertainties of seasonal weather and flooding that are the principal constraints to agricultural production in Bangladesh. Frequent cyclones, hailstorms, tidal surges, pest attacks, soil erosion, and soil fertility problems also damage the agriculture sector. About one million hectares of cropped land are highly flood-prone, and five million hectares are moderately flood-prone. The unprecedented flood of 1988 inundated about 60 percent of the country. On the other extreme, droughts annually affect about 2.3 million ha in the pre-monsoon (`Kharif-I') and 1.2 million ha in the dry (`Rabi') seasons. Pre-monsoon drought severely affects the transplanted Aman resulting in a reduction of about 1.5 million tons of rice which is about eight percent of the total annual production. During the dry season, the adverse effects of drought on production are visible in the wheat, potato, mustard and Aus paddy crops (BARC, 1991).

On most floodplains and valleys, the cropping pattern is determined by the dates when inundation begins and ends, the depth of inundation at peak levels, and the risk of damage to crop by early or late floods. Flooding, rainfall and temperature are the major hydro-climatic factors that determine crop performance and distribution in Bangladesh (Singh *et al.*, 1991).

Per capita land availability in Bangladesh is the lowest among the countries of south Asia (Table 1.1.) In this region arable land per capita is declining at an accelerated pace because of population growth and demand for non-agricultural land uses such as housing, industry, and roads. This loss of arable land has been partly compensated by encroachment into forestland and partly by movement to the frontier islands in the Bay of Bengal. Encroachment into the forest has reduced the forested area of the country to a critical level (8% of total area) to the detriment of the environment. Scarcity of arable land will continue to grow, therefore, more efficient use of land will be the principal means to sustain production.

Table 1.1. Land per capita and population density in selected countries, 1992 ***(Computed from FAO 1993 data).***

Countries	Total Population (Thousands)	Total Area (Thousands of ha)	Land per capita[a] (m^2 $person^{-1}$)	Population Density[b] (persons km^{-2})
Bangladesh	119,288	14,400	764.37	828
China	1,188,302	959,696	810.42	124
India	879,548	328,759	1,928.83	268
Indonesia	191,170	190,457	1,176.96	100
Japan	124,324	37,780	363.16	329
Korea, Rep	44,163	9,902	468.72	446
Malaysia	18,792	32,975	2,596.85	57
Myanmar	43,668	67,658	2,298.94	65
Nepal	20,577	14,080	1,144.00	146
Pakistan	124,773	79,610	1,691.87	157
Philippines	65,186	30,000	1,409.81	217
Sri Lanka	17,666	6,561	1,078.34	269
Thailand	56,129	51,312	3,586.38	109
Vietnam	69,485	33,169	963.81	209

[a] Based on total arable area and land under permanent crops, with double-cropped areas counted only once.

[b] Based on total land area, excluding area under inland water bodies.

A. Floods in Bangladesh

Flooding during the monsoon season from June to October is common. In a normal year about 2.6 million ha are affected. Recently it has been estimated that about 7.2 million ha, about half of total land area is flood-prone. Normally, the flooding depth varies from 30 cm to 2.5 m. More than 80 percent of the cultivable land is affected by floods, droughts, cyclones, and tidal-surges. Among these, floods are the most detrimental to the social and economic well being of the country.

In Bangladesh, floods of the following types are generally encountered (UNDP, 1988):

i) Flash floods in the eastern and northern rivers. These are characterized by a sharp rise in water levels followed by relatively rapid recession a few days later; they are often associated with high velocities that damage crop and property.

ii) Floods due to high-intensity rainfalls. These are caused by rainfall intensities and long rainfall durations in the monsoon season which generate water volumes in excess of local drainage capacity.

iii) Monsoon floods from the major rivers. The major rivers generally rise slowly over a period of 10 to 20 days, or more. Overflow from rivers and tributaries causes extensive damage particularly when the three major rivers (the Ganges, the Brahmaputra and the Meghna) rise simultaneously.

iv) Floods due to storm surges and tidal waves. These events occur in the coastal areas with large estuaries, extensive tidal flats, and low-lying islands. Storm surges caused by tropical cyclones cause extensive damage to life and property. Cyclones appear during the pre- and postmonsoon periods (April-May and October-November, respectively).

Flooding due to high-intensity rainfall and overflow of rivers is very common in Bangladesh. These floods affect the rice crop at different growth stages. Bangladesh floods can be categorized according to the extent of damage they cause. An analysis showing the relationship between frequency of occurrence and extent of flooding is shown in Table 1.2. On average, 22 percent area of the country is flooded each year. When more than 35 percent of the country is inundated, the damage can be catastrophic.

Table 1.2. Areas affected by floods in Bangladesh.

Return period (year)	Affected area (% of the country)
2	20
5	30
10	37
20	43
50	52
100	~ 60
500	~ 70
Mean	22

Source: French Engineering Consortium 1989.

Floods in Bangladesh have been categorized into early-flooding which occurs during mid-June to mid-July, normal-flooding which occurs during mid-August to mid-September and late-flooding which takes place between mid-September and late October. Among these, early-flooding is the most damaging even though its areal extent is small compared to the other categories because people are unprepared for them. The extent of normal-flooding is very large, but the amount of damage is small. Late-flooding causes moderate damage and is small in extent.

Practices and policies designed to manage one kind of flood do not work and can even be harmful when applied to other flooding situations. Time series data collected over the last four decades suggest that as more and more embankments were constructed, the area inundated has increased (*viz.*, 1954, 31068 km^2; 1955, 36246 km^2; 1974, 51780 km^2; 1987, 56958 km^2; and 1988, 77670 km^2) (BARC, 1989). The year to year variation in high flood and the affected areas are shown in Table 1.3. The evidence suggests that anticipated outcomes from flood control, drainage and irrigation projects have not been achieved in practice.

In Bangladesh the geologic process that creates land with high carrying capacity is the same process that places people in harm's way. Annual flooding replenishes soils with nutrients, but can also destroy crops and homes. As the population continues to expand, more people are compelled to occupy high risk zones.

Floods and cyclones can have serious consequences on the welfare of farmers and are events over which humans have no control. In agriculture, risk and uncertainty arise from these uncontrollable events. Investments in yield increasing management factors such as fertilizer applications, spraying for insects and diseases or choosing one type of seed over another can be lost to flood or drought. Thus in risky environments, risk avoidance becomes an important aspect of farming and policy making. One form of risk avoidance is to minimize losses by minimizing inputs. The farmer's aim is not to strive for high yields in the good or even average year, but to produce adequate food or income in the worst years. But human memory is fleeting. Three consecutive average years with

Table 1.3. Flooded areas for high flood years between 1954 and 1988

Year of occurrence	Affected area (Thousand km^2)
1954	36.78
1955	38.85
1956	35.48
1962	37.30
1963	35.23
1968	37.30
1970	42.48
1971	36.34
1974	52.52
1984	28.21
1987	54.95
1988	66.36

Source: Data for 1954-84 from Hossain *et al.*, 1987; and 1987-88 from Rogers *et al.*, 1989.

good prices may entice a farmer to again gamble with nature. Whatever the outcome, too much depends on chance. Farmers are well aware of this and appeal to their god or visit the village spiritual leaders to better their odds.

B. PURPOSE AND OBJECTIVES

The purpose of this dissertation research is to assemble a computer-based decision support system that can assist farmers and policy makers deal more effectively with the risk and uncertainty associated with annual flooding of agricultural lands in Bangladesh.

The objectives of assembling the decision support system are to:

1. Enable users of the decision aid to generate alternative strategies for minimizing flood damage on a site specific basis.
2. Enable policy makers to assess yield loss in real time to support food security decision making.

II. APPROACH AND METHODS

A. *Literature Review and Approach to Objective 1*

During the last three decades agricultural research has resulted in marked increases in crop yields. These increases were brought about by better agronomic practices developed through traditional agricultural research. Traditional agricultural research is however, not well suited to deal with risk because risk arises from random events, such as weather and prices, over which farmers have little or no control. Agricultural research mainly deals with factors which can be manipulated by humans. To deal with risk, one must be able to visualize whole probability distributions of outcomes, as risk resides in the tails of the distribution curve. One is not apt to see agronomic experiments designed to study the tail of a distribution. Anderson (1974) advocated greater investment in risk-oriented research and decried the emphasis on average-oriented research. Anderson's approach of using whole probability distributions is even more relevant today because computer technology and simulation models now enable decision makers to generate whole probability distributions at speeds unthinkable in 1974.

To simplify interpretation of a probability distribution, Anderson (1977) plotted cumulative probability on the ordinate and outcome such as yield or profit on the abscissa. The resultant curve with a positive slope was called the cumulative probability function (CPF). Two or more CPFs are needed because the analysis is comparative. In the case of two CPFs that do not intersect, the one to the right is said to be stochastically dominant. In such instances, the risk is lower and the mean is higher for the curve on the right. Anderson

(1977) referred to this situation as first order stochastic dominance. Given the option to choose, one would expect a farmer to select the stochastically dominant practice. Giving farmers a choice was one of Theodore Schultz's main tenants in his book "*Transforming Traditional Agriculture*." Schultz (1965) emphasized the need for more research that enabled farmers to exercise choice. In most situations, however, farmers are compelled to make choices when the comparative advantage is not so clear.

In risk analysis the CPFs, more often than not, intersect. When the two curves intersect, the case is referred to as second order stochastic dominance. Three second order cases can be visualized; the first involving intersection at 50 percent probability, and the other two intersecting above and below the 50 percent probability. In the first case the mean yield or profit is identical for the two CPFs but their variances differ. Although it is unwise to guess what farmers will choose, most would agree that risk-averse farmers would choose the one with the lower variance. The choice becomes even more difficult when the curves intersect above or below the 50 percent point. In this case, the high variance curve promises better outcomes for most years. The probability of doing better than the low variance option is specified by the point of intersection. In this case a farmer may still choose the low variance (low risk) option if the high variance option contains unacceptable outcomes in one or more years.

The aim of risk oriented research is to offer farmers a variety of alternatives and to enable them to exercise choice on the basis of productivity indicated by the mean and stability or risk associated with the variance.

Floods affect agricultural production in Bangladesh in a variety of complex ways. Bearing in mind that mild or normal flooding is beneficial in that it supplies water to summer and winter crops and replenishes nutrients through deposition of river sediments, the agricultural costs of flood damage can be divided into two categories: (1) the short-term damages to that year's crop, and (2) the long-term production loses from underinvestment in high yielding varieties, fertilizer, irrigation, labor, and other inputs.

Available literature shows that shifting rice transplanting date from the traditional time of planting, reduces yields to some extent and, in some cases, results in total crop failure (BRRI, 1981, 1984, 1985a, 1985b, 1985c, 1985d, and 1991). Farmers often either shift planting dates to avoid the risk of total crop failure from flooding or use late varieties which are usually low yielding. These practices usually result in substantial yield reduction and create unwanted food shortages which has to be met by imports or buffer stocks. A long sought national goai has been to estimate the annual food gap in a timely manner to enable the Government of Bangladesh to respond quickly to anticipated shortages.

One of the main advantages of using simulation models for risk analysis is their ability to generate information for decision making quickly and cheaply. But to do so, input data to run the models are needed. It is now generally believed that use of simulation models is constrained more by scarcity of input data than by model availability.

1. Status of Crop Simulation Models

Over the last 25 years, progress has been made in the development of dynamic models that are able to simulate the interactive effects of soil, weather, plant, and management practices on the growth and yield of crops. Jones *et al.*, (1989) stated that crop models are highly useful tools for scientists who want to better understand processes that contribute to the growth and yield of crops, and who also want to apply the models to improve crop management. They also indicated that planners and policy makers can apply simulation models to match policies to land capabilities and farming practices.

a. The Rice Model

There are several rice models but CERES-Rice version 3.0. model (Singh, *et al.*, 1994a) was used in this study. The model uses a minimum set of weather, soil, and variety-specific inputs, to simulate rice growth, development, and yield. The model takes into account several processes including (1) crop development, especially as it is affected by genotype and weather, (2) leaf, stem, and root extension, (3) biomass accumulation and partitioning, (4) water balance including daily evaporation, runoff, percolation, and crop water uptake under fully irrigated conditions and rainfed conditions with intermittent flooding and drying, and entirely rainfed conditions, and (5) soil nitrogen transformations associated with mineralization, immobilization, urea hydrolysis, nitrification, denitrification, ammonia volatilization, losses of nitrogen associated with runoff and percolation, and uptake and utilization by the crop.

b. Integration of Crop Models and GIS

The International Rice Research Institute (IRRI, 1992) used a combination of geographic information system (GIS) and a crop simulation model to analyze yield losses due to drought in the rainfed rice-growing area of Tarlac Province in the Philippines. van

Lanen *et al.*, (1992) developed qualitative and quantitative physical land evaluation methods and linked them with GIS to evaluate crop growth potential in the European Communities (EC). The evaluation methods used a combination of expert knowledge and crop models. The primary purpose of these models was to predict crop growth potential for exploring land use options. Calixte *et al.*, (1992) integrated the crop models in the DSSAT (Decision Support System for Agrotechnology Transfer) software (IBSNAT, 1989) with spatial data of soils and climate. In this effort, the Universities of Florida and Puerto Rico collaborated to develop the Agricultural and Environmental Geographic Information System (AEGIS, version 1.0). program. It provides decision makers with a decision aid to evaluate various options for production in a regional context. The second version, AEGIS+ v2.0 (Luyten *et al.*, 1994), links a GIS with the crop models in DSSAT, version 3.0 (Tsuji *et al.*, 1994). The system runs on the Sun Micro Systems' SPARC workstation and uses ARC/INFO version 6.0 (ESRI, 1991) as the GIS software.

B. METHODS

1. Input Data for Crop Simulation Models

Bangladesh possesses a wealth of information on its natural resources and weather. Several decades of rainfall, temperature, and other climatic records are available for use in this research. A reconnaissance soil survey carried out between 1963 and 1975 provides comprehensive information on soils, land levels, inundation regimes and several other aspects that are suitable for use in planning. The data generated in connection with the Agro-ecological Zone (AEZ) project (UNDP/FAO, 1988) constitute a key resource database for the country. While there is no scarcity of data, they are deficient in a number of ways. First the data are scattered and often do not meet the minimum data set required to operate crop models, and second the usable data have not been stored for easy retrieval. This is understandable as the data currently available were not collected for use in crop simulation. For this reason an effort was made to search for and collect the required minimum data set to operate the rice model including data sets for soil, crop, and weather.

a. Soil Minimum Data Set

Bangladesh is primarily a deltaic floodplain. Topographically, it is monotonously flat with elevation seldom exceeding 10 meters above mean sea level. The topography is broken in the southeast by the Chittagong Hill Tracts and by the northeastern hills. Floodplains and piedmont plains occupy almost 80 percent of the land area, slightly uplifted fault blocks (terrace) occupy about eight percent and hills occupy the remaining 12 percent.

"Floodplain soils" developed from alluvial sediments range in age from very recent to millennia. Moisture holding capacity is high in deep silt loams, moderate in loamy sands and low in sandy ridge soils. Based on the USDA Soil Taxonomy (Soil Survey Staff, 1975) the alluvial soils of Bangladesh are mostly *Typic* or *Aeric Fluvaquents*, with some *Haplaquents* and *Psammaquents*. Agricultural potential of "floodplain soils" is determined as much by depth and duration of flooding as by inherent soil properties. A wide range of terrace soils have formed from the Madhupur Clay. Differences in "terrace soils" are due to differences in drainage and in the depth and degree of weathering. Fertility of the "terrace soils" is generally low. The Northern and Eastern Hills include a variety of soils formed from consolidated and unconsolidated sandstones, siltstones and shales. Agricultural potential of these soils is severely limited by erosion hazards associated with steep slopes and heavy monsoon rainfall. Most soils on these slopes are unsuitable for bench terracing so that forestry and tree crop production are the most appropriate forms of land use (UNDP/FAO, 1988).

A total of 483 soil series have been characterized and described in the reconnaissance soil surveys of Bangladesh. These have been condensed to 19 "General Soil Types" as indicated in the map legend of the generalized map (Figure 2.1).

Eight soil profiles in DSSAT v3 input file format were created from information compiled from various sources (FAO/UNDP, 1971 and 1988; Joshua and Rahman, 1983) and were added to the SOIL.SOL file of DSSAT v3.0. (Appendix A) They each contain the following information.

1. General Soil Type
2. Soil classification based on USDA Soil Taxonomy
3. Particle size distribution [sand, silt and clay (%)]
4. Organic carbon content (%)
5. Bulk density (moist, g cm^{-3})
6. Evaporation limit (cm)
7. Color, moist (Munsell hue)
8. Drainage rate (fraction day^{-1})
9. Saturated water content, drained upper limit and lower limit (cm^3 cm^{-3})
10. Saturated hydraulic conductivity (cm h^{-1})
11. pH (in water)
12. Cation exchange capacity (cmol kg^{-1})
13. Total Nitrogen (%)

b. Agroclimatic Minimum Data Set

The number of rice crops grown each year is determined by climate and water availability. The major weather variables that influence crop growth and yields are daily solar radiation, rainfall, temperature, and day-length.

Ten year's weather data (daily) for six sites (Table 2.2) were obtained from the Bangladesh Meteorological Department and stored in the BARC Computer Center as ASCII files. The weather data include daily values for the following variables:

1. Rainfall (mm)
2. Maximum and Minimum Temperatures (^{o}C)
3. Bright Sunshine hours (hr)

The weather data files were converted to DSSAT v3.0 weather file format by a FORTRAN program and the bright sunshine hour data were converted to solar radiation (MJ m^{-2} day^{-1}) using the program named WFORM.EXE (EPA/USAID, 1990) program. Ten years' bright sunshine hour (daily) data were used to calculate the daily solar radiation for each station. Ten year's weather data in DSSAT v3.0. format for each location were used in this study.

i. Solar radiation

During the monsoon season water is plentiful, but solar radiation is frequently a limiting factor for rice production. Tanaka and Vergara (1967) and De Datta and Zarate (1970) reported that low yields of rice during the monsoon season are attributable to low solar radiation. They also reported that there is a strong relationship between yield and

Map Legend

1 = Non-calcareous Alluvium

2 = Calcareous Alluvium

3 = Acid Sulfate Soils

4 = Peat

5 = Gray Floodplain Soils

6 = Gray Floodplain Soils and Non-calcareous Brown Floodplain Soils

7 = Mixed Gray, Dark Gray and Brown Floodplain Soils

8 = Gray Floodplain Soils and Non-calcareous Dark Gray Floodplain Soils

9 = Gray Floodplain Soils and Acid Basin Clays

10 = Gray Piedmont Soils

11 = Acid Basin Clays

12 = Non-calcareous Dark Gray Floodplain Soils

13 = Non-calcareous Dark Gray Floodplain Soils and Calcareous Brown Floodplain Soils

14 = Calcareous Dark Gray Floodplain Soils with lime nodules

15 = Non-calcareous Brown Floodplain Soils and Gray Floodplain Soils

16 = Black Terai Soils

17 = Brown Hill Soils

18 = Red Brown Soils

19 = Gray Terrace Soils

20 = Urban Area

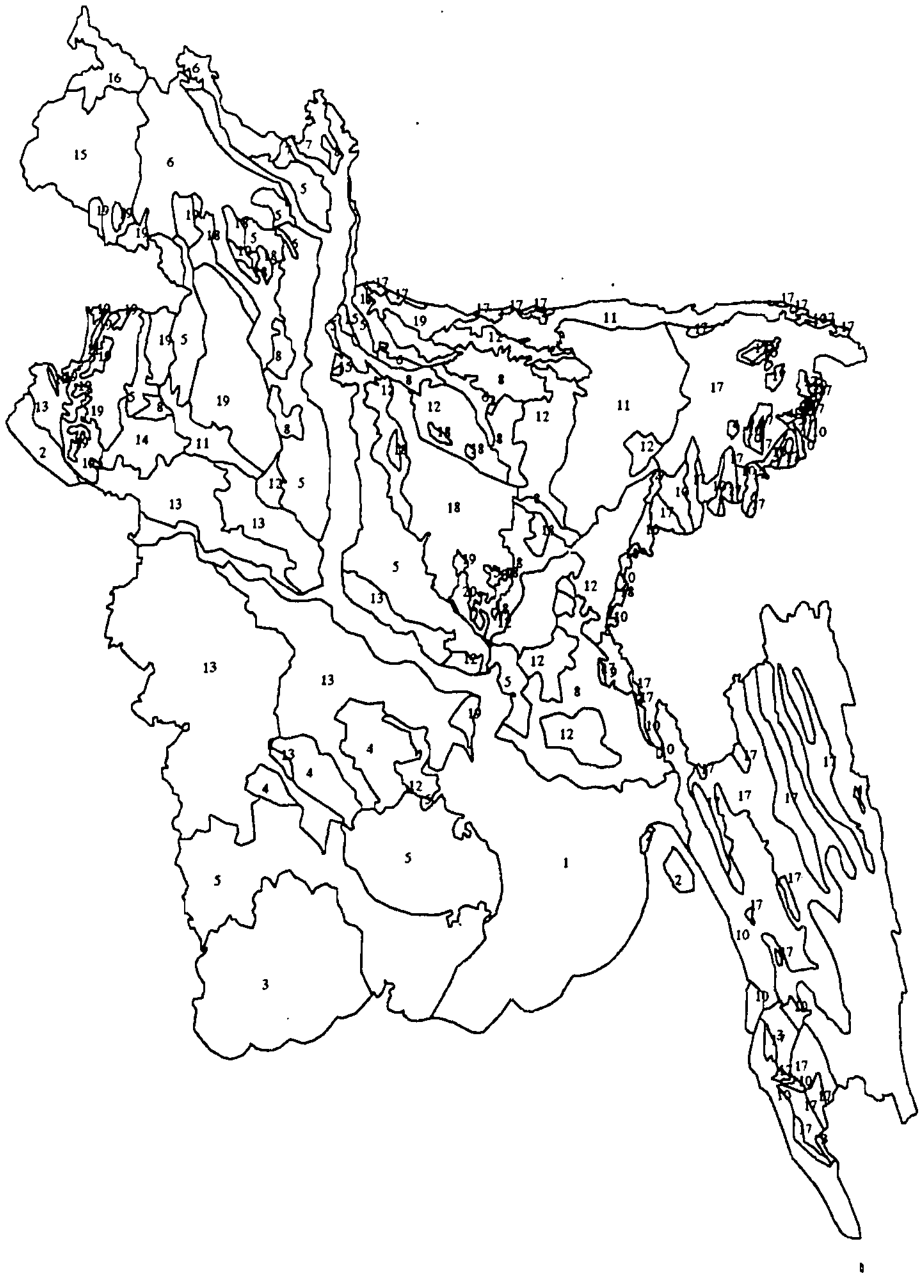


Figure 2.1. Generalized Soil Types of Bangladesh.

Table 2.1. Selected Weather Stations and their locations.

Weather Station	Latitude	Longitude
Comilla	23.28N	91.11E
Dhaka (for Munshiganj)	23.47N	90.14E
Jessore	23.11N	89.14E
Mymensingh (for Tangail)	24.46N	90.24E
Rajshahi	24.22N	88.34E
Sylhet	24.53N	91.56E

solar radiation, particularly during the period from panicle initiation to harvest. Maximum solar radiation occurs during the months of March, April, and May which ranges from 18 to 16 MJ m^{-2} day^{-1} and the minimum occurs during December with values between 14 and 12 MJ m^{-2} day^{-1} (Figure 2.2).

ii. Rainfall

According to IRRI (1974) more than 200 mm of water per month is needed to sustain a healthy crop of rice. Rainfall is adequate in most parts of Bangladesh to supply water for one irrigated rice crop. The cropping patterns depend both on rainfall and availability of irrigation water. The onset and ending dates of the monsoon are very important because they affect land preparation and harvesting. Distribution of rainfall during the development and growing period is also critical.

Complete or partial submergence of rice during the early stages of establishment especially just after transplanting, can drastically reduce yield. This type of crop damage is common in Bangladesh, the Philippines, China, and Vietnam because much of the rain falls during four to six months of the year. Rains start between March and April and average 1500 mm $year^{-1}$ in the drier regions to 5000 mm $year^{-1}$ in wetter regions (Figure 2.2). During this period large areas are subjected to intermediate flooding from overflowing rivers and rainwater.

iii Maximum and minimum temperatures

At flowering, the rice plant is most susceptible to high temperature (>35 °C), which causes high spikelet sterility (Satake and Yoshida 1978). In Bangladesh, this problem is encountered in crops grown during the dry-season in the drier regions. Low temperatures (<15 °C) also cause high sterility in rice undergoing panicle initiation (Yoshida 1981). This phenomenon is rare in Bangladesh.

Winter in Bangladesh covers the period from November to February. During this period the maximum and minimum daily temperatures fall between 26.6 °C and 7.2-12.2 °C respectively. Summer is the hottest period of the year (from April to September) with temperatures over 32 °C but rarely exceeding 40 °C (Figure 2.2).

c. Crop Minimum Data Set

The CERES Rice model uses as model inputs, coefficients that account for differences in growth and development among cultivars. These coefficients are referred to as genetic coefficients. Genetic coefficients allow the model to simulate performance of different varieties under diverse weather, and management conditions. The rice model requires eight genetic coefficients, four for phenology and four for growth. A brief description of these genetic coefficients is provided in Table 2.2.

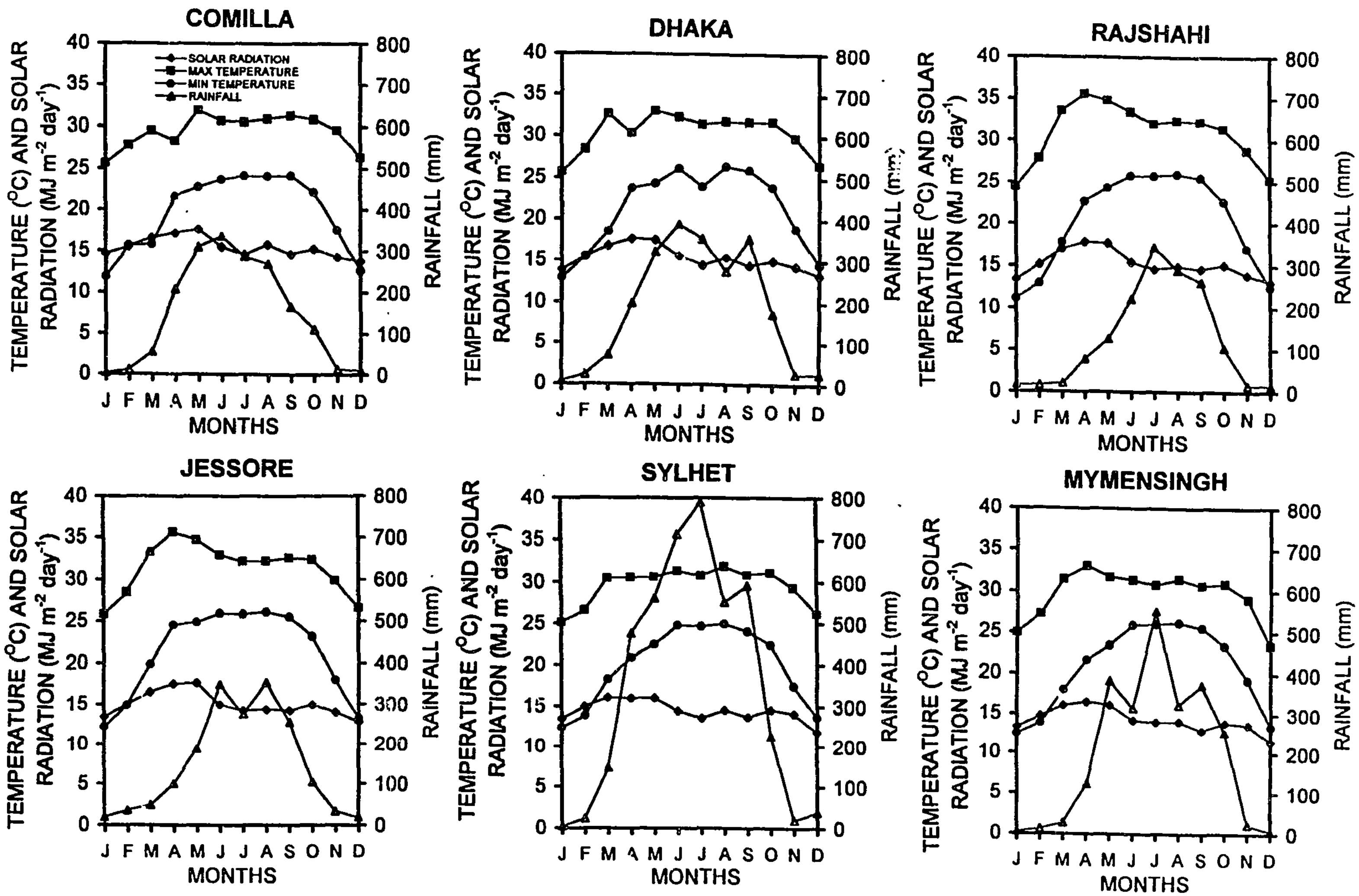


Figure 2.2. Monthly average agroclimatic curves of representative regions of Bangladesh.

The genetic coefficients of rice varieties cultivated by Bangladeshi farmers were estimated with a software called GENCALC (Hunt *et al.*, 1993) of DSSAT v3.0. The required information including the development, growth characteristics of the rice varieties along with the weather and management data was obtained from the Bangladesh Rice Research Institute (BRRI), BARC and the Bangladesh Agricultural Research Institute (BARI). The crop and management data are summarized in Table 2.3. Estimated genetic coefficients of three rice cultivars presented in Table 2.4 were used in this study.

d. Crop Management Information

Management factors that affect rice growth and yield include (1) planting date, (2) plant population, (3) seeding depth, (4) row spacing, (5) amount, timing, type and incorporation depth of organic residue applied, (6) amount, timing and type of inorganic fertilizer applied, (7) the placement and depth of fertilizer incorporation, and (8) irrigation method and amount of water applied. These factors are given for the three rice varieties used in this study in Table 2.5.

2. Locations

In this study 23 Thanas were selected on the basis of their economic importance and high frequency of flooding. These included all 11 Thanas from Tangail district, four from Comilla, two each from Sylhet, Jessore, and Munshiganj districts, and one each from Rajshahi and Chapai Nawabganj (Figure 2.3). It was not the intent of this study todo the analysis for the entire nation because (1) the minimum data set to run the model was not readily available and (2) time and resources did not permit it. It was deemed

Table 2.2. Phenology and growth genetic coefficients used in the CERES-Rice Model version 3.0.

Genetic coefficients	Definitions
	---------------------------Phenology coefficients---------------------
P1	Time period (growing degree days (GDD) in °C above a base temperature of 9°C) from seedling emergence during which the rice plant is not responsive to changes in photoperiod.
P2O	Critical photoperiod or the longest day length (in hours) at which development occurs at a maximum rate.
P2R	Extent to which phasic development leading to panicle initiation is delayed (GDD in °C) for each hour increase in photoperiod above P2O.
P5	Time period in GDD (°C) from beginning of grain filling (3 to 4 days after flowering) to physiological maturity with a base temperature of 9°C.
	---------------------------Growth coefficient---------------------
G1	Potential spikelet number coefficient as estimated from the number of spikelets per g of main culm dry weight.
G2	Single grain weight (g) under ideal growing conditions.
G3	Tillering coefficient relative to IR64 cultivar under ideal conditions. A higher tillering cultivar would have a coefficient greater than 1.0.
G4	Temperature tolerance coefficient. G4 for japonica type ≥ 1.0, value for indica type rice < 1.0.

Source: Singh *et al.*, 1994b.

Table 2.3. Development and growth characteristics of the selected varieties

Cultivars	BR3	BR11	BR14
Growing season	T. Aman / T.Aus	B. Aman	B. Aus
Duration from sowing to maximum tillering (days)	50 / 40	50	45
Duration from sowing to panicle initiation (days)	85 /75	80	70
Duration from sowing to ripening (days)	105-110/ 95-100	110-115	90-100
Duration from sowing to maturity (days)	130-135/ 120-125	140-145	115-125
Sensitivity to changes in daylength	Insensitive	Insensitive	Insensitive
Tillering habit (tillers $plant^{-1}$)	12-15 /10-12	10-12	10-12
Maximum recorded yield ($t\ ha^{-1}$)	5.0-5.5/ 4.0-4.5	5.5-6.5	4.5-5.0
Average 1000 grain weight (g)	27.0	24.0	29.0

Table 2.4. List of cultivars and their estimated genetic coefficients.

Variety	Phenology				Growth			
	P1	P2R	P5	P2O	G1	G2	G3	G4
BR11	780.0	180.0	400.0	10.5	55.0	.0240	1.00	0.90
BR3	650.0	110.0	420.0	12.0	65.0	.0270	1.00	1.00
BR14	650.0	180.0	420.0	8.0	65.0	.0290	1.00	0.70

more important to use the available time to develop a prototype decision support system for assessing yield loss from flooding, and to expand the study area later.

3. Operating AEGIS+

The simulations were carried out using AEGIS+ v2.0. This software can be used for any region or so-called "coverage", such as a farm, region, or country. For a coverage, different crop management practices can be assigned to different fields or homogenous land areas, called "polygons". AEGIS+ v2.0 enables a user to evaluate the effects of alternative practices on crop yields, to explore land use options, and to determine potential environmental impacts (Luyten *et. al.*, 1994).

Cloropleth maps of Administrative Units at Thana level, General Soil Types, Inundation Land Types, and Agricultural Landuse of Bangladesh were collected through the courtesy of the Soil Resources Development Institute, Dhaka, Bangladesh. The scale of the maps was 1:1,000,000. These maps were digitized using the Arc Digitizing System

Table 2.5. Crop management of selected varieties.

Cultivars	BR3	BR11	BR14
Growing seasons	T.Aman/T.Aus	B.Aman	B.Aus
Traditional planting date	Jul 01 & September 01/ April 01	April 01	April 01
Method of planting	Transplant	Broadcast	Broadcast
Seedling age at transplanting (days)	30	-	-
Plant population (plant m^{-2})	44	60	44
Row spacing (cm)	20	20	15
Depth of planting (cm)	5-7	5-7	0-3
Fertilizer management[a] N (Urea)	25 kg at 15 DAT[b], 30 kg at 25 DAT and 25 kg at 50 DAT / 20 kg at 15 DAT, 20 kg at 30 DAT and 20 kg at 50 DAT	25 kg at 15 DAS[c], 30 kg at 25 DAS and 25 kg at 50 DAS	20 kg at 15 DAS, 20 kg at 30 DAS and 20 kg at 50 DAS
P (Triple Super Phosphate)	20 kg at land preparation	20 kg at land preparation	20 kg at land preparation
K (Muriate of Potash)	35 kg at land preparation	35 kg at land preparation	35 kg at land preparation
Water management bund height (cm)	5-15	5-15	5-15

[a] Recommended fertilizer management.

[b] DAT = Days after transplanting

[c] DAS = Days after sowing

Farmers apply 25-10-12 kg N-P-K ha^{-1} to Aus rice, and 70-18-12 kg N-P-K ha^{-1} to T.Aman rice and to B.Aman 50-18-12 ha^{-1} (Source: Ahmed, 1992).

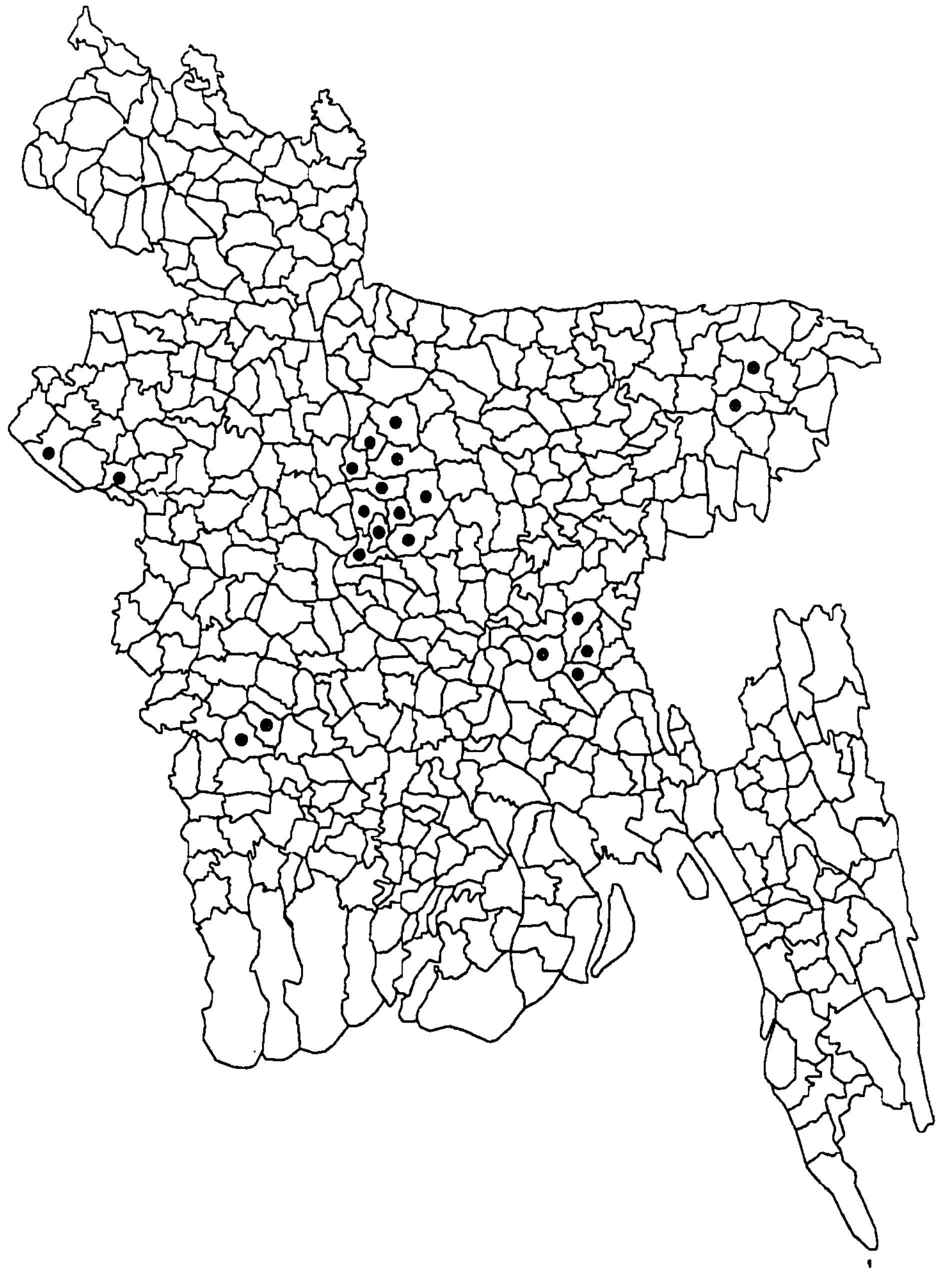


Figure 2.3. Map of administrative units known as Thana. Thanas selected for this study are marked with a dot.

(ADS) of ARC/INFO. These were used to build the GIS data-base. Subsequently, they were used in AEGIS+ and for preparing flooding scenarios.

To run AEGIS+ the selected coverage must have the soil (ID_SOIL) and weather station (WSTA) information in the polygon attribute table (PAT). The dominant soil types in each Thana were determined by overlaying the soil map (Figure 2.1) on the administrative (Figure 2.3) map. Since rice is not grown on all soils, and data for all soils were not available, the dominant soil for each Thana was assigned to each administrative unit in the polygon attribute table. Among the 23 selected Thanas, the number of soils in a Thana varied and the number for each Thana ranged from one to four. The dominant cropping patterns of the Thanas were determined by overlaying the administrative map on the cropping patterns map (Figure 2.4). Altogether five major and nine secondary cropping patterns were identified. Similarly the dominant inundation land types were determined by overlaying the inundation map (Figure 2.5) on the administrative map. Table 2.6. shows the dominant soil types, cropping patterns and inundation types for the 23 Thanas.

4. Application of AEGIS+

AEGIS+ enables a user to assess the effect of alternative planting dates and nitrogen fertilizer rates and to compare those results with current farmer's practice. This assessment was conducted for Aus and Aman rice growing seasons. The traditional planting date of Aus rice is April 01 for both medium highland and medium lowland situations, but the variety differs. In the former case farmers grow BR14 and in the latter case, BR3. The broadcast Aman rice is planted during the first week of April, on

MAP LEGEND

1 = Aus - Rabi crop - Fallow
2 = Aus - T. Aman - Rabi crop
3 = T.Aus - T.Aman - Fallow
4 = T.Aman - Boro
5 = T. Aman - Fallow
6 = Shrimp - T.Aman - Fallow
7 = Mixed Aus & B.Aman - Rabi crop
8 = Mixed Aus & B.Aman - Vegetables
9 = Boro - Fallow
10 = Sugarcane
11 = Bettlevine & Vegetables
12 = Orchard
13 = Tea
14 = Upland Forest
15 = Thickets & Grasses
16 = Natural Mangrove Forest
17 = Shrimp - Salt bed
18 = Beaches
19 = Fallow (water-logged)
20 = Urban Area

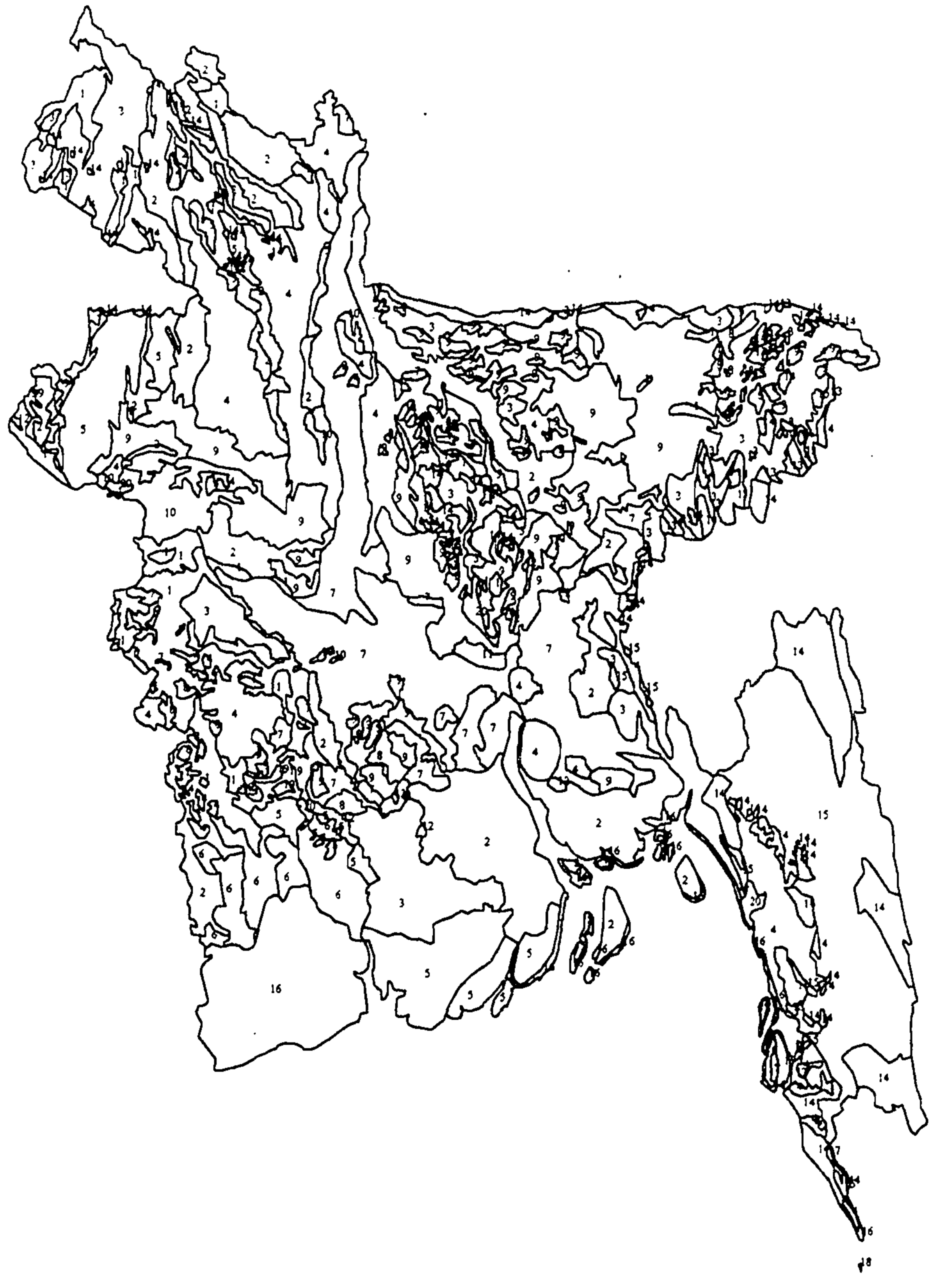


Figure 2.4. Cropping pattern/land use map of Bangladesh

MAP LEGEND

1 = Mainly Highland

2 = Highland to Medium Lowland

3 = Mainly Medium Highland

4 = Medium Highland and Highland

5 = Medium Highland and Medium Lowland

6 = Medium Highland to Lowland

7 = Medium Lowland and Lowland

8 = Lowland and Very Lowland

Where:

Highland	Land which is above normal flood-level.
Medium Highland	Land which normally is flooded up to about 90 cm deep during the flood season
Medium Lowland	Land which normally is flooded between 90 cm and 180 cm deep during the flood season
Lowland	Land which normally is flooded between 180 cm and 300 cm deep during the flood season
Very Lowland	Land which normally is flooded deeper than 300 cm deep during the flood season

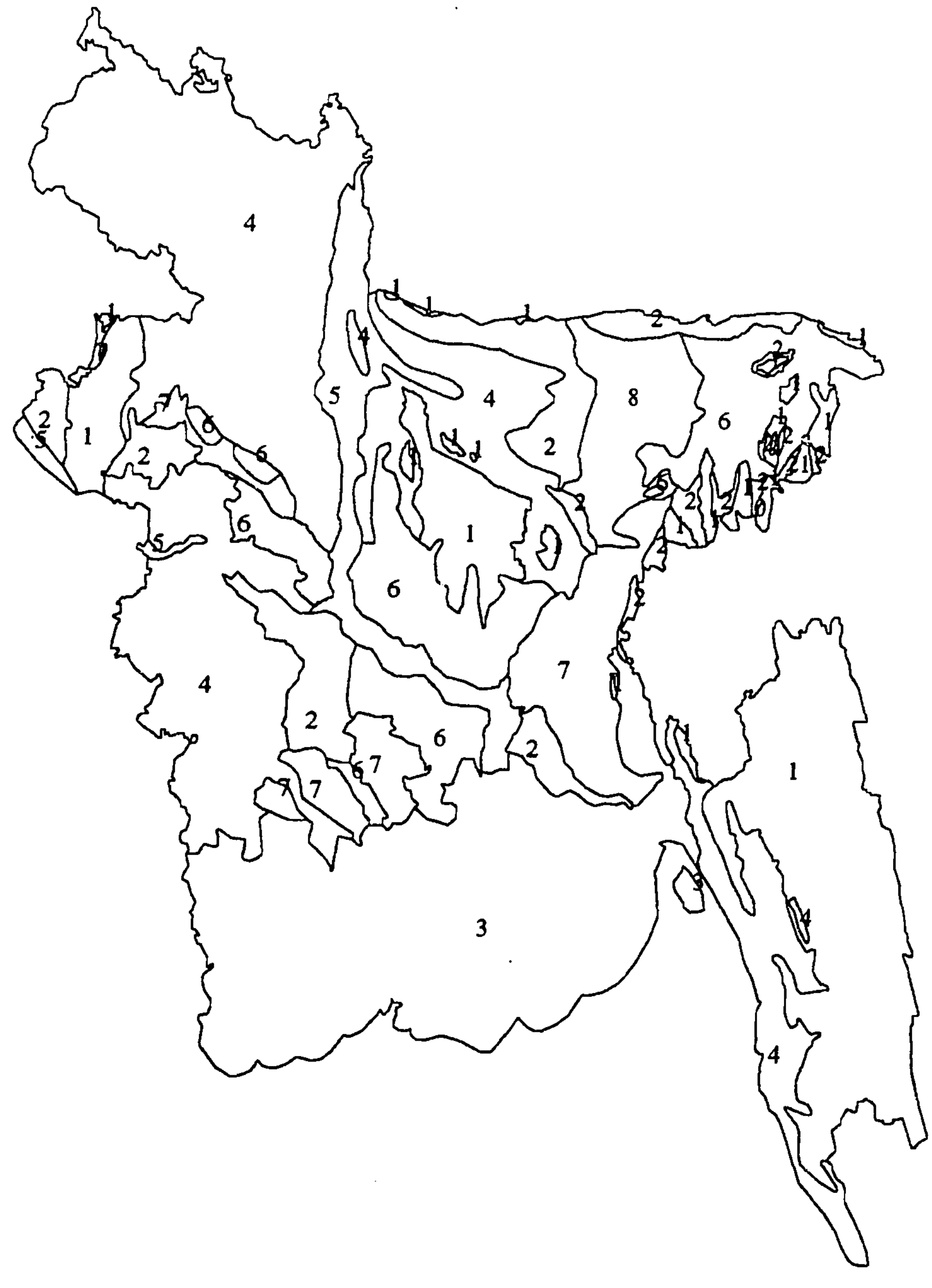


Figure 2.5. Inundation Land Types map of Bangladesh.

Table 2.6. Polygon number, dominant cropping pattern, General Soil Type and inundation land type of selected Thanas.

District/Thana	Polygon#	Cropping Pattern	Soil Type	Inundation Land Type
Tangail				
Tangail Sadar	207	Mixed Aus+B.Aman - Rabi crop	GFS	Medium Highland and Highland
Mirzapur	227	B.Aman - Rabi crop	GFS	Medium Highland to Lowland
Bhuyanpur	170	Mixed Aus+B.Aman - Rabi crop	NCA	Medium Highland and Medium Lowland
Delduar	224	B.Aman - Rabi crop	GFS	Medium Highland to Lowland
Kalihati	197	T.Aman -Boro	GFS	Medium Highland to Lowland
Madhupur	145	T.Aman -Boro	NCDGFS	Medium Highland and Highland
Gopalpur	159	T.Aman -Boro	GFS	Medium Highland and Highland
Ghatail	173	T.Aman -Boro	GFS	Medium Highland and Highland
Sakhipur	194	B.Aman - Rabi crop	BHS	Mainly Highland
Basail	213	T.Aman -Boro	GFS	Medium Highland to Lowland
Nagarpur	233	Mixed Aus+B.Aman - Rabi crop	GFS	Medium Highland to Lowland
Comilla				
Muradnagar	272	Mixed Aus+B.Aman - Rabi crop	NCDGFS	Medium Lowland and Lowland
Daudkandi	295	Mixed Aus+B.Aman - Rabi crop	NCDGFS	Medium Lowland and Lowland
Chandina	310	Aus - T.Aman - Rabi crop	NCDGFS	Medium Lowland and Lowland
Debidwar	285	Mixed Aus+B.Aman - Rabi crop	NCDGFS	Medium Lowland and Lowland
Munshiganj				
Lohajang	308	Mixed Aus+B.Aman - Rabi crop	NCDGFS	Medium Highland and Medium Lowland
Srinagar	299	Mixed Aus+B.Aman - Rabi crop	CDGFS	Medium Highland to Lowland

NCA = Non-calcareous Alluvium, CA = Calcareous Alluvium, GFS = Gray Floodplain Soils, NCDGFS = Non-calcareous Dark Gray Floodplain Soils, CDGFS = Calcareous Dark Gray Floodplain Soils and BHS = Brown Hill Soils.

Table 2.6. (Continued) Polygon number, dominant cropping pattern, General Soil Type and inundation land type of selected Thanas.

District/Thana	Polygon#	Cropping Pattern	Soil Type	Inundation Land Type
Jessore				
Jessore Sadar	344	T.Aman -Boro	CDGFS	Medium Highland and Highland
Bagherpara	334	T.Aman -Boro	CDGFS	Medium Highland and Highland
Rajshahi				
Paba	188	B.Aman - Fallow	CDGFS	Medium Highland and Highland
Chapai Nawabganj				
Nawabganj	158	Mixed Aus+B.Aman - Rabi crop	CA	Medium Highland and Highland
Sylhet				
Sylhet Sadar	96	T.Aus - T.Aman - Fallow	GFS	Medium Highland to Lowland
Balaganj	135	T.Aus - T.Aman - Fallow	GFS	Medium Highland to Lowland

medium lowland with variety BR11. Transplanted Aman rice season starts in July and ends in early September. On medium highlands, rice is transplanted in the first week of July, and in the medium lowland, it is transplanted in the first week of September. Fertilizer application rates vary with growing season, and variety, and follow the government recommended or farmers' practice (Table 2.5). Water management for all practices was automatically set at 10 cm bund height and replenished at 50% depletion. No organic residues were incorporated. In rural Bangladesh, farmers harvest most of the biomass for fuel and fodder. In acute situations they harvest the roots for fuel. Most farmers cannot afford to grow a green-manure crop and farmers who grow vegetables apply cow-dung at rates of 2 to 12 t ha^{-1} .

In this section, a combination of crop management choices such as crop variety, planting dates, planting density, row spacing, method and rate of fertilizer application and water management, assigned to a polygon or a set of polygons, is referred to as a practice. A plan consists of one or more practices. Six plans with three planting dates and two nitrogen application rates were selected for simulation. Each plan consisted of five practices. The planting dates included the traditional planting date, 30 days before the traditional planting date, and 30 days after the traditional planting date. Two nitrogen application rates were used, the first one was based on BRRI's recommendation and the second on farmers' practice. Figure 2.6. illustrates the yield assessment scenarios consisting of six plans with five practices. For easy reference, the practices are numbered.

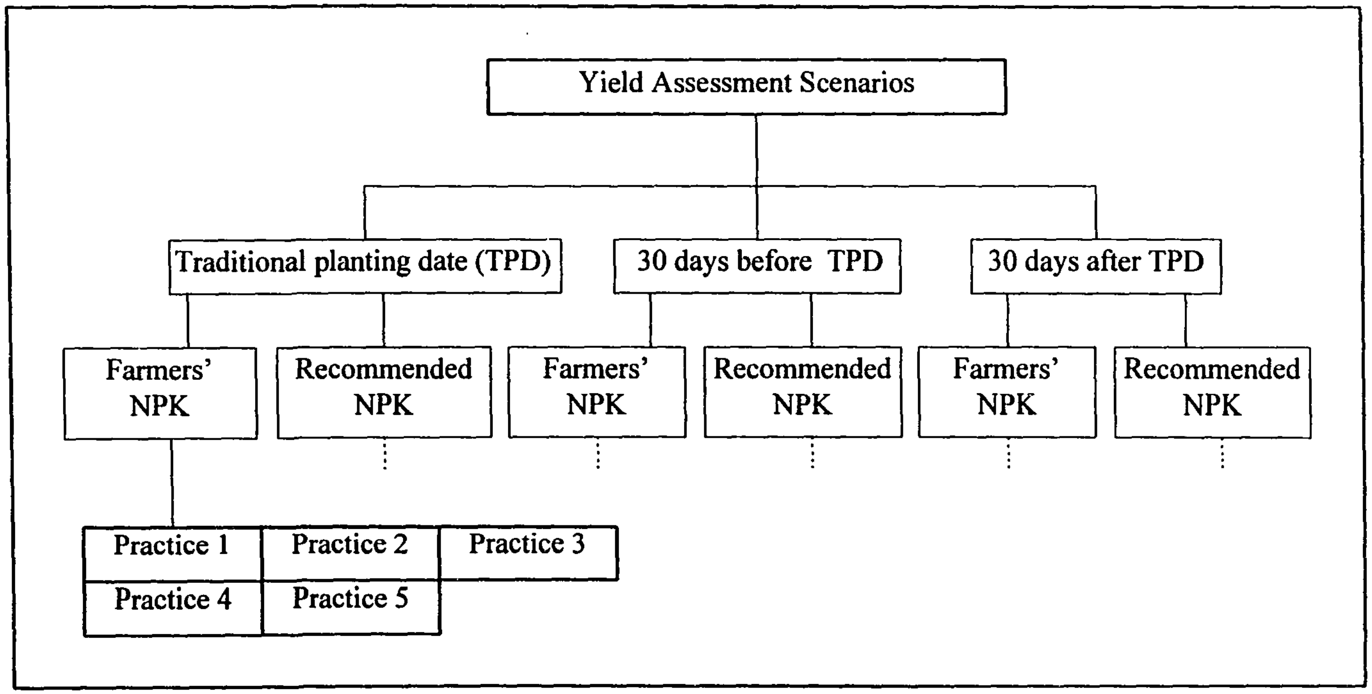


Figure 2.6. Yield assessment scenarios for 10 year simulation. The scenario consists of six plans containing five practices. The five practices are identical for every plan. Details of each practice is provided on the following page.

Practice 1	Practice 2	Practice 3
Thanas: Nawabganj, Bhuyanpur Lohajang and Tangail Sadar	Thanas: Sylhet Sadar, Balaganj Nagarpur, Muradnagar, Debidwar, Srinagar, Daudkandi, and Chandina	Thanas: Madhupur, Gopalpur, Ghatail, Paba,Bagherpara, and Jessore Sadar
Growing Season: Broadcast Aus	Growing season: Transplanted Aus	Growing season: Transplanted Aman
Traditional planting date: April 01	Traditional planting date: April 01	Traditional planting date: July 01
Rice variety: BR14	Rice variety: BR3	Rice variety: BR3
Planting density : 60	Planting density : 44	Planting density : 44
Row spacing : 15 cm.	Row spacing : 20 cm.	Row spacing : 20 cm.
Planting depth: 3 cm.	Planting depth: 5.9 cm.	Planting depth: 5.9 cm.
Organic residues: None	Organic residues: None	Organic residues: None
Water management: Automatic	Water management: Automatic	Water management: Automatic

Practice 4	Practice 5
Thanas: Kalihati and Basail	Thanas: Sakhipur, Delduar, and Mirjapur
Growing season: Transplanted Aman	Growing Season: Broadcast Aman
Traditional planting date: Sept. 01	Traditional planting date: April 01
Rice variety: BR3	Rice variety: BR11
Planting density : 44	Planting density : 60
Row spacing : 20 cm.	Row spacing : 15 cm.
Planting depth: 5.9 cm.	Planting depth: 3 cm.
Organic residues: None	Organic residues: None
Water management: Automatic	Water management: Automatic

Figure 2.6. (Continued) Yield assessment scenarios for 10 year simulation. The scenario consists of six plans containing five practices. The five practices are identical for every plan.

C. Literature Review and Approach to Objective 2

Several attempts have been made to assess the impact of flooding on rice yields in Bangladesh. One attempt was made to assess the potential of the NOAA-AVHRR (National Organization and Atmospheric Agency-Advanced Very High Resolution Radiometer) satellite images for monitoring crop conditions, stages of growth, and crop damage due to flooding. Ground verification of color coded NOAA satellite imageries taken during October and November 1987 were conducted in the three regions of Gaibandha-Rangpur, Tangail, and Brahmanbaria. The observed data were then matched and correlated with the satellite data. The study indicated that high NVI (Normalized Vegetation Index) values corresponded to denser green canopy and better conditions of Aman rice. It also revealed that high expected yield for the Aman crop was associated with high NVI values. It was also shown that low NVI values were associated with either crop damaged by flooding or low yielding Aman crops (BARC, 1988). At present Bangladesh has no suitable mechanism for assessing the impact of flooding on rice production.

Since the rice model is not designed to simulate the effect of high water on crop yields, another approach was needed to estimate yield loss from flooding. The aim of this approach should be to enable local yield losses to be aggregated into yield losses for larger administrative units up to the national level. To do this the decision support system for estimating yield loss for the country as a whole must consist of three parts. The first should be a crop model that can estimate crop yield for the non-flooded situation, the second, a rule-based system that organizes existing knowledge about the effects of flooding on rice yields to assess yield loss, and the third, a geographic information system that enables users to visualize the extent and spatial distribution of flood damage for the entire country. The first and third components have already been described in the previous section and therefore will not require further description. This section will describe the second component of the decision support system.

Several studies have been conducted at a number of institutions involving the integration of crop models with a Geographic Information System (GIS), (van Lanen *et al.*, 1992; Calixte *et al.*., 1992; IRRI, 1992; Luyten *et al.*, 1994). A GIS provides the crop models with access to spatial databases so that model output can be displayed spatially. Simulated results from the crop models are stored in the GIS database, and can be presented in map form. Crop model-GIS analysis has considerable potential because complex interactions among crops, soils, and climate can be displayed spatially. This enables alternative management strategies on agricultural productivity and environmental degradation to be mapped and presented to policy makers and planners more effectively. It is also helpful for policy makers and planners to be able to evaluate different outcomes of crop and soil management options and to have alternative strategies prepared and ready to implement when flooding occurs.

An expert system is a computer-based system that mimics the capability of human experts in some particular field. It is possible to build expert systems that perform at remarkable levels (Duda and Shortliffe, 1983). Expert systems or knowledge-based systems, are designed to organize knowledge and problem-solving skills, and to make them accessible to non-experts (Caudle, 1991). MYCIN, developed in 1972 at Stanford University, is an expert system used for diagnosing bacterial infection in blood. Other early expert systems included DENDRAL (mass spectroscopy), PROSPECTOR (mineral ore exploration), and INTERNIST/ CADUCEUS (internal medicine). Several expert systems were also developed to solve agricultural problems. Examples include PLANT/tm (weed identification), PLANT/ds (diagnosing soybean diseases) developed in the University of Illinois at Urbana-Champaign, and ACID4 (diagnosing lime requirement for acid soils) was developed in the University of Hawaii (Yost *et al.,* 1988). Davis (1986) stated that among several methods available for designing expert systems, rule-based systems have emerged as the popular architecture. Deriving their knowledge from relatively easily understood facts and rules, rule-based systems offer surprising power and versatility. Currently, experts in Bangladesh use rules based on their experience and expertise for assessing flood damages to crops. There is, on the one hand, a limited number of experts in this domain and, on the other, a large number of planners and policy makers, who need expert advice. It would be useful for planners and policy makers to have access to expert knowledge. Therefore, development of a rule-based system is a promising way of making existing knowledge accessible to users who need it.

1. Developing the Rule-based System

a. Acquisition of Published Knowledge

To develop a rule-based system one should understand the problem thoroughly and identify the source of knowledge. This section reviews the extent to which the subject of yield loss assessment of rice from submergence has been studied in Bangladesh and elsewhere.

The ability of a rice plant to withstand prolonged submergence is a genetic characteristic and is referred to as submergence tolerance. Several factors that affect survival after submergence have been identified (Richharia and Parasuram, 1963; Palada and Vegara, 1972). A rice variety that can withstand long submergence, high water temperature, high water turbidity, low light intensity, deep submergence, and high soil nitrogen content has a better chance of surviving a flood. Plants are less tolerant to submergence when they are young and this tolerance differs with varieties (Palada, 1970; Weerapat and Woraniman, 1974; and Supapoj *et al.*, 1978). The significance of growth stage, duration of submergence, and clarity of flood water has been reported by FAO/UN (1972), and Undan (1977) [Tables 2.7-2.9].

Mazaredo and Vegara (1982) reported that tolerant varieties maintain high photosynthesis and respiratory rates, high levels of carbohydrate and nitrogen, withstand low oxygen supply in the root zone, and retain stiffness and rigidity of culm during submergence. Reddy and Mittra (1985) found that of the three growth stages, flowering was most critical when completely submerged followed by the seedling establishment and maximum tillering stages. Among the three stages of reproductive growth phase, the plant was most susceptible to damage during booting followed by flowering and post-flowering. Submergence for four days at booting caused as much damage as six to eight days of submergence at flowering. They also observed that submergence increased the nitrogen and decreased phosphorus and potassium content in leaf, stem and grain.

In 1987, extensive field surveys and discussions with farmers in several flooded areas of Bangladesh resulted in the following conclusions (MOA, 1987):

i) 30-day old transplanted seedlings of several high yielding varieties (HYVs) survived 10-12 days of submergence without incidence of tiller rot. Several younger seedlings transplanted 20-25 days prior to flooding showed good recovery up to 10 days of submergence. Local varieties of transplanted Aman rice were less tolerant to submergence than the high yielding varieties, but could survive four days of submergence provided they were well established. Cloud cover and light rain also increased the survival by reducing rotting incidence. Submergence damage was partly compensated by increased tillering of surviving plants.

ii) Upland crops such as sesame, foxtail millet and chillies were found to be very susceptible to short periods of submergence. Rice plants with high tissue nitrogen were more susceptible to tiller rot than those with low nitrogen. Rotting was also accelerated by bright sunlight.

iii) Strong water currents can damage the submerged crop.

Table 2.7. Submergence damage of rice according to growth stages in Korea.

Crop Growth Stages	Period	Clear Water				Muddy Water			
		Days of Submergence							
		1	3	5	7	1	3	5	7
		Percent Yield Reduction							
Tillering period	mid-July	25	55	100	100	30	100	100	100
Panicle formation	early Aug.	15	45	90	95	20	50	90	100
Head sprouting	late Aug.	25	95	100	100	45	100	100	100
After-flowering	early Sept.	15	50	50	50	45	85	85	85
Milky stage	mid-Sept.	5	5	10	10	15	35	40	65
Ripening		5	20	20	30	10	20	30	30

Source: FAO/UN, 1972. Report on the Mokpo's Yongsan Scheme (1965).

Table 2.8. Submergence damage of rice according to growth stages in Japan.

Crop Growth Stages	Clear Water				Muddy Water			
	Days of Submergence							
	1-2	3-4	5-7	7+	1-2	3-4	5-7	7+
	Percent Yield Reduction[a]							
20 days after transplanting	10	20	30	35				
Young panicle formation, partly inundated[b]	10	30	65	90-100	20	50	85	90-100
Young panicle formation, completely inundated	25	45	80	80-100	70	80	85	90-100
Heading stage	15	25	30	70	30	80	90	90-100
Ripening stage	0	15	20	20	5	20	30	30

Source: FAO/UN, 1972. Irrigation in Japan by H. Fukuda and H. Tsutsui (1968).

[a] Damage figures are reduced by 50 percent for half-day submersion.

[b] "partly" means leaves (9 to 15 cm. long) remain above water surface.

Table 2.9. Projected yield reduction due to inundation of IR-30 rice variety (tons/ha)[a], (Undan, 1977).

Crop Growth Stages	Plant Height Submerged (cm)	Period of Submergence (days) 1	2[b]	3	4	5
2 weeks after transplanting (early tillering)	30	1.29	2.25	3.21	3.34	4.42
	15	0.36	0.18	0.00	0.54	0.54
4 weeks after transplanting (maximum tillering)	48	1.29	1.63	1.97	4.47	4.97
	24	0.01	0.02	0.40	0.46	0.25
6 weeks after transplanting (panicle initiation)	68	3.89	4.41	4.93	5.06	5.25
	34	0.54	0.48	0.42	0.50	0.59

[a] Based on average yield of IR-30, which was 5.25 tons ha^{-1} for uninundated crops.
[b] Interpolated values.

Khandaker *et al.*,(1992) investigated the tolerance of transplanted Aman rice to flooding and found that HYV BR11 and a local variety *Gobindabhog* were more tolerant to submergence than *Chakkal, Pajam* and *Binni* varieties. Older seedlings, whether newly transplanted or at maximum tillering stage, were more tolerant to flooding than young seedlings.

b. Acquisition of Knowledge from Experts

To supplement knowledge on the effect of submergence on rice yield, researchers from several agricultural research and extension organizations were consulted for their expert knowledge. The method recommended by Medsker and Liebowitz (1994) was used for this purpose. Three experts, who are involved in research and planning were interviewed individually in a semi-structured manner. The purpose of the interview was first explained to them, and were later asked to complete the forms shown in Tables 2.10.-2.12. The forms were patterned after several in the literature (FAO/UN, 1972 and Undan, 1977) and modified by incorporation of suggested changes. Responses from the three experts were averaged and returned to them for their comments. Modifications suggested by them were incorporated and the results were finalized (Tables 2.10.-2.12.). In addition information on varietal characteristics, growth stages, and expert recommendations for varieties suitable for flood-prone areas were also collected.

D. FLOODEX - A Rule-Based System for Yield Loss Assessment

Using Arc Macro Language (AML), a computer applications programming language of ARC/INFO (ESRI, 1991), the accumulated knowledge on the effect of submergence on rice yield was used to produce FLOODEX. FLOODEX is a menu-driven, prototype rule-based system designed to estimate percent yield reduction of rice from flooding. The knowledge base for FLOODEX is contained in Tables 2.10-2.12. A forward chaining or event-driven reasoning method was used to develop FLOODEX. An example of a production rule used in FLOODEX to estimate percent yield loss is as follows:

> *If the crop in the field is rice, its growth stage is at maximum tillering, it is submerged up to 50% of plant height, the clarity of the flood water is turbid, and the crop has been submerged for 3 days, then the grain yield is likely to be 75 % of the uninundated case.*

The system was designed to estimate percent rice yield reduction due to differences in duration and depth of submergence and to different growth stages and clarity of flood water. The system can accommodate other crops like jute and wheat but lack of a complete knowledge-base did not permit their inclusion in this study. The system can be used as a

Table 2.10. Submergence (25-50% of plant height) damage of rice according to growth stages in Bangladesh (Karim *et al.*, 1994).

Crop Growth Stages	Clear Water				Muddy Water			
	Days of Submergence							
	3	7	10	15	3	7	10	15
	Percent Yield Reduction							
10 days after transplanting	10	15	20	30	25	45	50	60-70
Maximum tillering	10	15	25	40	25	45	55	70-90
Panicle initiation	0	0	30	40	15	15	60	70-90
Heading	0	0	30	40	15	15	60	70-90
Early grain filling	0	0	30	40	20	20	60	70-90
Maturity	0	25	40	40	15	45	70	70-100

Table 2.11. Submergence (50-75% of plant height) damage of rice according to growth stages in Bangladesh (Karim *et al.*, 1994).

Crop Growth Stages	Clear Water				Muddy Water			
	Days of Submergence							
	3	7	10	15	3	7	10	15
	Percent Yield Reduction							
10 days after transplanting	10	40	50	60	35	70	80	90-100
Maximum tillering	5	50	60	70	30	80	90	90-100
Panicle initiation	15	40	50	60	45	70	80	90-100
Heading	15	40	50	60	45	70	80	90-100
Early grain filling	20	40	60	70	50	70	90	90-100
Maturity	20	40	60	70	50	70	90	90-100

Table 2.12. Submergence (75-100% of plant height) damage of rice according to growth stages in Bangladesh (Karim *et al.*, 1994).

Crop Growth Stages	Clear Water				Muddy Water			
	Days of Submergence							
	3	7	10	15	3	7	10	15
	Percent Yield Reduction							
10 days after transplanting	40	80	100	100	60	90	100	100
Maximum tillering	40	60	80	100	60	90	100	100
Panicle initiation	50	70	100	100	70	90	100	100
Heading	40	80	100	100	60	90	100	100
Early grain filling	30	60	80	100	40	80	100	100
Maturity	30	60	80	100	40	80	100	100

stand-alone or interfaced with AEGIS+. When FLOODEX is used as a stand-alone, the percent yield reduction can be estimated, and the output can be displayed and printed for each polygon. No maps or reports are generated.

The integrated FLOODEX- AEGIS+ decision support system requires that the FLOODEX rules be applied prior to running the simulations in AEGIS+. The polygon number(s) of the target region (coverage), for which the percent yield reduction is to be estimated must have the four-character WSTA (weather station) code and ten-character soil code in the polygon attribute table. The *weather* and *data* subdirectories of the target region must have the weather files for the run year(s) and the soil profile data in the SOIL.SOL file in DSSAT v3 format; respectively.

1. Modification of AEGIS+

To incorporate the output from FLOODEX into AEGIS+, it was necessary to make several program modifications. Table 2.13. shows the directory, filename and brief explanation for these modifications. Figure 2.7 illustrates schematically how FLOODEX is linked to AEGIS+. First, the FORTRAN program *read_results.exe* reads three files, namely (1) the file that contains the simulation results (*summary.out*), (2) the file that contains the run numbers and the number of years for each run, and (3) the file which contains the numbers, the field numbers, the strategy numbers, and the initial condition (IC) numbers. These data from files (1), (2), and (3) are transferred to a new temporary file (*results.tmp*). It then reads the FLOODEX output file (*fxresult.out*) that contains the polygon number(s) and percent yield reduction values, and the *results.tmp* file and writes to the *results.out* file. The format of the data in the *results.out* file is identical to the definitions of the items in the INFO data base *RESULTS* in which the *results.out* file is loaded.

2. The FLOODEX Interface

The schematic structure of the FLOODEX interface is depicted in Figure 2.8.

a. The Main Menu

The main menu of FLOODEX provides five options to select from (Figure 2.9). The options are activated by clicking the left mouse button.

By clicking on [Flood Scenario Menu] in the main menu, "Assign Flood Factors Menu" is activated (Figure 2.10). This is the menu in which data for the crop and flood factors are specified. Upon completion, clicking on [Assign to polygon] causes

Table 2.13. Directory, file name, and purpose of modifications in several AEGIS+ programs.

Directory	File name	Purpose of modification
../aegis+/aegis_aml	define_db_results.aml	To create INFO data file RESULTS that stores the statistics of six simulation factors, and estimated reduction in predicted yields and percent yield reductions.
	variable_init.aml	To show estimated reduction in yields and percent yield reductions on maps and reports.
	setup_map.aml	-as above-
	create_report.aml	-as above-
	save_results.aml	To save the estimated reduction in yields and percent yield reductions along with the simulation results.
../aegis+/aegis_for	read_results.for	This FORTRAN program was modified to incorporate output from FLOODEX and calculate estimated reduction in yields.
../aegis+/aegis_cov/info	RESULTS.LUT	This data file was modified. It is used as a lookup table for producing maps of simulation results. To incorporate estimated reduction in yields and percent yield reductions.

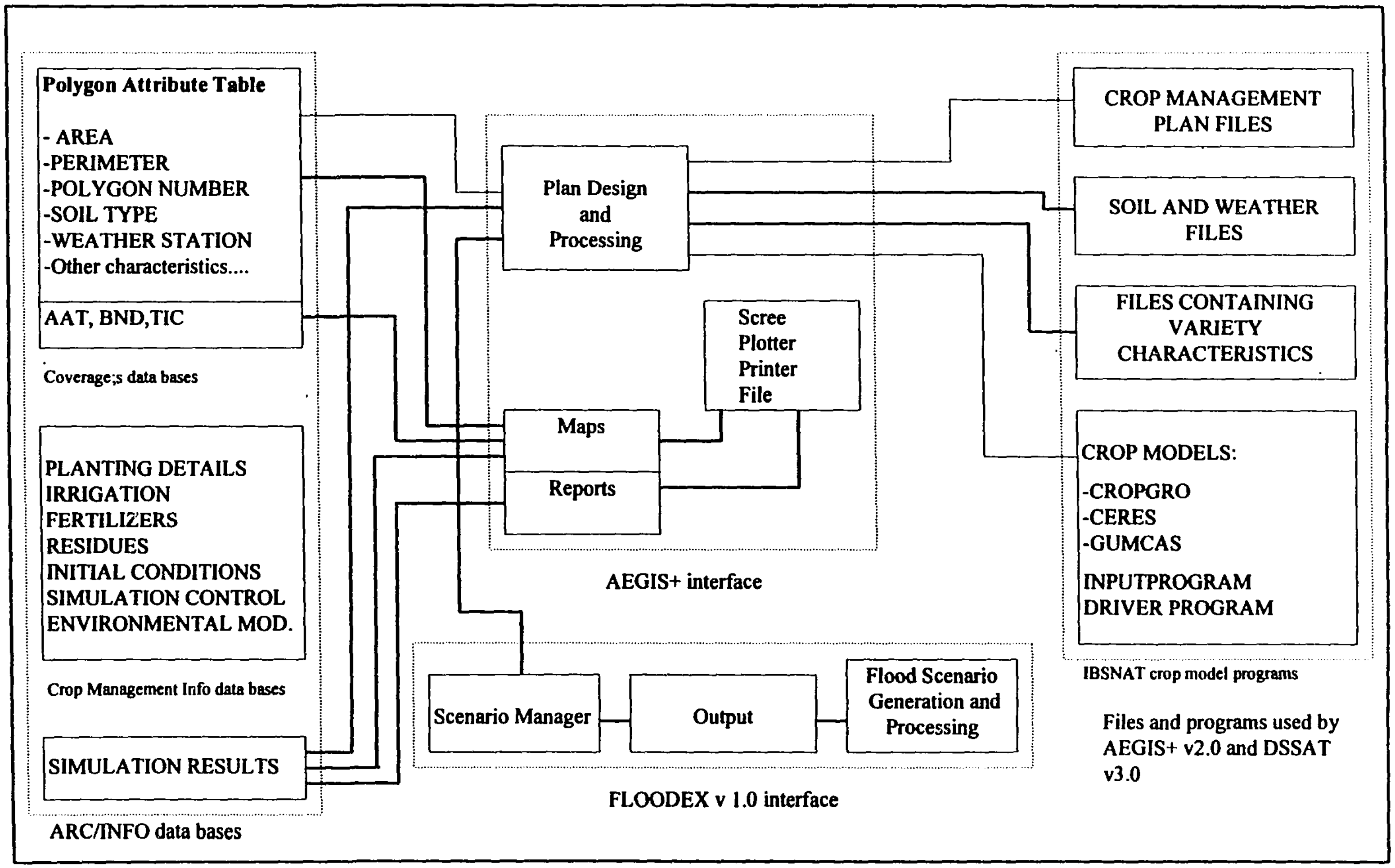


Figure 2.7. Linkage of FLOODEX with AEGIS+

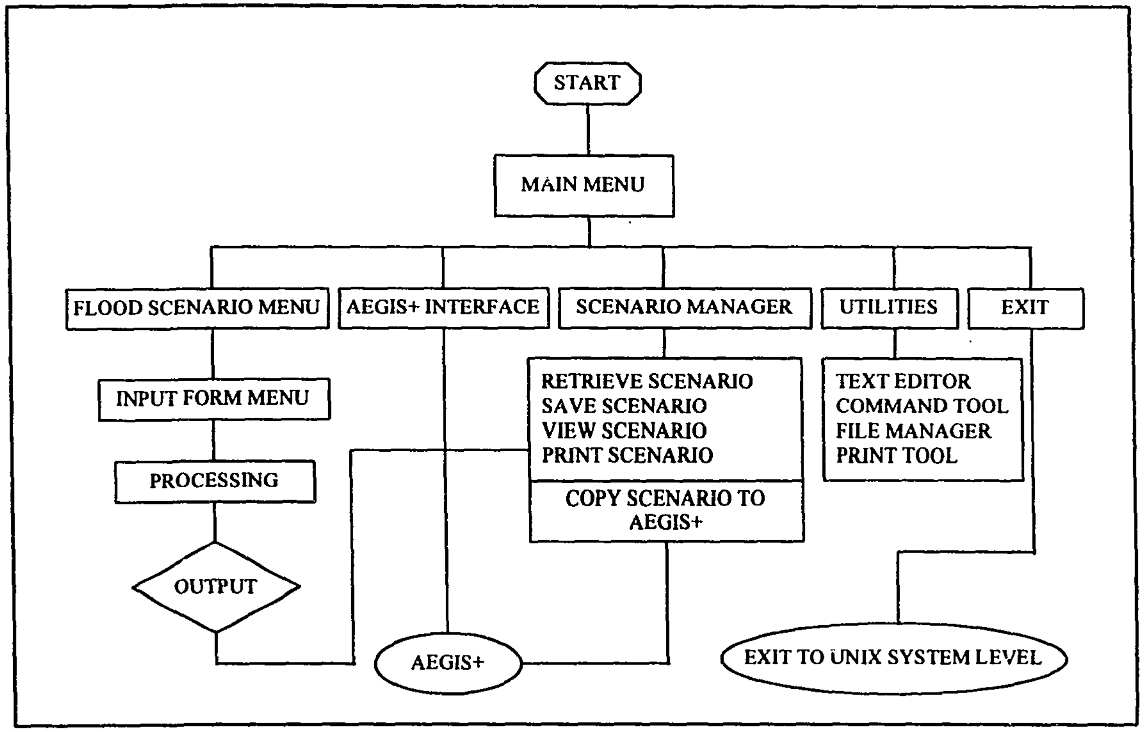


Figure 2.8 Schematic FLOODEX Structure

FLOODEX to assigns the crop and flood factors to the polygon and to estimate the percentage of yield reduction for the selected factors. After the last set of selections are made and assigned to the polygon (by clicking on [Assign to Polygon]) the user can exit to the main menu by clicking on [Exit Menu].

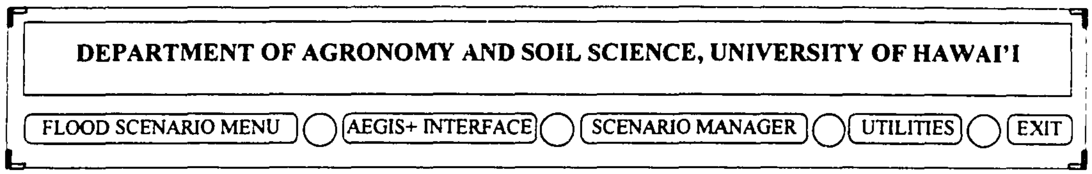


Figure 2.9. Main menu of FLOODEX

By clicking on the [AEGIS+Interface] button (Figure 2.9), the user is prompted by a query, [Enter AEGIS+ Menu]. If Yes is chosen FLOODEX is cleared from the screen and the user enters into the AEGIS+ program. If No is chosen, the user is returned to the FLOODEX main menu.

By pressing the right mouse button with the cursor on [Scenario Manager] the options available in the Scenario Manager menu are shown (Figure 2.11) and described below.

Options	**Function**
Retrieve Scenario	Retrieves a previously saved scenario
Save Scenario	Saves the output of the system to a specified file
View/Edit Scenario	Views the current or previously saved scenario which can be edited.
Print Scenario	Prints the scenario
Copy Scenario to AEGIS+	Copies the current or retrieved scenario to ../aegis_cov/data directory

Clicking on [Utilities] gives the menu shown in Figure 2.12. This menu allows the user to use various Unix Open Windows tools. The functions of each available option in this menu are described as follows:

Options	Function
Command Tool	Activates an Open Windows command tool.
Text Editor	Activates an Open Windows text editor.
File Manager	Activates an Open Windows file manager.
Print Tool	Activates an Open Windows print tool.

Clicking on [Exit] gives the Exit Menu, which prompts the user for a Yes or No response. If Yes is chosen, then FLOODEX is terminated and exits to the Unix system level. If No is chosen then the user is returned to the FLOODEX main menu.

b. FLOODEX Directory

The main directory of FLOODEX is *../floodex* (Table 2.14). This directory contains three subdirectories, and three files named (1) *fx.aml* (which starts FLOODEX), (2) *fxicon.rs* an image file which is the logo of the system that is shown in the introduction screen, and (3) the *floodex.shadeset* which contains colors for displaying the introduction screen. The *floodex_aml* subdirectory contains all the Arc Macro Language (AML) programs except *fx.aml* used by FLOODEX. The *floodex_mnu* subdirectory contains all menu programs used in FLOODEX. The subdirectory named *floodex_out* is a repository of all outputs from FLOODEX. All AML and Menu programs are presented in Appendix B.

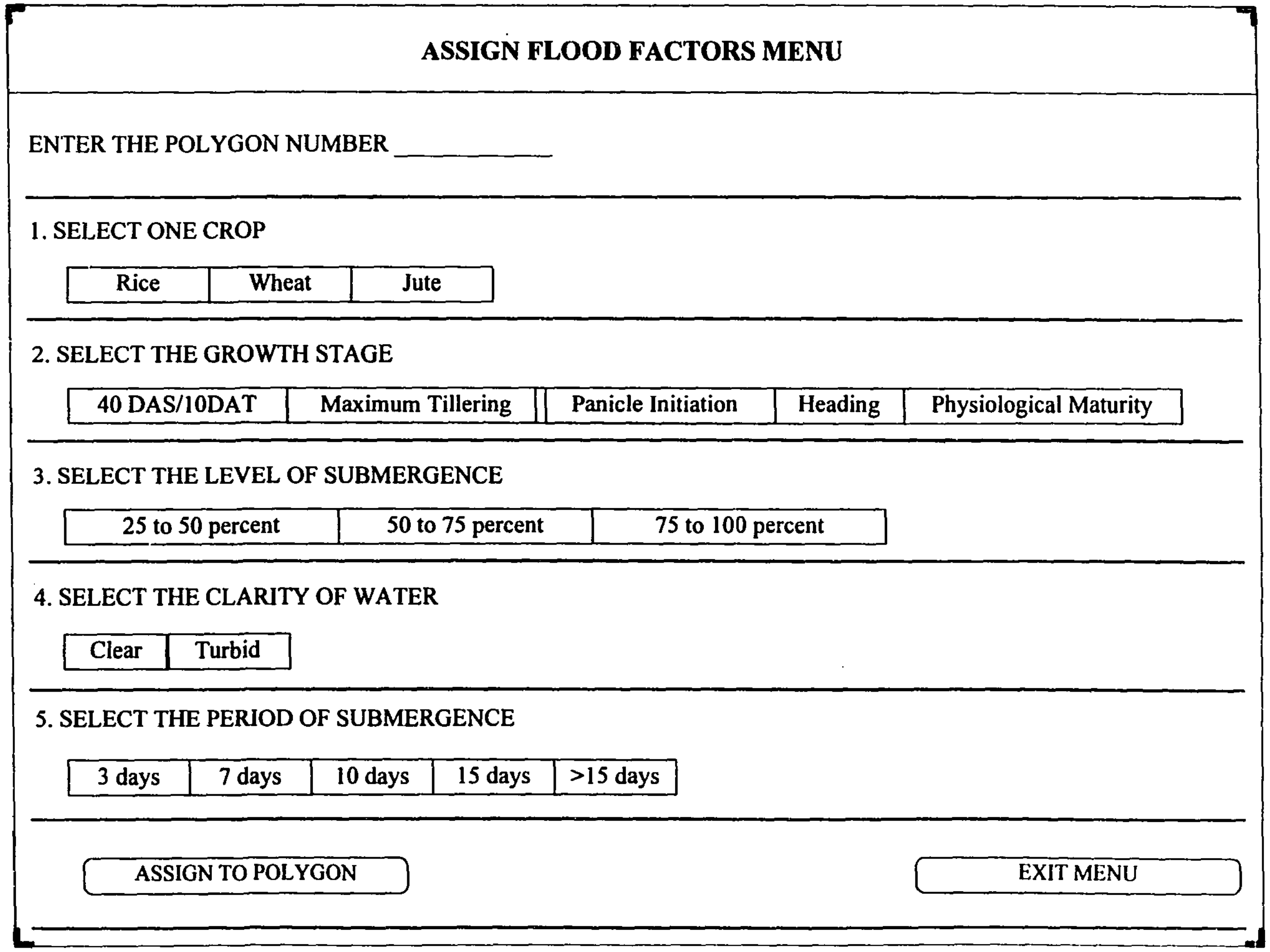


Figure 2.10. Form for Assign flood factors menu.

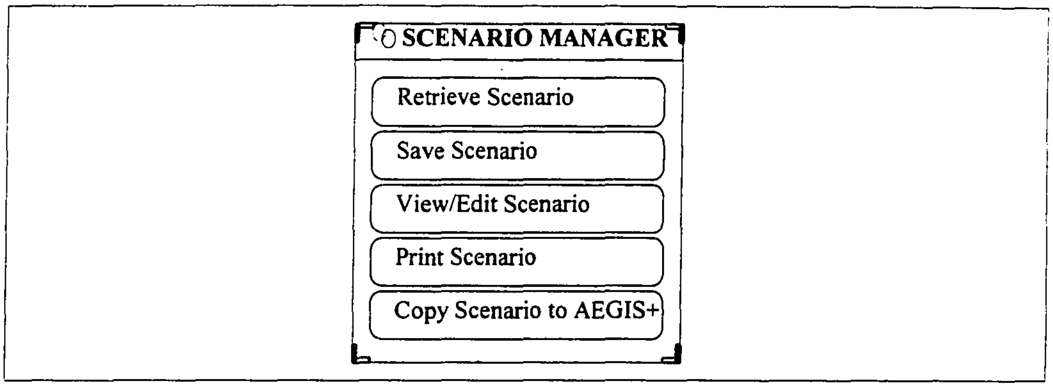


Figure 2.11. Scenario Manager options.

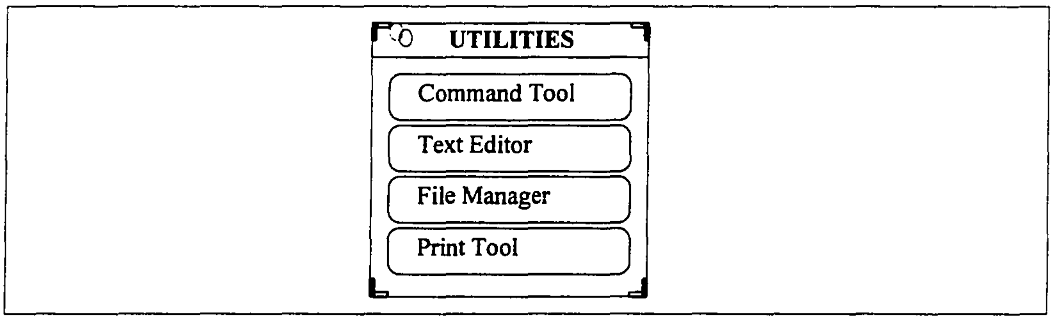


Figure 2.12. Utilities options.

c. *Future Development*

The core of FLOODEX is the rule-based program, which contains the knowledge-base for estimating percent yield loss for different flooding conditions. Other crops affected by floods may be added to this system when sufficient knowledge about their behavior under submerged conditions is accumulated. The main benefit of this work is to demonstrate the potential utility of decision support systems and to guide and prioritize future research. It also points to the need for developing a national minimum data set to support decision making.

Table 2.14. Directory structure of FLOODEX

Directory/Subdirectories	Files
../floodex/	fx.aml fxicon.rs floodex.shadeset
../floodex/floodex_aml/	a+inter.aml del_all_thread.aml exit_floodex.aml floodex.aml fxintro_screen.aml message.aml rules.aml save_scenario.aml print_scenario.aml retrieve_scenario.aml copy_result.aml
../floodex/floodex_mnu/	dialog_box.menu fxmain.menu rules.menu save_scenario.menu
../floodex/floodex_out/	fxresult.out other user files.

d. Software and Hardware Requirements

i. Hardware

1. Sun Micro System's SPARC workstation.
2. File system with one megabyte of free space when FLOODEX is run alone; if used in combination with AEGIS+ the file system must have over 30 megabytes of free space.

ii. Software

1. Sun OS version 4.1 or higher.
2. Open Windows version 3.0 or higher.
3. ARC/INFO version 6.1 or higher.
4. CERES-Rice Model (DSSAT v3.0)

3. Assessing Rice Yield Losses to Flooding with FLOODEX

Twelve scenarios were created for three flooding dates, two submergence heights and two submergence periods. The flooding dates were early (June 30), normal (August 30), and late (September 30). The submergence heights were 50 percent and 100 percent of plant height and durations of submergence were seven days and 15 days. The effects of these flooding scenarios were compared with non-inundated rice yields in the 23 Thanas for a traditional planting date, and the usual farmer's nitrogen application. The growth stage of the crop was determined from the growing season, the variety and the age of the plant at the onset of flooding.

A scenario may be defined as one of many possible situations during a flood in relation to crop and flood water. It includes (1) the crop, (2) its growth stage, (3) the period of submergence, (4) clarity of flood water, and (5) percent of plant height submerged. A scenario file may contain information for one or more fields. For the rice plant, no damage was assumed for water levels less than 25% of plant height.

III. RESULTS AND DISCUSSION

Up to this point the major focus has been on assembling the decision support system. This might give the impression that the sole purpose of this research was to develop such a system. But the purpose and objectives of this work clearly indicated that the decision support system was merely a means to enable its users to make better choices about how to deal with the risk and uncertainty of flooding.

In the following sections, the decision support system is subjected to a series of tests to ascertain whether it is capable of generating reasonable results. As stated in the research objectives, the system was designed to:

1. Enable users to generate alternative strategies for minimizing flood damage on a site-specific basis, and
2. Enable policy makers to assess yield losses in real time to support food security decision making.

A. OBJECTIVE 1

1. Rice Yield as Affected by Planting Dates and Fertilizer Rate

Tables 3.1 to 3.6 show the average, maximum and minimum simulated grain yields, and average rice production for each Thana for three planting dates and two fertilizer rates for practices described in Figure 2.6. In general, the BRRI recommended fertilizer rate (Tables 3.1, 3.3, 3.5) resulted in higher rice yields than the farmers' rate (Tables 3.2, 3.4, 3.6), irrespective of planting dates. Figure

Table 3.1. Average, maximum and minimum simulated rice yield for traditional planting date and recommended fertilizer rates.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Maximum Yield (kg ha^{-1})	Minimum Yield (kg ha^{-1})	Average Production (tonnes)
1	Nawabganj	44,448	1,652	5,422	954	73,419
	Bhuyanpur	21,057	1,978	4,520	1,457	41,651
	Tangail Sadar	30,072	1,306	4,270	680	39,277
1		95,577				154,347
2	Sylhet Sadar	48,170	1,462	5,292	693	70,434
	Balaganj	38,201	1,462	5,292	693	55,858
	Nagarpur	23,955	1,547	5,391	739	37,058
	Muradnagar	33,796	901	1,294	247	30,464
	Debidwar	23,307	901	1,294	247	21,009
	Daudkandi	35,532	901	1,294	247	32,029
	Srinagar	19,711	2,827	6,172	1,436	55,715
	Lohajang	10,928	1,530	5,295	590	16,719
	Chandina	20,201	901	1,294	247	18,209
2		253,801				337,494
3	Madhupur	47,929	854	1,954	429	40,931
	Gopalpur	21,498	1,086	3,397	395	23,351
	Ghatail	45,057	1,086	3,397	395	48,941
	Paba	23,288	2,266	4,843	961	52,773
	Bagherpara	27,208	2,378	5,904	1,267	64,695
	Jessore Sadar	42,397	2,378	5,904	1,267	100,812
3		207,377				331,503
4	Kalihati	29,040	907	3,285	285	26,331
	Basail	15,539	907	3,285	285	14,089
4		44,579				40,420
5	Sakhipur	44,283	2,592	4,691	2,021	114,764
	Delduar	17,432	1,541	3,820	966	26,854
	Mirzapur	37,297	1,541	3,820	966	57,456
5		99,012				199,074
Total		700,346				1062,838

Table 3.2. Average, maximum and minimum simulated rice yield for traditional planting date and farmers' fertilizer rates.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Maximum Yield (kg ha^{-1})	Minimum Yield (kg ha^{-1})	Average Production (tonnes)
1	Nawabganj	44,448	1,419	3,093	954	63,067
	Bhuyanpur	21,057	1,801	2,753	1,457	37,930
	Tangail Sadar	30,072	1,125	2,455	680	33,819
1		95,577				134,816
2	Sylhet Sadar	48,170	1,252	3,191	693	60,314
	Balaganj	38,201	1,252	3,191	693	47,831
	Nagarpur	23,955	1,327	3,195	739	31,798
	Muradnagar	33,796	901	1,294	247	30,464
	Debidwar	23,307	901	1,294	247	21,009
	Daudkandi	35,532	901	1,294	247	32,029
	Srinagar	19,711	2,656	4,470	1,436	52,360
	Lohajang	10,928	1,304	3,035	590	14,249
	Chandina	20,201	901	1,294	247	18,209
2		253,801				308,263
3	Madhupur	47,929	835	1,767	429	40,035
	Gopalpur	21,498	1,066	3,194	395	22,915
	Ghatail	45,057	1,066	3,194	395	48,026
	Paba	23,288	2,216	4,338	961	51,597
	Bagherpara	27,208	2,315	5,278	1,267	62,992
	Jessore Sadar	42,397	2,315	5,278	1,267	98,158
3		207,377				323,722
4	Kalihati	29,040	891	3,141	285	25,866
	Basail	15,539	891	3,141	285	13,841
4		44,579				39,707
5	Sakhipur	44,283	2,560	4,370	2,021	113,342
	Delduar	17,432	1,502	3,435	966	26,183
	Mirzapur	37,297	1,502	3,435	966	56,020
5		99,012				195,545
Total		700,346				1,002,053

Table 3.3. Average, maximum and minimum simulated rice yield for 30 days before traditional planting date and recommended fertilizer rates.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Maximum Yield (kg ha^{-1})	Minimum Yield (kg ha^{-1})	Average Production (tonnes)
1	Nawabganj	44,448	1,591	4,608	834	70,721
	Bhuyanpur	21,057	2,006	4,134	1,018	42,234
	Tangail Sadar	30,072	1,564	3,842	952	47,024
1		95,577				159,979
2	Sylhet Sadar	48,170	1,768	5,117	1,223	85,165
	Balaganj	38,201	1,768	5,117	1,223	67,539
	Nagarpur	23,955	1,605	5,048	934	38,445
	Muradnagar	33,796	998	1,431	248	33,735
	Debidwar	23,307	998	1,431	248	23,265
	Daudkandi	35,532	998	1,431	248	35,468
	Srinagar	19,711	3,062	5,937	2,449	60,355
	Lohajang	10,928	1,667	4,947	1,069	18,215
	Chandina	20,201	998	1,431	248	20,165
2		253,801				382,352
3	Madhupur	47,929	1,191	4,604	475	57,098
	Gopalpur	21,498	1,214	5,014	282	26,105
	Ghatail	45,057	1,214	5,014	282	54,713
	Paba	23,288	2,373	5,519	1,512	55,272
	Bagherpara	27,208	2,479	6,307	1,639	67,454
	Jessore Sadar	42,397	2,479	6,307	1,639	105,111
3		207,377				365,752
4	Kalihati	29,040	876	1,829	441	25,433
	Basail	15,539	876	1,829	441	13,609
4		44,579				39,042
5	Sakhipur	44,283	2,833	5,023	2,053	125,440
	Delduar	17,432	1,742	4,127	1,174	30,372
	Mirzapur	37,297	1,742	4,127	1,174	64,983
5		99,012				220,795
Total		700,346				1,167,920

Table 3.4. Average, maximum and minimum simulated rice yield for 30 days before traditional planting date and farmers' fertilizer rates.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Maximum Yield (kg ha^{-1})	Minimum Yield (kg ha^{-1})	Average Production (tonnes)
1	Nawabganj	44,448	1,360	3,129	834	60,445
	Bhuyanpur	21,057	1,822	3,249	1,018	38,357
	Tangail Sadar	30,072	1,341	2,465	952	40,318
1		95,577				139,120
2	Sylhet Sadar	48,170	1,590	3,337	1,223	76,590
	Balaganj	38,201	1,590	3,337	1,223	60,740
	Nagarpur	23,955	1,424	3,234	934	34,100
	Muradnagar	33,796	998	1,431	248	33,735
	Debidwar	23,307	998	1,431	248	23,265
	Daudkandi	35,532	998	1,431	248	35,468
	Srinagar	19,711	2,944	4,761	2,449	58,037
	Lohajang	10,928	1,501	3,293	1,069	16,407
	Chandina	20,201	998	1,431	248	20,165
2		253,801				358,507
3	Madhupur	47,929	1,144	4,135	475	54,850
	Gopalpur	21,498	1,166	4,533	282	25,071
	Ghatail	45,057	1,166	4,533	282	52,545
	Paba	23,288	2,310	4,887	1,512	53,800
	Bagherpara	27,208	2,430	5,816	1,639	66,118
	Jessore Sadar	42,397	2,430	5,816	1,639	103,029
3		207,377				355,413
4	Kalihati	29,040	853	1,628	441	24,783
	Basail	15,539	853	1,628	441	13,261
4		44,579				38,044
5	Sakhipur	44,283	2,805	4,746	2,053	124,214
	Delduar	17,432	1,706	3,766	1,174	29,742
	Mirzapur	37,297	1,706	3,766	1,174	63,636
5		99,012				217,592
Total		700,346				1,108,676

Table 3.5. Average, maximum and minimum simulated rice yield for 30 days after traditional planting date and recommended fertilizer rates.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Maximum Yield (kg ha^{-1})	Minimum Yield (kg ha^{-1})	Average Production (tonnes)
1	Nawabganj	44,448	1,595	4,020	886	70,881
	Bhuyanpur	21,057	2,080	3,730	674	43,805
	Tangail Sadar	30,072	1,362	3,118	382	40,952
1		95,577				155,638
2	Sylhet Sadar	48,170	1,287	5,634	376	62,000
	Balaganj	38,201	1,287	5,634	376	49,169
	Nagarpur	23,955	1,430	4,715	362	34,253
	Muradnagar	33,796	751	1,044	209	25,388
	Debidwar	23,307	751	1,044	209	17,508
	Daudkandi	35,532	751	1,044	209	26,692
	Srinagar	19,711	2,624	6,004	1,585	51,728
	Lohajang	10,928	1,423	5,231	588	15,554
	Chandina	20,201	751	1,044	209	15,175
2		253,801				297,465
3	Madhupur	47,929	641	186	317	30,713
	Gopalpur	21,498	917	3,649	286	19,709
	Ghatail	45,057	917	3,649	286	41,308
	Paba	23,288	1,474	2,013	810	34,324
	Bagherpara	27,208	1,949	6,210	573	53,018
	Jessore Sadar	42,397	1,949	6,210	573	82,615
3		207,377				261,687
4	Kalihati	29,040	978	3,183	374	28,390
	Basail	15,539	978	3,183	374	15,191
4		44,579				43,580
5	Sakhipur	44,283	2,432	4,498	1106	107,687
	Delduar	17,432	1,471	3,768	703	42,391
	Mirzapur	37,297	1,471	3,768	703	54,871
5		99,012				204,950
Total		700,346				963,321

Table 3.6. Average, maximum and minimum simulated rice yield for 30 days after traditional planting date and farmers' fertilizer rates.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Maximum Yield (kg ha^{-1})	Minimum Yield (kg ha^{-1})	Average Production (tonnes)
1	Nawabganj	44,448	1,346	2,385	871	59,827
	Bhuyanpur	21,057	1,822	2,702	629	38,366
	Tangail Sadar	30,072	1,097	1,568	378	32,974
1		95,577				131,167
2	Sylhet Sadar	48,170	1,060	3,398	352	51,041
	Balaganj	38,201	1,060	3,398	352	40,478
	Nagarpur	23,955	1,193	2,446	340	28,569
	Muradnagar	33,796	747	1,070	203	25,232
	Debidwar	23,307	747	1,070	203	17,401
	Daudkandi	35,532	747	1,070	203	26,528
	Srinagar	19,711	2,484	4,580	1,583	48,968
	Lohajang	10,928	1,213	3,223	580	13,255
	Chandina	20,201	747	1,070	203	15,082
2		253,801				266,553
3	Madhupur	47,929	835	1,767	429	40,035
	Gopalpur	21,498	1,066	3,194	395	22,915
	Ghatail	45,057	1,066	3,194	395	48,026
	Paba	23,288	2,216	4,338	961	51,597
	Bagherpara	27,208	2,315	5,278	1,267	62,992
	Jessore Sadar	42,397	2,315	5,278	1,267	98,158
3		207,377				323,722
4	Kalihati	29,040	891	3,141	285	25,866
	Basail	15,539	891	3,141	285	13,841
4		44,579				39,707
5	Sakhipur	44,283	2,393	4,111	1,106	105,974
	Delduar	17,432	1,424	3,298	703	24,827
	Mirzapur	37,297	1,424	3,298	703	53,118
5		99,012				183,919
Total		700,346				945,068

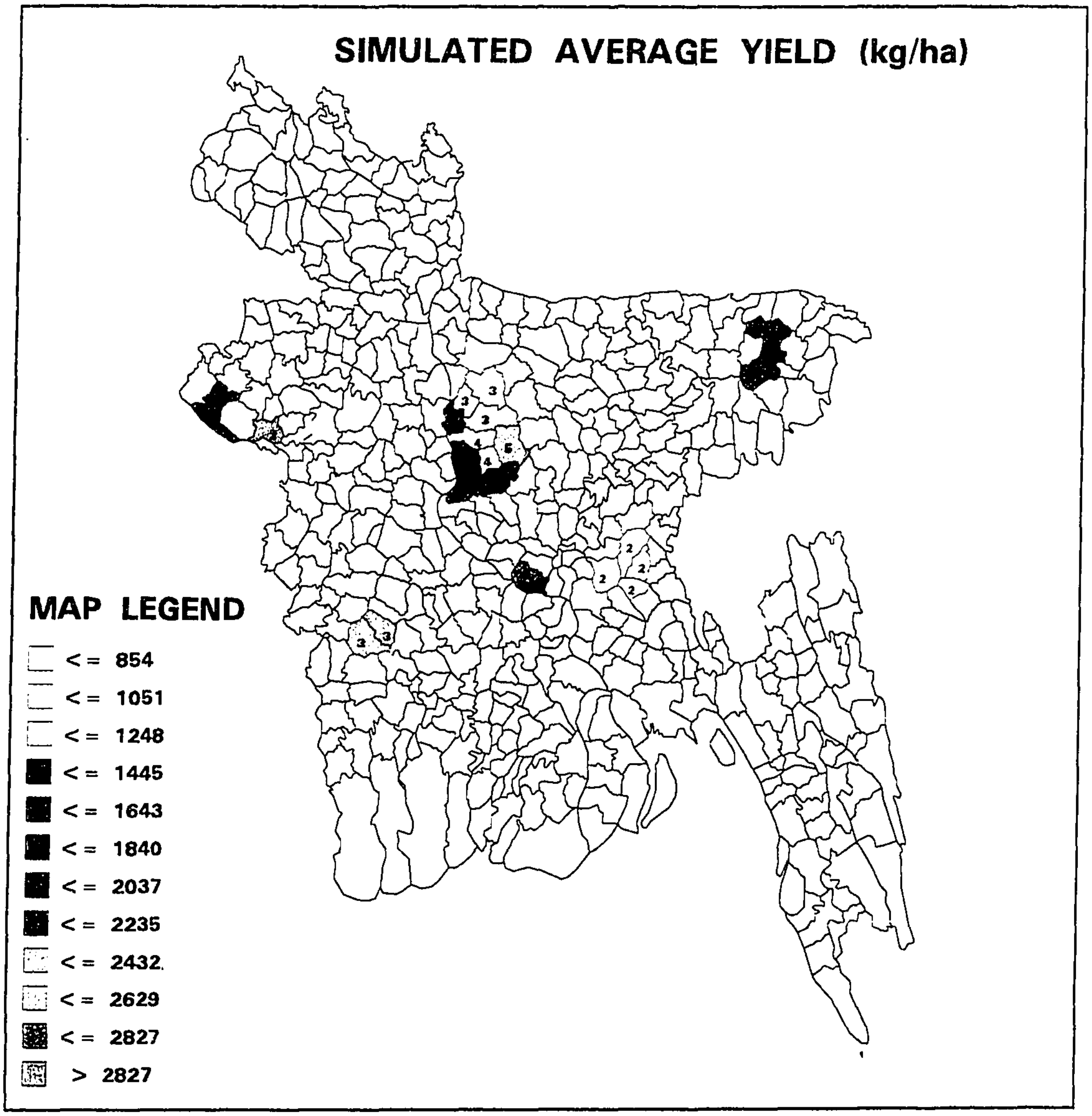


Figure 3.1. Spatial distribution of simulated average rice yields obtained for the traditional planting date and recommended fertilizer rates in different Thanas. The areas outlined are Thanas and the numbers within polygons refer to practice numbers.

3.1 shows the spatial distribution of simulated average rice yields obtained for the traditional planting dates and recommended fertilizer rates in different Thanas.The numbers within the polygons refer to practice numbers. To avoid redundancy only one map is shown.

For Practice 1, advancing the planting date of Aus rice from April 01 to March 01 increased yields in Bhuyanpur and Tangail Sadar but, decreased it in Nawabganj Thana. When the planting was delayed 30 days the trend was the same. In Practice 2, advancing the planting date increased yield, while delaying it reduced yield. Similar results were obtained with Practice 3, where the Aman rice was traditionally transplanted on July 01.

In the case of Practice 4, advancing the planting date from the traditional date (September 01) by 30 days reduced the transplanted Aman rice yields. Delaying planting by 30 days increased yields. With Practice 5, advancing the planting date of broadcast Aman rice by 30 days increased the yields, whereas delaying planting reduced yields.

Although the farmers' nitrogen fertilizer rate nearly approached the BRRI recommended rate, the farmers' rates for phosphorus and potassium were less than half the recommended amount. Since the rice model is not yet able to simulate rice response to phosphorus and potassium, these nutrients were assumed to occur in non-limiting amounts.

2. Aggregation of Rice Yields in Tangail District

One of the aims of this study was to use AEGIS+ to aggregate site-specific local rice production into production levels of larger administrative units up to the national level. In this example for the Tangail district rice production levels from the 11 Thanas were aggregated to the district level.

When the total rice production in Tangail district for the BRRI recommended fertilizer rate and traditional planting date is simulated, 0.471 million tonnes of rice were produced on 0.333 million ha. Advancing the planting dates increased production to 0.525 million tonnes. But when the planting was delayed 30 days, the production declined to 0.459 million tonnes. A similar trend was noted for farmers' practice. When the entire rice crop (Aus and Aman) was planted on the traditional planting dates using farmers' fertilizer rates, 0.450 million tonnes of rice were produced. Advancing the planting dates produced 0.501 million tonnes of rice, whereas delaying planting reduced production to 0.434 million tonnes. The aggregated results are summarized in Tables 3.7 to 3.12.

3. Estimating Rice Deficit or Surplus

The total population of Tangail district is 3.108 million and per capita rice consumption is 423.6 g $person^{-1}$ day^{-1} (BBS, 1994). Hence, the total rice requirement for Tangail district is 0.480 million tonnes of clean rice or 0.686 million tonnes of rough rice. Thus for the traditional planting date and BRRI recommended fertilizer rate, (0.686 – 0.401) or 0.215 million tonnes of rice must be procured from other sources. If planting dates are advanced by 30 days then the deficit is lowered to 0.161 million tonnes. Delaying the planting date aggravates the situation as the deficit rises to 0.227 million tonnes. When the scenarios were simulated for farmers' fertilizer

Table 3.7. Aggregated rice production for Tangail district for traditional planting date and recommended fertilizer rates.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Maximum Yield (kg ha^{-1})	Minimum Yield (kg ha^{-1})	Average Production (tonnes)
1	Bhuyanpur	21,057	1,978	4,520	1,457	41,651
1	Tangail Sadar	30,072	1,306	4,270	680	39,277
2	Nagarpur	23,955	1,547	5,391	739	37,058
3	Madhupur	47,929	854	1,954	429	40,931
3	Gopalpur	21,498	1,086	3,397	395	23,351
3	Ghatail	45,057	1,086	3,397	395	48,941
4	Kalihati	29,040	907	3,285	285	26,331
4	Basail	15,539	907	3,285	285	14,089
5	Sakhipur	44,283	2,592	4,691	2,021	114,764
5	Delduar	17,432	1,541	3,820	966	26,854
5	Mirzapur	37,297	1,541	3,820	966	57,456
Total		333,159				470,703

Table 3.8. Aggregated rice production for Tangail district for traditional planting date and farmers' fertilizer rates.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Maximum Yield (kg ha^{-1})	Minimum Yield (kg ha^{-1})	Average Production (tonnes)
1	Bhuyanpur	21,057	1,801	2,753	1,457	37,930
1	Tangail Sadar	30,072	1,125	2,455	680	33,819
2	Nagarpur	23,955	1,327	3,195	739	31,798
3	Madhupur	47,929	835	1,767	429	40,035
3	Gopalpur	21,498	1,066	3,194	395	22,915
3	Ghatail	45,057	1,066	3,194	395	48,026
4	Kalihati	29,040	891	3,141	285	25,866
4	Basail	15,539	891	3,141	285	13,841
5	Sakhipur	44,283	2,560	4,370	2,021	113,342
5	Delduar	17,432	1,502	3,435	966	26,183
5	Mirzapur	37,297	1,502	3,435	966	56,020
Total		333,159				449,775

Table 3.9. Aggregated rice production for Tangail district for 30 before traditional planting date and recommended fertilizer rates.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Maximum Yield (kg ha^{-1})	Minimum Yield (kg ha^{-1})	Average Production (tonnes)
1	Bhuyanpur	21,057	2,006	4,134	1,018	42,234
1	Tangail Sadar	30,072	1,564	3,842	952	47,024
2	Nagarpur	23,955	1,605	5,048	934	38,445
3	Madhupur	47,929	1,191	4,604	475	57,098
3	Gopalpur	21,498	1,214	5,014	282	26,105
3	Ghatail	45,057	1,214	5,014	282	54,713
4	Kalihati	29,040	876	1,829	441	25,433
4	Basail	15,539	876	1,829	441	13,609
5	Sakhipur	44,283	2,833	5,023	2,053	125,440
5	Delduar	17,432	1,742	4,127	1,174	30,372
5	Mirzapur	37,297	1,742	4,127	1,174	64,983
Total		333,159				525,456

Table 3.10. Aggregated rice production for Tangail district for 30 days before traditional planting date and farmers' fertilizer rates.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Maximum Yield (kg ha^{-i})	Minimum Yield (kg ha^{-1})	Average Production (tonnes)
1	Bhuyanpur	21,057	1,822	3,249	1,018	38,357
1	Tangail Sadar	30,072	1,341	2,465	952	40,318
2	Nagarpur	23,955	1,424	3,234	934	34,100
3	Madhupur	47,929	1,144	4,135	475	54,850
3	Gopalpur	21,498	1,166	4,533	282	25,071
3	Ghatail	45,057	1,166	4,533	282	52,545
4	Kalihati	29,040	853	1,628	441	24,783
4	Basail	15,539	853	1,628	441	13,261
5	Sakhipur	44,283	2,805	4,746	2,053	124,214
5	Delduar	17,432	1,706	3,766	1,174	29,742
5	Mirzapur	37,297	1,706	3,766	1,174	63,636
Total		333,159				500,877

Table 3.11. Aggregated rice production for Tangail district for 30 days after traditional planting date and recommended fertilizer rates.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Maximum Yield (kg ha^{-1})	Minimum Yield (kg ha^{-1})	Average Production (tonnes)
1	Bhuyanpur	21,057	2,080	3,730	674	43,805
1	Tangail Sadar	30,072	1,362	3,118	382	40,952
2	Nagarpur	23,955	1,430	4,715	362	34,253
3	Madhupur	47,929	641	1,586	317	30,713
3	Gopalpur	21,498	917	3,649	286	19,709
3	Ghatail	45,057	917	3,649	286	41,308
4	Kalihati	29,040	978	3,183	374	28,390
4	Basail	15,539	978	3,183	374	15,191
5	Sakhipur	44,283	2,432	4,498	1,106	107,687
5	Delduar	17,432	1,471	3,768	703	42,391
5	Mirzapur	37,297	1,471	3,768	703	54,871
Total		333,159				459,271

Table 3.12. Aggregated rice production for Tangail district for 30 days after traditional planting date and farmers' fertilizer rates.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Maximum Yield (kg ha^{-1})	Minimum Yield (kg ha^{-1})	Average Production (tonnes)
1	Bhuyanpur	21,057	1,822	2,702	629	38,366
1	Tangail Sadar	30,072	1,097	1,568	378	32,974
2	Nagarpur	23,955	1,193	2,446	340	28,569
3	Madhupur	47,929	835	1,767	429	40,035
3	Gopalpur	21,498	1,066	3,194	395	22,915
3	Ghatail	45,057	1,066	3,194	395	48,026
4	Kalihati	29,040	891	3,141	285	25,866
4	Basail	15,539	891	3,141	285	13,841
5	Sakhipur	44,283	2,393	4,111	1,106	105,974
5	Delduar	17,432	1,424	3,298	703	24,827
5	Mirzapur	37,297	1,424	3,298	703	53,118
Total		333,159				434,510

rates, similar trends were obtained, but the yields and production levels were lower and, therefore, the deficits were greater.

The observed yields of the BR14 rice variety grown during the Aus season ranged from 3.8 to 7.1 tonnes ha^{-1} under recommended fertilizer rates. This range is higher than the reported yields of the BR3 variety for the Aus season which ranged from 2.6 to 5.4 tonnes ha^{-1} and from 3.3 to 4.6 tonnes ha^{-1} for the Aman season under farmers' fertilizer management. Reported yields of BR11 grown as broadcast Aman rice ranged from 1.7 to 2.4 tonnes ha^{-1} (Ahmed, 1992). It was also observed that rice yields varied with location and year. In general, irrespective of varieties, BRRI recommended fertilizer rates gave higher yields than farmers fertilizer rates. The rice model was able to simulate the effects of variety by planting date and nitrogen rates, but the simulated average yields were lower than reported yields. This is probably due to the extra care given to farmers' fields from which yield records were obtained.

Although the simulated results for the non-flooded condition show advantages of advancing the planting dates, it may very well be that in reality, farmers are operating at a low risk and near optimum conditions. The simulated advantage may disappear when flooding becomes a factor.

B. OBJECTIVE 2

1. Assessment of Yield Reduction from Flooding

The addition of FLOODEX now enables the Decision Support System to compute rice yield losses from flooding. In Tables 3.13 to 3.24, the simulated yields for the uninundated case can be compared to the inundated situation. Each table contains yields for percent submergence, duration and flood type with turbid water.

Yield loss assessments are separated into three parts according to type of flooding. Tables 3.13 to 3.16 deal with normal flooding, Tables 3.17 to 3.20 with early flooding and Tables 3.21 to 3.24 with late flooding.

a. Normal Flooding

The results for normal flooding show that the broadcast and transplanted Aus rice crops were not affected by normal flooding which commenced near the end of August because the crops had already been harvested. The transplanted Aman rice grown on medium lowland during early September was also not affected because the crop was transplanted after the floods had receded. However, the Aman rice transplanted in early July and the Aman rice sown by broadcast in early April were at risk. the former reaches the maximum tillering growth stage while the latter would be at physiological maturity at the on set of normal flooding. When rice crops were submerged for 15 days up to 100% of plant height, the damage ranged from 80 to 100%, irrespective of growth stage. When yield reduction is more than 80% it is usually considered a total loss because farmers do not consider it worth harvesting.

Figures 3.2 and 3.3 show the spatial distribution of estimated yield losses and percent yield reduction respectively, for normal flooding with 50% submergence for 7 days. The numbers within the polygons refer to practice numbers.

Table 3.13. Average simulated rice yield, and estimated yield reduction as influenced by normal flooding with 50% submergence for 7 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Harvested	Nawabganj	44,448	1,419	1,419	-	63,067	63,067
		Bhuyanpur	21,057	1,801	1,801	-	37,930	37,930
		Tangail Sadar	30,072	1,125	1,125	-	33,819	33,819
1			95,577				134,816	134,816
2	Harvested	Sylhet Sadar	48,170	1,252	1,252	-	60,314	60,314
		Balaganj	38,201	1,252	1,252	-	47,831	47,831
		Nagarpur	23,955	1,327	1,327	-	31,798	31,798
		Muradnagar	33,796	901	901	-	30,464	30,464
		Debidwar	23,307	901	901	-	21,009	21,009
		Daudkandi	35,532	901	901	-	32,029	32,029
		Srinagar	19,711	2,656	2,656	-	52,360	52,360
		Lohajang	10,928	1,304	1,304	-	14,249	14,249
		Chandina	20,201	901	901	-	18,209	18,209
2			253,801				308,263	308,263

Table 3.13. (Continued) Average simulated rice yield, and estimated yield reduction as influenced by normal flooding with 50% submergence for 7 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
3	Maximum Tillering	Madhupur	47,929	835	459	45	40,035	22,019
		Gopalpur	21,498	1,066	586	45	22,915	12,602
		Ghatail	45,057	1,066	586	45	48,026	26,412
		Paba	23,288	2,216	1,219	45	51,597	28,379
		Bagherpara	27,208	2,315	1,273	45	62,992	34,647
		Jessore Sadar	42,397	2,315	1,273	45	98,158	53,988
3			207,377				323,722	178,047
4	Not planted	Kalihati	29,040	891	891	-	25,866	25,866
		Basail	15,539	891	891	-	13,841	13,841
4			44,579				39,707	39,707
5	Physiological Maturity	Sakhipur	44,283	2,560	1,408	45	113,342	62,337
		Delduar	17,432	1,502	826	45	26,183	14,401
		Mirzapur	37,297	1,502	826	45	56,020	30,811
5			99,012				195,545	107,549
Total			700,346				1,002,053	768,381
							Loss	233,672

Table 3.14. Average simulated rice yield, and estimated yield reduction as influenced by normal flooding with 50% submergence for 15 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Harvested	Nawabganj	44,448	1,419	1,419	-	63,067	63,067
		Bhuyanpur	21,057	1,801	1,801	-	37,930	37,930
		Tangail Sadar	30,072	1,125	1,125	-	33,819	33,819
1			95,577				134,816	134,816
2	Harvested	Sylhet Sadar	48,170	1,252	1,252	-	60,314	60,314
		Balaganj	38,201	1,252	1,252	-	47,831	47,831
		Nagarpur	23,955	1,327	1,327	-	31,798	31,798
		Muradnagar	33,796	901	901	-	30,464	30,464
		Debidwar	23,307	901	901	-	21,009	21,009
		Daudkandi	35,532	901	901	-	32,029	32,029
		Srinagar	19,711	2,656	2,656	-	52,360	52,360
		Lohajang	10,928	1,304	1,304	-	14,249	14,249
		Chandina	20,201	901	901	-	18,209	18,209
2			253,801				308,263	308,263

Table 3.14. (Continued) Average simulated rice yield, and estimated yield reduction as influenced by normal flooding with 50% submergence for 15 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
3	Maximum Tillering	Madhupur	47,929	835	251	70	40,035	12,011
		Gopalpur	21,498	1,066	320	70	22,915	6,875
		Ghatail	45,057	1,066	320	70	48,026	14,409
		Paba	23,288	2,216	665	70	51,597	15,480
		Bagherpara	27,208	2,315	695	70	62,992	18,899
		Jessore Sadar	42,397	2,315	695	70	98,158	29,449
3			207,377				323,722	97,122
4	Not planted	Kalihati	29,040	891	891	-	25,866	25,866
		Basail	15,539	891	891	-	13,841	13,841
4			44,579				39,707	39,707
5	Physiological Maturity	Sakhipur	44,283	2,560	384	85	113,342	17,000
		Delduar	17,432	1,502	225	85	26,183	3,927
		Mirzapur	37,297	1,502	225	85	56,020	8,403
5			99,012				195,545	29,331
Total			700,346				1,002,053	609,39
							Loss	392,815

Table 3.15. Average simulated rice yield, and estimated yield reduction as influenced by normal flooding with 100% submergence for 7 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Harvested	Nawabganj	44,448	1,419	1,419	-	63,067	63,067
		Bhuyanpur	21,057	1,801	1,801	-	37,930	37,930
		Tangail Sadar	30,072	1,125	1,125	-	33,819	33,819
1			95,577				134,816	134,816
2	Harvested	Sylhet Sadar	48,170	1,252	1,252	-	60,314	60,314
		Balaganj	38,201	1,252	1,252	-	47,831	47,831
		Nagarpur	23,955	1,327	1,327	-	31,798	31,798
		Muradnagar	33,796	901	901	-	30,464	30,464
		Debidwar	23,307	901	901	-	21,009	21,009
		Daudkandi	35,532	901	901	-	32,029	32,029
		Srinagar	19,711	2,656	2,656	-	52,360	52,360
		Lohajang	10,928	1,304	1,304	-	14,249	14,249
		Chandina	20,201	901	901	-	18,209	18,209
2			253,801				308,263	308,263

Table 3.15. (Continued.) Average simulated rice yield, and estimated yield reduction as influenced by normal flooding with 100% submergence for 7 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
3	Maximum Tillering	Madhupur	47,929	835	84	90	40,035	4,004
		Gopalpur	21,498	1,066	107	90	22,915	2,291
		Ghatail	45,057	1,066	107	90	48,026	4,803
		Paba	23,288	2,216	222	90	51,597	5,160
		Bagherpara	27,208	2,315	232	90	62,992	6,299
		Jessore Sadar	42,397	2,315	232	90	98,158	9,816
3			207,377				323,722	32,372
4	Not planted	Kalihati	29,040	891	891	-	25,866	25,866
		Basail	15,539	891	891	-	13,841	13,841
4			44,579				39,707	39,707
5	Physiological Maturity	Sakhipur	44,283	2,560	512	80	113,342	22,668
		Delduar	17,432	1,502	300	80	26,183	5,237
		Mirzapur	37,297	1,502	300	80	56,020	11,204
5			99,012				195,545	39,109
Total			700,346				1,002,053	554,267
							Loss	447,786

Table 3.16. Average simulated rice yield, and estimated yield reduction as influenced by normal flooding with 100% submergence for 15 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Harvested	Nawabganj	44,448	1,419	1,419	-	63,067	63,067
		Bhuyanpur	21,057	1,801	1,801	-	37,930	37,930
		Tangail Sadar	30,072	1,125	1,125	-	33,819	33,819
1			95,577				134,816	134,816
2	Harvested	Sylhet Sadar	48,170	1,252	1,252	-	60,314	60,314
		Balaganj	38,201	1,252	1,252	-	47,831	47,831
		Nagarpur	23,955	1,327	1,327	-	31,798	31,798
		Muradnagar	33,796	901	901	-	30,464	30,464
		Debidwar	23,307	901	901	-	21,009	21,009
		Daudkandi	35,532	901	901	-	32,029	32,029
		Srinagar	19,711	2,656	2,656	-	52,360	52,360
		Lohajang	10,928	1,304	1,304	-	14,249	14,249
		Chandina	20,201	901	901	-	18,209	18,209
2			253,801				308,263	308,263

Table 3.16. (Continued) Average simulated rice yield, and estimated yield reduction as influenced by normal flooding with 100% submergence for 15 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
3	Maximum Tillering	Madhupur	47,929	835	-	100	40,035	-
		Gopalpur	21,498	1,066	-	100	22,915	-
		Ghatail	45,057	1,066	-	100	48,026	-
		Paba	23,288	2,216	-	100	51,597	-
		Bagherpara	27,208	2,315	-	100	62,992	-
		Jessore Sadar	42,397	2,315	-	100	98,158	-
3			207,377				323,722	-
4	Not planted	Kalihati	29,040	891	891	-	25,866	25,866
		Basail	15,539	891	891	-	13,841	13,841
4			44,579				39,707	39,707
5	Physiological Maturity	Sakhipur	44,283	2,560	-	100	113,342	-
		Delduar	17,432	1,502	-	100	26,183	-
		Mirzapur	37,297	1,502	-	100	56,020	-
5			99,012				195,545	-
Total			700,346				1,002,053	482,785
							Loss	519,268

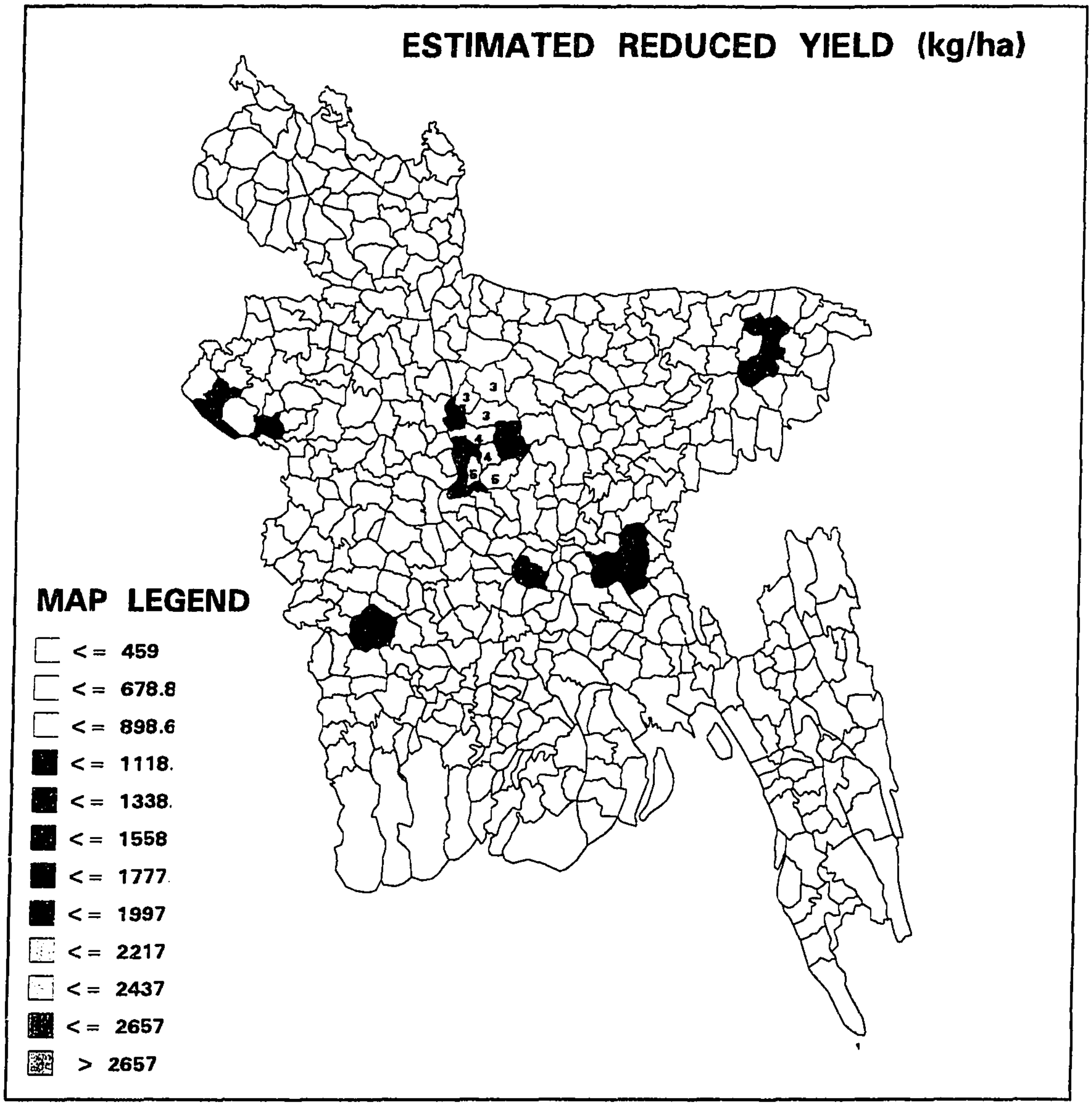


Figure 3.2. Spatial distribution of estimated yield losses from normal flooding with 50% submergence for 7 days in turbid water. The numbers within polygons refer to practice number.

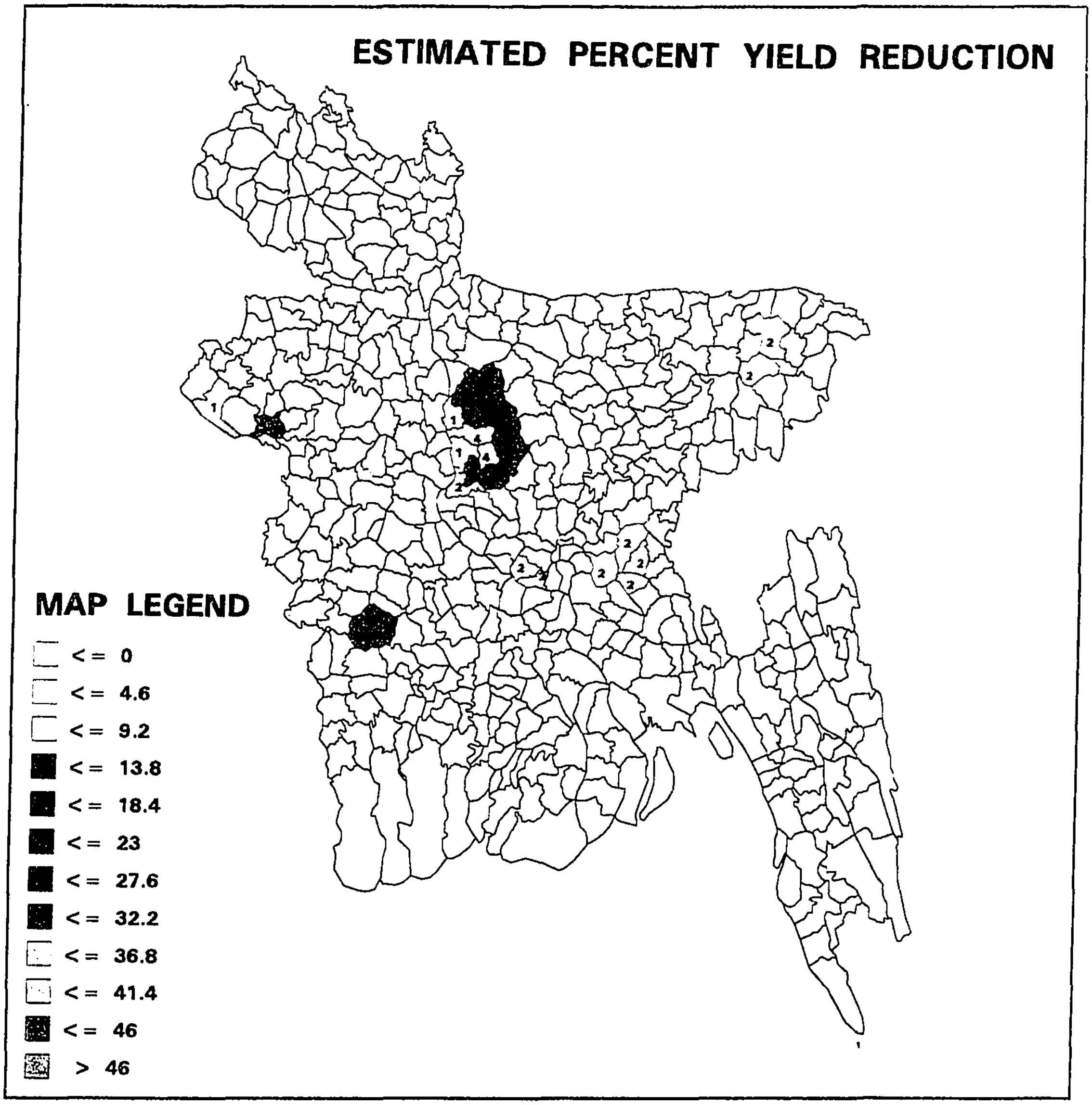


Figure 3.3. Spatial distribution of percent yield reduction of rice from normal flooding with 50% submergence for 7 days in turbid water. The numbers within polygons refer to practice number.

b. Early Flooding

Yield loss assessment associated with early flooding is shown in Tables 3.17 to 3.20. Early flooding occurs during the latter part of June and affects both the broadcast and transplanted Aus and the broadcast Aman rice crops, both the broadcast and transplanted Aus crops were at panicle initiation, and the broadcast Aman rice was at maximum tillering stage. In the case of where submergence was up to 50% of plant height for 7 days, yield losses were 15% and 45% for Aus and Aman rice, respectively. When the period of submergence increased to 15 days, the yield loss was 75% for both the Aus and Aman crops. Total crop damage resulted with increased level of submergence coupled with increased length of submergence (15 days).

c. Late Flooding

Tables 3.21 to 3.24 show the average rice yields for the non-inundated case and yield losses caused by different levels and lengths of submergence for late flooding. When late floods appear in late September, the Aus rice crops would have already been harvested. However, the broadcast Aman, traditional (July 01) and late transplanted (September 01) Aman rice were still at risk to flooding as these crops would be at susceptible stages of growth. The July transplanted Aman rice would be at the panicle initiation stage, the September crop would have just been transplanted, and the broadcast Aman rice would be about to mature. When submerged up to 50% of the plant height for 7 days, a 15% yield reduction was noted for the

Table 3.17. Average simulated rice yield, and estimated reduced yield as influenced by early flooding with 50% submergence for 7 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Panicle Initiation	Nawabganj	44,448	1,419	1,206	15	63,067	53,609
		Bhuyanpur	21,057	1,801	1,531	15	37,930	32,240
		Tangail Sadar	30,072	1,125	956	15	33,819	28,746
1			95,577				134,816	114,595
2	Panicle Initiation	Sylhet Sadar	48,170	1,252	1,064	15	60,314	51,267
		Balaganj	38,201	1,252	1,064	15	47,831	40,657
		Nagarpur	23,955	1,327	1,128	15	31,798	27,028
		Muradnagar	33,796	901	766	15	30,464	25,894
		Debidwar	23,307	901	766	15	21,009	17,858
		Daudkandi	35,532	901	766	15	32,029	27,225
		Srinagar	19,711	2,656	2,258	15	52,360	44,505
		Lohajang	10,928	1,304	1,108	15	14,249	12,112
		Chandina	20,201	901	766	15	18,209	15,478
2			253,801				308,263	262,025

Table 3.17. (Continued) Average simulated rice yield, and estimated reduced yield as influenced by early flooding with 50% submergence for 7 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
3	Not planted	Madhupur	47,929	835	835	-	40,035	40,035
		Gopalpur	21,498	1,066	1,066	-	22,915	22,915
		Ghatail	45,057	1,066	1,066	-	48,026	48,026
		Paba	23,288	2,216	2,216	-	51,597	51,597
		Bagherpara	27,208	2,315	2,315	-	62,992	62,992
		Jessore Sadar	42,397	2,315	2,315	-	98,158	98,158
3			207,377				323,722	323,722
4	Not planted	Kalihati	29,040	891	891	-	25,866	25,866
		Basail	15,539	891	891	-	13,841	13,841
4			44,579				39,707	39,707
5	Maximum Tillering	Sakhipur	44,283	2,560	1,408	45	113,342	62,337
		Delduar	17,432	1,502	826	45	26,183	14,401
		Mirzapur	37,297	1,502	826	45	56,020	30,811
5			99,012				195,545	107,549
Total			700,346				1,002,053	847,598
							Loss	154,455

Table 3.18. Average simulated rice yield, and estimated reduced yield as influenced by early flooding with 50% submergence for 15 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Panicle Initiation	Nawabganj	44,448	1,418	354	75	63,067	15,766
		Bhuyanpur	21,057	1,801	450	75	37,930	9,482
		Tangail Sadar	30,072	1,124	281	75	33,819	8,453
1			95,577				134,816	33,701
2	Panicle Initiation	Sylhet Sadar	48,170	1,252	313	75	60,314	15,077
		Balaganj	38,201	1,252	313	75	47,831	11,957
		Nagarpur	23,955	1,327	331	75	31,798	7,951
		Muradnagar	33,796	901	225	75	30,464	7,618
		Debidwar	23,307	901	225	75	21,009	5,253
		Daudkandi	35,532	901	225	75	32,029	8,009
		Srinagar	19,711	2,656	664	75	52,360	13,090
		Lohajang	10,928	1,303	326	75	14,249	3,563
		Chandina	20,201	901	225	75	18,209	4,553
2			253,801				308,263	77,071

Table 3.18. (Continued) Average simulated rice yield, and estimated reduced yield as influenced by early flooding with 50% submergence for 15 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
3	Not planted	Madhupur	47,929	835	835	0	40,035	40,035
		Gopalpur	21,498	1,065	1,065	0	22,915	22,915
		Ghatail	45,057	1,065	1,065	0	48,026	48,026
		Paba	23,288	2,215	2,215	0	51,597	51,597
		Bagherpara	27,208	2,315	2,315	0	62,992	62,992
		Jessore Sadar	42,397	2,315	2,315	0	98,158	98,158
3			207,377				323,722	323,722
4	Not planted	Kalihati	29,040	890	890	0	25,866	25,866
		Basail	15,539	890	890	0	13,841	13,841
4			44,579				39,707	39,707
5	Maximum Tillering	Sakhipur	44,283	2,559	639	75	113,342	28,337
		Delduar	17,432	1,502	375	75	26,183	6,546
		Mirzapur	37,297	1,502	375	75	56,020	14,005
5			99,012				195,545	48,887
Total			700,346				1,002,053	523,088
							Loss	478,965

Table 3.19. Average simulated rice yield, and estimated reduced yield as influenced by early flooding with 100% submergence for 7 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Panicle Initiation	Nawabganj	44,448	1,419	142	90	63,067	6,307
		Bhuyanpur	21,057	1,801	180	90	37,930	3,792
		Tangail Sadar	30,072	1,125	113	90	33,819	3,383
1			95,577				134,816	13,483
2	Panicle Initiation	Sylhet Sadar	48,170	1,252	125	90	60,314	6,031
		Balaganj	38,201	1,252	125	90	47,831	4,783
		Nagarpur	23,955	1,327	133	90	31,798	3,179
		Muradnagar	33,796	901	90	90	30,464	3,045
		Debidwar	23,307	901	90	90	21,009	2,100
		Daudkandi	35,532	901	90	90	32,029	3,201
		Srinagar	19,711	2,656	266	90	52,360	5,235
		Lohajang	10,928	1,304	130	90	14,249	1,425
		Chandina	20,201	901	90	90	18,209	1,820
2			253,801				308,263	30,819

Table 3.19. (Continued) Average simulated rice yield, and estimated reduced yield as influenced by early flooding with 100% submergence for 7 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
3	Not planted	Madhupur	47,929	835	835	0	40,035	40,035
		Gopalpur	21,498	1,066	1,066	0	22,915	22,915
		Ghatail	45,057	1,066	1,066	0	48,026	48,026
		Paba	23,288	2,216	2,216	0	51,597	51,597
		Bagherpara	27,208	2,315	2,315	0	62,992	62,992
		Jessore Sadar	42,397	2,315	2,315	0	98,158	98,158
3			207,377				323,722	323,722
4	Not planted	Kalihati	29,040	891	891	0	25,866	25,866
		Basail	15,539	891	891	0	13,841	13,841
4			44,579				39,707	39,707
5	Maximum Tillering	Sakhipur	44,283	2,560	256	90	113,342	11,332
		Delduar	17,432	1,502	150	90	26,183	2,618
		Mirzapur	37,297	1,502	150	90	56,020	5,602
5			99,012				195,545	19,552
Total			700,346				1,002,053	427,283
							Loss	574,770

Table 3.20. Average simulated rice yield, and estimated reduced yield as influenced by early flooding with 100 % submergence for 15 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Panicle Initiation	Nawabganj	44,448	1,419	0	100	63,067	-
		Bhuyanpur	21,057	1,801	0	100	37,930	-
		Tangail Sadar	30,072	1,125	0	100	33,819	-
1			95,577				134,816	-
2	Panicle Initiation	Sylhet Sadar	48,170	1,252	0	100	60,314	-
		Balaganj	38,201	1,252	0	100	47,831	-
		Nagarpur	23,955	1,327	0	100	31,798	-
		Muradnagar	33,796	901	0	100	30,464	-
		Debidwar	23,307	901	0	100	21,009	-
		Daudkandi	35,532	901	0	100	32,029	-
		Srinagar	19,711	2,656	0	100	52,360	-
		Lohajang	10,928	1,304	0	100	14,249	-
		Chandina	20,201	901	0	100	18,209	-
2			253,801				308,263	-

Table 3.20. (Continued) Average simulated rice yield, and estimated reduced yield as influenced by early flooding with 100% submergence for 15 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
3	Not planted	Madhupur	47,929	835	835	0	40,035	40,035
		Gopalpur	21,498	1,066	1,066	0	22,915	22,915
		Ghatail	45,057	1,066	1.066	0	48,026	48,026
		Paba	23,288	2,216	2.216	0	51,597	51,597
		Bagherpara	27,208	2,315	2,315	0	62,992	62,992
		Jessore Sadar	42,397	2,315	2,315	0	98,158	98,158
3			207,377				323,722	323,722
4	Not planted	Kalihati	29,040	891	891	0	25,866	25,866
		Basail	15,539	891	891	0	13,841	13,841
4			44,579				39,707	39,707
5	Maximum Tillering	Sakhipur	44,283	2,560	0	100	113,342	-
		Delduar	17,432	1,502	0	100	26,183	-
		Mirzapur	37,297	1,502	0	100	56,020	-
5			99,012				195,545	-
Total			700,346				1,002,053	363,429
							Loss	638,624

Table 3.21. Average simulated rice yield, and estimated reduced yield as influenced by late flooding with 50% submergence for 7 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Harvested	Nawabganj	44,448	1,419	1,419	-	63,067	63,067
		Bhuyanpur	21,057	1,801	1,801	-	37,930	37,930
		Tangail Sadar	30,072	1,125	1,125	-	33,819	33,819
1			95,577				134,816	134,816
2	Harvested	Sylhet Sadar	48,170	1,252	1,252	-	60,314	60,314
		Balaganj	38,201	1,252	1,252	-	47,831	47,831
		Nagarpur	23,955	1,327	1,327	-	31,798	31,798
		Muradnagar	33,796	901	901	-	30,464	30,464
		Debidwar	23,307	901	901	-	21,009	21,009
		Daudkandi	35,532	901	901	-	32,029	32,029
		Srinagar	19,711	2,656	2,656	-	52,360	52,360
		Lohajang	10,928	1,304	1,304	-	14,249	14,249
		Chandina	20,201	901	901	-	18,209	18,209
2			253,801				308,263	308,263

Table 3.21. (Continued) Average simulated rice yield, and estimated reduced yield as influenced by late flooding with 50% submergence for 7 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
3	Panicle Initiation	Madhupur	47,929	835	710	15	40,035	34,030
		Gopalpur	21,498	1,066	906	15	22,915	19,477
		Ghatail	45,057	1,066	906	15	48,026	40,822
		Paba	23,288	2,216	1,883	15	51,597	43,858
		Bagherpara	27,208	2,315	1,968	15	62,992	53,543
		Jessore Sadar	42,397	2,315	1,968	15	98,158	83,433
3			207,377				323,722	275,162
4	10 Days After Transplanting	Kalihati	29,040	891	490	45	25,866	14,227
		Basail	15,539	891	490	45	13,841	7,613
4			44,579				39,707	21,839
5	Physiological Maturity	Sakhipur	44,283	2,560	1,280	50	113,342	56,673
		Delduar	17,432	1,502	751	50	26,183	13,091
		Mirzapur	37,297	1,502	751	50	56,020	28,010
5			99,012				195,545	97,775
Total			700,346				1,002,053	837,855
							Loss	164,198

Table 3.22. Average simulated rice yield, and estimated reduced yield as influenced by late flooding with 50% submergence for 15 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Harvested	Nawabganj	44,448	1,419	1,419	0	63,067	63,067
		Bhuyanpur	21,057	1,801	1,801	0	37,930	37,930
		Tangail Sadar	30,072	1,125	1,125	0	33,819	33,819
1			95,577				134,816	134,816
2	Harvested	Sylhet Sadar	48,170	1,252	1,252	0	60,314	60,314
		Balaganj	38,201	1,252	1,252	0	47,831	47,831
		Nagarpur	23,955	1,327	1,327	0	31,798	31,798
		Muradnagar	33,796	901	901	0	30,464	30,464
		Debidwar	23,307	901	901	0	21,009	21,009
		Daudkandi	35,532	901	901	0	32,029	32,029
		Srinagar	19,711	2,656	2,656	0	52,360	52,360
		Lohajang	10,928	1,304	1,304	0	14,249	14,249
		Chandina	20,201	901	901	0	18,209	18,209
2			253,801				308,263	308,263

Table 3.22. (Continued) Average simulated rice yield, and estimated reduced yield as influenced by late flooding with 50% submergence for 15 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
3	Panicle Initiation	Madhupur	47,929	835	167	80	40,035	8,009
		Gopalpur	21,498	1,066	213	80	22,915	4,583
		Ghatail	45,057	1,066	213	80	48,026	9,606
		Paba	23,288	2,216	443	80	51,597	10,319
		Bagherpara	27,208	2,315	463	80	62,992	12,597
		Jessore Sadar	42,397	2,315	463	80	98,158	19,630
3			207,377				323,722	64,744
4	10 Days After Transplanting	Kalihati	29,040	891	312	65	25,866	9,052
		Basail	15,539	891	312	65	13,841	4,844
4			44,579				39,707	13,895
5	Physiological Maturity	Sakhipur	44,283	2,560	256	90	113,342	11,332
		Delduar	17,432	1,502	150	90	26,183	2,618
		Mirzapur	37,297	1,502	150	90	56,020	5,602
5			99,012				195,545	19,552
Total			700,346				1,002,053	541,271
						Loss		460,782

Table 3.23. Average simulated rice yield, and estimated reduced yield as influenced by late flooding with 100% submergence for 7 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Harvested	Nawabganj	44,448	1,419	1,419	-	63,067	63,067
		Bhuyanpur	21,057	1,801	1,801	-	37,930	37,930
		Tangail Sadar	30,072	1,125	1,125	-	33,819	33,819
1			95,577				134,816	134,816
2	Harvested	Sylhet Sadar	48,170	1,252	1,252	-	60,314	60,314
		Balaganj	38,201	1,252	1,252	-	47,831	47,831
		Nagarpur	23,955	1,327	1,327	-	31,798	31,798
		Muradnagar	33,796	901	901	-	30,464	30,464
		Debidwar	23,307	901	901	-	21,009	21,009
		Daudkandi	35,532	901	901	-	32,029	32,029
		Srinagar	19,711	2,656	2,656	-	52,360	52,360
		Lohajang	10,928	1,304	1,304	-	14,249	14,249
		Chandina	20,201	901	901	-	18,209	18,209
2			253,801				308,263	308,263

Table 3.23. (Continued) Average simulated rice yield, and estimated reduced yield as influenced by late flooding with 100% submergence for 7 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
3	Panicle Initiation	Madhupur	47,929	835	84	90	40,035	4,002
		Gopalpur	21,498	1,066	107	90	22,915	2,292
		Ghatail	45,057	1,066	107	90	48,026	4,803
		Paba	23,288	2,216	222	90	51,597	5,161
		Bagherpara	27,208	2,315	232	90	62,992	6,299
		Jessore Sadar	42,397	2,315	232	90	98,158	9,815
3			207,377				323,722	32,371
4	10 Days After Transplanting	Kalihati	29,040	891	89	90	25,866	2,587
		Basail	15,539	891	89	90	13,841	1,385
4			44,579				39,707	3,972
5	Physiological Maturity	Sakhipur	44,283	2,560	512	80	113,342	22,668
		Delduar	17,432	1,502	300	80	26,183	5,237
		Mirzapur	37,297	1,502	300	80	56,020	11,204
5			99,012				195,545	39,109
Total			700,346				1,002,053	518,531
							Loss	483,522

Table 3.24. Average simulated rice yield, and estimated reduced yield as influenced by late flooding with 100% submergence for 15 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Harvested	Nawabganj	44,448	1,419	1,419	-	63,067	63,067
		Bhuyanpur	21,057	1,801	1,801	-	37,930	37,930
		Tangail Sadar	30,072	1,125	1,125	-	33,819	33,819
1			95,577				134,816	134,816
2	Harvested	Sylhet Sadar	48,170	1,252	1,252	-	60,314	60,314
		Balaganj	38,201	1,252	1,252	-	47,831	47,831
		Nagarpur	23,955	1,327	1,327	-	31,798	31,798
		Muradnagar	33,796	901	901	-	30,464	30,464
		Debidwar	23,307	901	901	-	21,009	21,009
		Daudkandi	35,532	901	901	-	32,029	32,029
		Srinagar	19,711	2,656	2,656	-	52,360	52,360
		Lohajang	10,928	1,304	1,304	-	14,249	14,249
		Chandina	20,201	901	901	-	18,209	18,209
2			253,801				308,263	308,263

Table 3.24. (Continued) Average simulated rice yield, and estimated reduced yield as influenced by late flooding with 100% submergence for 15 days in turbid water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
3	Panicle Initiation	Madhupur	47,929	835	84	90	40,035	4,002
		Gopalpur	21,498	1,066	107	90	22,915	2,292
		Ghatail	45,057	1,066	107	90	48,026	4,803
		Paba	23,288	2,216	222	90	51,597	5,161
		Bagherpara	27,208	2,315	232	90	62,992	6,299
		Jessore Sadar	42,397	2,315	232	90	98,158	9,815
3			207,377				323,722	32,371
4	10 Days After Transplanting	Kalihati	29,040	891	89	90	25,866	2,587
		Basail	15,539	891	89	90	13,841	1,385
4			44,579				39,707	3,972
5	Physiological Maturity	Sakhipur	44,283	2,560	512	80	113,342	22,668
		Delduar	17,432	1,502	300	80	26,183	5,237
		Mirzapur	37,297	1,502	300	80	56,020	11,204
5			99,012				195,545	39,109
Total			700,346				1,002,053	518,531
							Loss	483,522

The loss was 45% for the September transplanted Aman rice, and 50% for the broadcast Aman.

To illustrate the effect of water clarity on yield loss, the case represented in Table 3.25 was repeated with clear instead of turbid water. This particular situation was selected because if the crop is fully submerged, water clarity becomes an important yield-reducing factor when water level is high. The effect of water clarity can be seen by comparing yield reductions in Tables 3.19 and 3.25.

2. Aggregation of Rice Yield Loss from Flooding in Tangail District

The second objective of this study was to enable policy makers to assess yield loss in real time to support food security decision making. To do this location specific results from the Thana level were aggregated to the district level Further aggregation to higher (division and national) levels requires additional effort and resource.

a. Estimation of Aggregated Crop Damage from Normal Flooding

Tables 3.26 to 3.29 show the simulated aggregated rice production of the Tangail district under different flooding scenarios. For the non-inundated case, with traditional planting dates and farmers' fertilizer rates, the total production for Tangail district was 0.045 million tonnes. Superimposing different flooding scenarios resulted in a range of losses. An estimated loss of 0.138 million tonnes to a production level of 0.312 million tonnes resulted after seven days at 50% submergence.

Table 3.25. Average simulated rice yield, and estimated reduced yield as influenced by early flooding with 100% submergence for 7 days in clear water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Panicle Initiation	Nawabganj	44,448	1,419	425.67	70	63,067	18,920
		Bhuyanpur	21,057	1,801	540.39	70	37,930	11,379
		Tangail Sadar	30,072	1,125	337.38	70	33,819	10,146
1			95,577				134,816	40,445
2	Panicle Initiation	Sylhet Sadar	48,170	1,252	375.63	70	60,314	18,094
		Balaganj	38,201	1,252	375.63	70	47,831	14,349
		Nagarpur	23,955	1,327	398.22	70	31,798	9,539
		Muradnagar	33,796	901	270.42	70	30,464	9,139
		Debidwar	23,307	901	270.42	70	21,009	6,303
		Daudkandi	35,532	901	270.42	70	32,029	9,609
		Srinagar	19,711	2,656	796.92	70	52,360	15,708
		Lohajang	10,928	1,304	391.17	70	14,249	4,275
		Chandina	20,201	901	270.42	70	18,209	5,463
2			253,801				308,263	92,479

Table 3.25. (Continued) Average simulated rice yield, and estimated reduced yield as influenced by early flooding with 100% submergence for 7 days in clear water.

Practice Number	Growth Stage at onset of Flooding	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
3	Not planted	Madhupur	47,929	835	835	0	40,035	40,035
		Gopalpur	21,498	1,066	1066	0	22,915	22,915
		Ghatail	45,057	1,066	1066	0	48,026	48,026
		Paba	23,288	2,216	2216	0	51,597	51,597
		Bagherpara	27,208	2,315	2315	0	62,992	62,992
		Jessore Sadar	42,397	2,315	2315	0	98,158	98,158
3			207,377				323,722	323,722
4	Not planted	Kalihati	29,040	891	891	0	25,866	25,866
		Basail	15,539	891	891	0	13,841	13,841
4			44,579				39,707	39,707
5	Maximum Tillering	Sakhipur	44,283	2,560	1023.8	60	113,342	45,337
		Delduar	17,432	1,502	600.8	60	26,183	10,473
		Mirzapur	37,297	1,502	600.8	60	56,020	22,408
5			99,012				195,545	78,218
Total			700,346				1,002,053	574,571
							Loss	427,482

Table 3.26. Aggregated rice production and loss for Tangail district as affected by normal flooding with 50% submergence for 7 days in turbid water.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Bhuyanpur	21,057	1,801	1,801	-	37,930	37,930
1	Tangail Sadar	30,072	1,125	1,125	-	33,819	33,819
2	Nagarpur	23,955	1,327	1,327	-	31,798	31,798
3	Madhupur	47,929	835	459	45	40,035	22,019
3	Gopalpur	21,498	1,066	586	45	22,915	12,602
3	Ghatail	45,057	1,066	586	45	48,026	26,412
4	Kalihati	29,040	891	891	-	25,866	25,866
4	Basail	15,539	891	891	-	13,841	13,841
5	Sakhipur	44,283	2,560	1,408	45	113,342	62,337
5	Delduar	17,432	1,502	826	45	26,183	14,401
5	Mirzapur	37,297	1,502	826	45	56,020	30,811
Total		333,159				449,775	311,835
						Loss	137,939

Table 3.27. Aggregated rice production and loss for Tangail district as affected by normal flooding with 50% submergence for 15 days in turbid water.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Bhuyanpur	21,057	1,801	1,801	-	37,930	37,930
1	Tangail Sadar	30,072	1,125	1,125	-	33,819	33,819
2	Nagarpur	23,955	1,327	1,327	-	31,798	31,798
3	Madhupur	47,929	835	251	70	40,035	12,011
3	Gopalpur	21,498	1,066	320	70	22,915	6,875
3	Ghatail	45,057	1,066	320	70	48,026	14,409
4	Kalihati	29,040	891	891	-	25,866	25,866
4	Basail	15,539	891	891	-	13,841	13,841
5	Sakhipur	44,283	2,560	384	85	113,342	17,000
5	Delduar	17,432	1,502	225	85	26,183	3,927
5	Mirzapur	37,297	1,502	225	85	56,020	8,403
Total		333,159				449,775	205,879
						Loss	243,895

Table 3.28. Aggregated rice production and loss for Tangail district as affected by normal flooding with 100% submergence for 7 days in turbid water.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Bhuyanpur	21,057	1,801	1,801	-	37,930	37,930
1	Tangail Sadar	30,072	1,125	1,125	-	33,819	33,819
2	Nagarpur	23,955	1,327	1,327	-	31,798	31,798
3	Madhupur	47,929	835	84	90	40,035	4,004
3	Gopalpur	21,498	1,066	107	90	22,915	2,291
3	Ghatail	45,057	1,066	107	90	48,026	4,803
4	Kalihati	29,040	891	891	-	25,866	25,866
4	Basail	15,539	891	891	-	13,841	13,841
5	Sakhipur	44,283	2,560	512	80	113,342	22,668
5	Delduar	17,432	1,502	300	80	26,183	5,237
5	Mirzapur	37,297	1,502	300	80	56,020	11,204
Total		333,159				449,775	193,460
						Loss	256,315

Table 3.29. Aggregated rice production and loss for Tangail district as affected by normal flooding with 100% submergence for 15 days in turbid water.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Bhuyanpur	21,057	1,801	1,801	-	37,930	37,930
1	Tangail Sadar	30,072	1,125	1,125	-	33,819	33,819
2	Nagarpur	23,955	1,327	1,327	-	31,798	31,798
3	Madhupur	47,929	835	-	100	40,035	-
3	Gopalpur	21,498	1,066	-	100	22,915	-
3	Ghatail	45,057	1,066	-	100	48,026	-
4	Kalihati	29,040	891	891	-	25,866	25,866
4	Basail	15,539	891	891	-	13,841	13,841
5	Sakhipur	44,283	2,560	-	100	113,342	-
5	Delduar	17,432	1,502	-	100	26,183	-
5	Mirzapur	37,297	1,502	-	100	56,020	-
		333,159				449,775	143,253
Total							
						Loss	306,521

Increasing the submergence period to 15 days reduced production to 0.206 million tonnes. In the real situation, farmers would not harvest a crop damaged beyond 80%. Thus, by treating yield loss greater than 80% as a total loss, the production level declines further to 0.196 million tonnes. The decision support system appears to produce reasonable results, but will eventually have to be tested against real inputs and outputs.

b. Estimation of Aggregated Crop Damage from Early Flooding

The aggregated rice production levels of Tangail district for early, normal and late flooding are summarized in Tables 3.30 to 3.33. For early flooding with 50% submergence for 7 days, rice production fell from 0.450 million tonnes to 0.346 million tonnes. Increasing the submergence period to 15 days resulted in a further decrease to 0.225 million tonnes or a 50% loss. When the scenarios for 100% submergence for 7 and 15 days were evaluated, rice production levels were even more drastically reduced to 0.180 and 0.150 million tonnes, respectively.

c. Estimation of Aggregated Crop Damage from Late Flooding

For the late flooding scenario of 50% submergence for 7 days, rice production in Tangail district declined to 0.317 million tonnes. Increasing the length of submergence to 15 days resulted in a further reduction to 0.159 million tonnes. If the heavily damaged rice is assumed not to be harvestable, the estimated loss rises to 0.306 million tonnes. The aggregated results are summarized in Tables 3.34 to 3.37.

Table 3.30. Aggregated rice production and loss for Tangail district as affected by early flooding with 50% submergence for 7 days in turbid water.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Bhuyanpur	21,057	1,801	1,531	15	37,930	32,240
1	Tangail Sadar	30,072	1,125	956	15	33,819	28,746
2	Nagarpur	23,955	1,327	1,128	15	31,798	27,028
3	Madhupur	47,929	835	835	-	40,035	40,035
3	Gopalpur	21,498	1,066	1,066	-	22,915	22,915
3	Ghatail	45,057	1,066	1,066	-	48,026	48,026
4	Kalihati	29,040	891	891	-	25,866	25,866
4	Basail	15,539	891	891	-	13,841	13,841
5	Sakhipur	44,283	2,560	1,408	45	113,342	62,337
5	Delduar	17,432	1,502	826	45	26,183	14,401
5	Mirzapur	37,297	1,502	826	45	56,020	30,811
Total		333,159				449,775	346,246
						Loss	103,528.68

Table 3.31. Aggregated rice production and loss for Tangail district as affected by early flooding with 50% submergence for 15 days in turbid water.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Bhuyanpur	21,057	1,801	450	75	37,930	9,482
1	Tangail Sadar	30,072	1,124	281	75	33,819	8,453
2	Nagarpur	23,955	1,327	331	75	31,798	7,951
3	Madhupur	47,929	835	835	0	40,035	40,035
3	Gopalpur	21,498	1,065	1,065	0	22,915	22,915
3	Ghatail	45,057	1,065	1,065	0	48,026	48,026
4	Kalihati	29,040	890	890	0	25,866	25,866
4	Basail	15,539	890	890	0	13,841	13,841
5	Sakhipur	44,283	2,559	639	75	113,342	28,337
5	Delduar	17,432	1,502	375	75	26,183	6,546
5	Mirzapur	37,297	1,502	375	75	56,020	14,005
Total		333,159				449,775	225,456
						Loss	224,319

Table 3.32. Aggregated rice production and loss for Tangail district as affected by early flooding with 100% submergence for 7 days in turbid water.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Bhuyanpur	21,057	1,801	180	90	37,930	3,792
1	Tangail Sadar	30,072	1,125	113	90	33,819	3,383
2	Nagarpur	23,955	1,327	133	90	31,798	3,179
3	Madhupur	47,929	835	835	0	40,035	40,035
3	Gopalpur	21,498	1,066	1066	0	22,915	22,915
3	Ghatail	45,057	1,066	1066	0	48,026	48,026
4	Kalihati	29,040	891	891	0	25,866	25,866
4	Basail	15,539	891	891	0	13,841	13,841
5	Sakhipur	44,283	2,560	256	90	113,342	11,332
5	Delduar	17,432	1,502	150	90	26,183	2,618
5	Mirzapur	37,297	1,502	150	90	56,020	5,602
Total		333,159				449,775	180,589
						Loss	269,185

Table 3.33. Aggregated rice production and loss for Tangail district as affected by early flooding with 100% submergence for 15 days in turbid water.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Bhuyanpur	21,057	1,801	0	100	37,930	-
1	Tangail Sadar	30,072	1,125	0	100	33,819	-
2	Nagarpur	23,955	1,327	0	100	31,798	-
3	Madhupur	47,929	835	835	0	40,035	40,035
3	Gopalpur	21,498	1,066	1066	0	22,915	22,915
3	Ghatail	45,057	1,066	1066	0	48,026	48,026
4	Kalihati	29,040	891	891	0	25,866	25,866
4	Basail	15,539	891	891	0	13,841	13,841
5	Sakhipur	44,283	2,560	0	100	113,342	-
5	Delduar	17,432	1,502	0	100	26,183	-
5	Mirzapur	37,297	1,502	0	100	56,020	-
Total		333,159				449,775	150,683
						Loss	299,092

Table 3.34. Aggregated rice production and loss for Tangail district as affected by late flooding with 50% submergence for 7 days in turbid water.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Bhuyanpur	21,057	1,801	1,801	0	37,930	37,930
1	Tangail Sadar	30,072	1,124	1,124	0	33,819	33,819
2	Nagarpur	23,955	1,327	1,327	0	31,798	31,798
3	Madhupur	47,929	835	710	15	40,035	34,030
3	Gopalpur	21,498	1,065	906	15	22,915	19,477
3	Ghatail	45,057	1,065	906	15	48,026	40,822
4	Kalihati	29,040	890	489	45	25,866	14,227
4	Basail	15,539	890	489	45	13,841	7,613
5	Sakhipur	44,283	2,559	1,279	50	113,342	56,673
5	Delduar	17,432	1,502	751	50	26,183	13,091
5	Mirzapur	37,297	1,502	751	50	56,020	28,010
Total		333,159				449,775	317,489
						Loss	132,285

Table 3.35. Aggregated rice production and loss for Tangail district as affected by late flooding with 50% submergence for 15 days in turbid water.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Bhuyanpur	21,057	1,801	1,801	-	37,930	37,930
1	Tangail Sadar	30,072	1,125	1,125	-	33,819	33,819
2	Nagarpur	23,955	1,327	1,327	-	31,798	31,798
3	Madhupur	47,929	835	167	80	40,035	8,009
3	Gopalpur	21,498	1,066	213	80	22,915	4,583
3	Ghatail	45,057	1,066	213	80	48,026	9,606
4	Kalihati	29,040	891	312	65	25,866	9,052
4	Basail	15,539	891	312	65	13,841	4,844
5	Sakhipur	44,283	2,560	256	90	113,342	11,332
5	Delduar	17,432	1,502	150	90	26,183	2,618
5	Mirzapur	37,297	1,502	150	90	56,020	5,602
Total		333,159				449,775	159,193
						Loss	290,582

Table 3.36. Aggregated rice production and loss for Tangail district as affected by late flooding with 100% submergence for 7 days in turbid water.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Bhuyanpur	21,057	1,801	1,801	0	37,930	37,930
1	Tangail Sadar	30,072	1,125	1,125	0	33,819	33,819
2	Nagarpur	23,955	1,327	1,327	0	31,798	31,798
3	Madhupur	47,929	835	84	90	40,035	4,002
3	Gopalpur	21,498	1,066	107	90	22,915	2,292
3	Ghatail	45,057	1,066	107	90	48,026	4,803
4	Kalihati	29,040	891	89	90	25,866	2,587
4	Basail	15,539	891	89	90	13,841	1,385
5	Sakhipur	44,283	2,560	512	80	113,342	22,668
5	Delduar	17,432	1,502	300	80	26,183	5,237
5	Mirzapur	37,297	1,502	300	80	56,020	11,204
Total		333,159				449,775	157,725
					Loss		292,050

Table 3.37. Aggregated rice production and loss for Tangail district as affected by early flooding with 100% submergence for 15 days in turbid water.

Practice Number	Thana Name	Cultivated Area (ha)	Average Yield (kg ha^{-1})	Reduced Yield (kg ha^{-1})	Percent Yield Reduction	Average Production (tonnes)	Reduced Production (tonnes)
1	Bhuyanpur	21,057	1,801	1,801	-	37,930	37,930
1	Tangail Sadar	30,072	1,125	1,125	-	33,819	33,819
2	Nagarpur	23,955	1,327	1,327	-	31,798	31,798
3	Madhupur	47,929	835	84	90	40,035	4,002
3	Gopalpur	21,498	1,066	107	90	22,915	2,292
3	Ghatail	45,057	1,066	107	90	48,026	4,803
4	Kalihati	29,040	891	89	90	25,866	2,587
4	Basail	15,539	891	89	90	13,841	1,385
5	Sakhipur	44,283	2,560	512	80	113,342	22,668
5	Delduar	17,432	1,502	300	80	26,183	5,237
5	Mirzapur	37,297	1,502	300	80	56,020	11,204
Total		333,159				449,774.69	157,725
					Loss		292,050

d. Spatial and Temporal Aggregation of Yield Loss

Since rice is grown throughout the year in Bangladesh, yield loss assessment from flooding requires data collection over space and time. The smallest spatial unit will probably be a soil series within a land type. The land types can then be aggregated to the Thana level and on up to the national level. The soil series and types are biophysical units, whereas the Thana, district and higher levels are administrative units. The natural temporal unit is the seasonal rice crop indicated by Aus, Aman and Boro rice. The chronological units would be months of the year.

A complete assessment of yield loss due to flooding requires aggregation of gains and losses in productions over the entire country for at least the Aus and Aman crops. The Boro rice crop which is irrigated rice grown in the dry (Rabi) season is not subject to flooding. The constant threat of flood from April to September indicates that to apply this yield loss assessment to rice, a national flood monitoring system will need to be established to observe and report flood status over space and time.

IV. SUMMARY AND CONCLUSIONS

The goal and hope of every developer of decision support systems are to have their product adopted and used by its intended audience. This goal has not been achieved as often as developers, users, and especially people who finance product development would like. One way to increase the probability of achieving this goal is to identify and involve the user group from the problem identification stage through the product design and development stages. This was clearly not a realistic option for this study. Objectives 1 and 2 remain unfinished. It was, however, necessary to state the objectives in terms of user needs to serve as a constant reminder of the product's purpose.

When this work was first conceived it was not certain whether the product as it now exists could be assembled even though several of the main components of the system already existed. The challenge was to assemble the parts into an integrated unit capable of approaching and achieving the stated objectives.

The rice model (Singh *et al.,* 1994) had been upgraded several times before and could simulate most of the processes required to achieve the first objective. Furthermore, the mechanics of coupling a simulation model to a geographic information system had already been accomplished for the bean model (Calixte *et al.*, 1992). The actual coupling of the CERES-rice model to the geographic information system was more difficult than anticipated owing to the complexity of the rice model. The complexity stems from the need to simulate nitrogen dynamics in submerged soils. The earlier work of others (Luyten *et al.*, 1994) made a difficult task much easier to handle.

Unlike the first objective, the second could be attained only by assembling parts that already existed. What was missing was the capability to estimate yield loss from flooding. Fortunately, a small body of knowledge on this topic was available in the literature (FAO/UN, 1972 and Undan, 1977). In addition expert knowledge on this subject was also available in Bangladesh. From this knowledge base a set of simple rules was formulated to estimate yield losses. The losses were estimated from observations of depth and duration of flooding for a specified growth stage and water clarity. Factors such as water temperature, flood velocity and plant nitrogen status were not included because their effects on yield were not as well known. These factors would need to be incorporated in later versions.

In its current form, the prototype system can simulate growth, development and grain yield of different rice cultivars, sown or transplanted in different soils, for different weather sequences, and with varying supplied amounts of nitrogen fertilizers. When applied to conditions in Bangladesh, the effects of planting date and fertilizer rate were clearly evident. However, the simulated results which assumed no flooding would not necessarily be the same for the optimum planting date and fertilizer rate with the risk of flooding.

For example, the Aus crop traditionally sown on April 01 is broadcast rather than transplanted because their is insufficient water for transplanting. A successful crop depends on sufficient rains on the one hand and the absence of flooding on the other. This situation represents a high risk case wherein farmers are willing to risk sowing rice seeds with the hope that a harvestable crop will result, but are unwilling to invest in fertilizer.

In contrast, the farmers of the transplanted Aman crop faces flooding risk but not drought. In this case, farmers apply heavier doses of fertilizer, nearly equaling the government recommended rates. The difference in the way farmers respond to the management of the risky Aus crop to the less risky Aman crop indicates that farmers are more sensitive to risk than government workers in matters related to on-farm decision making. The results show that farmers are willing to take risks when they perceive the benefits to outweigh the risk.

While the decision support system is not yet able to assess multiple risks from weather and flooding, future versions will need to have this capability so that the element of risk can be incorporated into government recommended practices.

The value of this research, therefore, is not the useable decision support system that was assembled but a demonstration of the comparative advantages the new tools of information technology have over traditional methods. Its principal advantage is that it enables users to obtain answers to complex questions quickly and inexpensively. The usefulness of a decision support system resides in its utility to serve the needs of users (extension agents, researchers, administrators, policy makers) and beneficiaries (farmers). Such a system allows public workers to focus on their clients' problems and concerns. And because product development requires the collective knowledge of experts in soils, crops, economics and weather, it can be the basis for establishing interdisciplinary teams in which each member's role is clearly defined. A decision support system also helps to prioritize research on the basis of need. For example, it is clear that if policy makers in government choose to supplement the current agricultural extension service with computerized decision aids, a national data base with agreed upon standard would have to be organized. In the past, national inventories of soil, weather and crop data were collected without defined purposes. This is not the case with computerized decision support systems. The quantitative data requirements to simulate outputs of natural systems give new meaning and significance to the word *data*. That may be the incentive needed to renew and continue efforts to complete data collection work.

The prototype decision support system described herein, while incomplete, can serve as a framework for developing a functional product.

APPENDICES

APPENDIX A

Soil Data File

The soil data file contains information collected for the soil pedon at a specified site, and supplemental information extracted from soil survey reports for a soil with similar taxonomic classification. The file is created by strictly maintaining the format required by the DSSAT v3.0 crop models. These data are used by the soil water, nitrogen, and root growth submodels of the CERES-rice model.

```
*SOIL INPUT FILE

*BARI940001   BDSOILRESOR SILO      74 Noncalcareous Alluvium
@SITE         COUNTRY           LAT      LONG SCS FAMILY
 TANGAIL      BANGLADESH      24.32     89.50 Silty, Typic Psammaquent
@ SCOM  SALB  SLU1  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
   5/1  0.12  11.3  0.01  84.0  1.00  1.00   -99   -99   -99
@  SLB  SLMH  SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI  SLHW  SLHB  SCEC
    13   -99 0.169 0.295 0.439 1.000   -99  1.69  0.57  18.0  72.0  10.0  0.04   7.3   -99  13.4
    20   -99 0.158 0.288 0.422 1.000   -99  1.57  0.31   8.0  78.0  14.0  0.02   7.5   -99  10.1
    56   -99 0.164 0.201 0.359 0.250   -99  1.79  0.61  18.0  80.0   2.0  0.04   7.4   -99  12.2
    74   -99 0.159 0.259 0.399 0.050   -99  1.99  0.23   4.0  67.0  29.0   -99   7.3   -99   8.5

*BARI940002   BDSOILRESOR SILO     137 Calcareous Alluvium
@SITE         COUNTRY           LAT      LONG SCS FAMILY
 HATIYA       BANGLADESH      22.24     91.08 Silty, Aeric Fluvaquent
@ SCOM  SALB  SLU1  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
   4/3  0.12  11.3  0.01  84.0  1.00  1.00   -99   -99   -99
@  SLB  SLMH  SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI  SLHW  SLHB  SCEC
    13   -99 0.171 0.300 0.414 1.000   -99  1.38  0.97  23.0  68.5   8.5  0.07   6.8   -99  16.6
    17   -99 0.157 0.281 0.409 1.000   -99  1.43  0.57  26.0  69.3   4.7  0.04   7.8   -99  16.1
    45   -99 0.144 0.261 0.386 0.250   -99  1.44  0.24  14.6  77.5   7.9  0.02   8.3   -99   8.9
    76   -99 0.152 0.259 0.379 0.050   -99  1.52  0.23  16.8  77.3   5.9  0.02   8.3   -99   8.5
   107   -99 0.148 0.220 0.360 0.000   -99  1.52  0.14  20.9  75.4   3.7  0.01   8.3   -99  11.4
   137   -99 0.137 0.201 0.343 0.000   -99  1.48  0.09  29.1  66.6   4.3   -99   8.3   -99  14.3

*BARI940003   BDSOILRESOR SICLL    114 Grey Floodplain Soil
@SITE         COUNTRY           LAT      LONG SCS FAMILY
 TANGAIL      BANGLADESH      24.29     89.59 Silty clay loam, Aeric Haplaquept
@ SCOM  SALB  SLU1  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
   5/1  0.12  11.3  0.02  84.0  1.00  1.00   -99   -99   -99
@  SLB  SLMH  SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI  SLHW  SLHB  SCEC
    13   -99 0.183 0.311 0.428 1.000   -99  1.25  1.39  38.0  52.0  10.0  0.11   5.0   -99  19.4
    33   -99 0.143 0.298 0.419 1.000   -99  1.34  0.65  56.0  37.0   7.0  0.07   6.9   -99  18.9
    53   -99 0.134 0.254 0.370 0.250   -99  1.42  0.53  53.0  40.0   7.0  0.04   7.0   -99  18.1
    96   -99 0.128 0.259 0.366 0.000   -99  1.45  0.29  37.0  54.0   7.0  0.02   6.9   -99  18.9
   114   -99 0.112 0.220 0.341 0.000   -99  1.56  0.11  17.0  50.0  33.0  0.02   6.8   -99  14.2
```

```
*BARI940004  BDSOILRESOR SILO    116 Noncalcareous Dark Grey Floodplain Soil
@SITE        COUNTRY          LAT     LONG SCS FAMILY
 MYMENSHIGH  BANGLADESH     24.53    90.27 Silty, Aeric Haplaquept
@ SCOM  SALB  SLU1  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
   5/2  0.10  11.3  0.01  84.0  1.00  1.00   -99   -99   -99
@  SLB  SLMH  SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI  SLHW  SLHB  SCEC
    10   -99 0.181 0.300 0.419 1.000   -99  1.43  1.26  25.0  54.0  21.0  0.06   5.6   -99  11.6
    15   -99 0.146 0.298 0.408 0.500   -99  1.56  0.56  34.0  51.0  15.0  0.05   7.4   -99  16.3
    38   -99 0.123 0.214 0.350 0.200   -99  1.64  0.56  38.0  48.0  14.0  0.05   7.3   -99  17.8
    63   -99 0.134 0.225 0.359 0.000   -99  1.62  0.46  37.0  52.0  11.0  0.04   7.3   -99  15.0
    86   -99 0.135 0.220 0.349 0.000   -99  1.59  0.23  18.0  53.0  29.0  0.03   7.3   -99  15.6
   116   -99 0.102 0.205 0.345 0.000   -99  1.77  0.20   8.0  36.0  56.0  0.03   7.4   -99  11.0

*BARI940005  BDSOILRESOR CL      127 Calcareous Dark Grey Floodplain Soil
@SITE        COUNTRY          LAT     LONG SCS FAMILY
 NATORE      BANGLADESH     24.26    89.03 Clay, Aeric Haplaquept
@ SCOM  SALB  SLU1  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
   4/1  0.09   6.8  0.01  76.0  1.00  1.00   -99   -99   -99
@  SLB  SLMH  SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI  SLHW  SLHB  SCEC
    10   -99 0.173 0.229 0.386 1.000   -99  0.99  4.56  76.0  22.0   2.0  0.35   5.5   -99  52.3
    35   -99 0.144 0.201 0.379 0.750   -99  1.15  1.32  79.0  15.0   6.0  0.10   7.6   -99  48.8
    63   -99 0.152 0.199 0.366 0.200   -99  1.29  1.17  76.0  17.0   7.0  0.09   7.8   -99  43.7
    96   -99 0.148 0.170 0.321 0.000   -99  1.32  0.15  68.0  23.0   9.0  0.07   7.8   -99  41.4
   127   -99 0.137 0.162 0.309 0.000   -99  1.23  0.09  64.0  29.0   7.0  0.02   7.8   -99  39.5

*BARI940006  BDSOILRESOR SILO    127 Grey Terrace Soil
@SITE        COUNTRY          LAT     LONG SCS FAMILY
 JOYDEBPUR   BANGLADESH     24.05    90.30 Silty, Aeric Albaquept
@ SCOM  SALB  SLU1  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
   6/1  0.13  11.3  0.01  84.0  1.00  1.00   -99   -99   -99
@  SLB  SLMH  SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI  SLHW  SLHB  SCEC
     8   -99 0.115 0.234 0.367 1.000   -99  1.26  0.85  18.9  69.9  11.2  0.07   5.0   -99   7.7
    13   -99 0.157 0.218 0.355 1.000   -99  1.33  0.50  23.3  70.2   6.5  0.04   5.5   -99   8.8
    18   -99 0.133 0.212 0.349 0.500   -99  1.48  0.40  31.8  59.7   8.5  0.04   5.6   -99  10.3
    40   -99 0.124 0.193 0.305 0.300   -99  1.54  0.25  45.4  41.6  13.0  0.02   5.3   -99  13.7
    58   -99 0.132 0.179 0.315 0.000   -99  1.54  0.16  45.4  41.6  13.0  0.01   5.3   -99  19.3
    99   -99 0.122 0.173 0.329 0.000   -99  1.58  0.09  47.7  39.6  12.7   -99   5.6   -99  22.5
   127   -99 0.113 0.171 0.334 0.000   -99  1.61  0.05  48.8  40.6  10.6   -99   5.8   -99  21.9

*BARI940007  BDSOILRESOR VFSAL   111 Acid Basin Clay
@SITE.       COUNTRY          LAT     LONG SCS FAMILY
 BURICHANG   BANGLADESH     23.29    91.09 Clay,Typic Haplaquept
@ SCOM  SALB  SLU1  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
   5/1  0.12   8.3  0.01  78.0  1.00  1.00   -99   -99   -99
@  SLB  SLMH  SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI  SLHW  SLHB  SCEC
    15   -99 0.189 0.312 0.429 1.000   -99  1.55  3.00  69.7  25.6   4.7  0.21   4.7   -99  24.2
    33   -99 0.188 0.298 0.411 1.000   -99  1.47  2.35  72.3  20.4   7.3  0.19   4.8   -99  30.4
    20   -99 0.154 0.271 0.379 0.250   -99  1.66  1.42  72.3  21.6   6.1  0.12   4.8   -99  26.3
    71   -99 0.149 0.269 0.358 0.050   -99  1.69  0.83  72.5  21.3   6.2   -99   4.7   -99  18.5
   111   -99 0.140 0.238 0.340 0.000   -99  1.32  0.47  68.1  21.9  10.0   -99   4.5   -99  10.4

*BARI940018  BDSOILRESOR VFSAL   185 Brown Hill Soil
@SITE        COUNTRY          LAT     LONG SCS FAMILY
 SRIMANGAL   BANGLADESH     24.18    91.44 Very Fine Sandy Loam,Udic Ustochrept
@ SCOM  SALB  SLU1  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
   5/4  0.13   8.3  0.01  88.0  1.00  1.00   -99   -99   -99
@  SLB  SLMH  SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI  SLHW  SLHB  SCEC
    10   -99 0.115 0.235 0.351 1.000   -99  1.58  0.83  29.0  27.0  44.0  0.05   4.6   -99  11.3
    33   -99 0.124 0.241 0.359 1.000   -99  1.47  1.52  29.0  26.0  45.0  0.11   4.6   -99  11.1
    66   -99 0.131 0.221 0.344 0.250   -99  1.44  1.08  30.0  27.0  43.0  0.08   4.7   -99  10.9
   104   -99 0.112 0.211 0.331 0.050   -99  1.64  0.55  31.0  26.0  43.0  0.04   4.7   -99  10.2
   132   -99 0.108 0.211 0.306 0.000   -99  1.72  0.24  29.0  26.0  43.0  0.03   5.1   -99  -9.9
   185   -99 0.097 0.200 0.303 0.000   -99  1.78  0.19  29.0  26.0  43.0   -99   5.4   -99  -9.9
```

APPENDIX B

AML and Menu Program Files

The AML (ARC Macro Language) and menu programs that constitute the FLOODEX system are presented in the following section. A brief description of each program and its purpose is provided.

Program: fx.aml

```
/***********************************************************
/* Name         : fx.aml
/* Purpose      :    Sets initial conditions to run FLOODEX
/*                   and begins FLOODEX.
/* Date         : 2/07/95  S.G.  Hussain
/* Called by    : USER (START COMMAND FLOODEX)
/*
/* Amls called : floodex.aml
/***********************************************************
&echo &off
&severity &error &ignore
&term 9999
&station 9999
/* Several directories
&amlpath floodex_aml          /* Aml files &menupath
floodex_mnu                   /* Menu files
w ..aegis_cov                 /* Working directory
arcplot
display 9999 4
shadeset  ../floodex.shadeset
textcolor 1
textfont 94023
textquality PROPORTIONAL
linecolor 1
&thread &create FLOODEX &r floodex
&thread &delete FLOODEX
&delvar .*
q
&workspace /usr2/sk.aegis+/floodex
&thread &delete &all
&return
```

Program; fxintro_screen.aml

```
/**********************************************************/
/* Name         : fxintro_screen.aml
/* Purpose      :    Draws the screen when you start FLOODEX.
                     The screen contains an welcome message.
/*
/* Date         : 2/10/95, S.G.  Hussain
/*
/* Amls called : none
/*
/* Called by    : fx.aml
/**********************************************************/
&ARGS error_status
&if [NULL %error_status%] &then
&do
 /* display welcome message
 clear
 linetype wide
 linehollow 0
 linesize 0.08
 box 2.9 1.30 11.1 10
 linesize 0
 linetype hardware
 textcolor 1
 textsize 0.65
 textfont 93716
 move 5.3 9
 text 'WELCOME'
 move 6.5 8.35
 text 'TO'
 textsize 1.5
 textcolor 5
 move 3.4 6.3
 text 'FLOODEX'
 linecolor 1
 textcolor 1
 textsize 0.22
 move 3.4 5.2
 text ' A Rule-Based System for Crop Damage Estimation
from Fooding'
linetype wide
linehollow 0
linesize  0.02
```

Program: fxintro_screen.aml (contd..)

```
 box  3.2 5 10.8 5.5
 linesize 0
 linetype hardware
 textsize 0.25
 move 6.33 4
 text 'Release 1.0'
 move 4.9 2.9
 text 'Department of Agronomy and Soil Science'
 move 5.8 2.6
 text 'University of Hawai''i '
 textsize 0.20
 move 6.0 1.8
 text '   S.  G.  Hussain'
 textfont 94023
 shadesymbol 26
 patch 0.3 8 2.3 10
 mapext image floodex/floodex.rs
 maplimits 0.3 8 2.3 10
 mapposition cen cen
 image floodex/floodex.rs
 maplimits page
 linetype wide
 linehollow 0
 linesize 0.02
 box 0.3 8 2.3 10
 linesize 0
 linetype hardware
&end
&return
```

Program: floodex.aml

```
/*************************************************************/
/* Name          :    floodex.aml
/* Purpose       :    Main program that calls AMLs for
/*                    initializes some global variables.
/*Date           : 2/07/95, S.G.  Hussain
/*
/* Menu called : main
/*
/* Amls called : message and main.menu
/*
/* Called by    : fx.aml
/*************************************************************/
&thread &focus &off &others    /* to stop execution of FX.AML
&if not [show &thread &exists dialog_box] &then
&thread &create dialog_box
  &menu dialog_box &stripe 'MESSAGES' ~
   &pos 0 820 &size 1150 80
&r fxintro_screen
&r message 'Initializing FLOODEX.  Please Wait.'
/* Checks available program modules
&r message '- Checking Rules'
&s file = rules.aml
&if [null %file%] &then
  &r message 'RULES MODULES'
   &else
&do
  &r message 'READY'
  &r message ' '
&end
/* Display main menu FLOODEX
&menu fxmain &pulldown  ~
&stripe 'DEPARTMENT OF AGRONOMY AND SOIL SCIENCE   -
   UNIVERSITY OF HAWAI''I'

&pos &UC
&return
&thread &delete &self
```

Program: rules.aml

```
/*****************************************************
/* Name         : rules.aml
/* Purpose      :    Determines percent yield reduction
/*                   of rice due to submergence.
/* Date         : 4/03/1995, S.G.  Hussain
/*
/* Amls called : message
/*
/* Called by    : rules.menu
/*****************************************************
 &args file
&workspace ..floodex/floodex_out
&s file = fxresult.out
/*Do some error checking.
&if [null %file%] &then
  &return &inform No file name entered.
&s fileunit := [open fxresult.out openstat -a]
&if %openstat% ne 0 &then
&do
   &message ' Error opening file'
    &message ' '
  &return /*&error Error opening file.
&end

/*Rules for determining percent yield reduction of rice
/*due to flooding.
/*The global variables are: .Cr = crop, .Gr = growth stage,
/*.Ps = percent height of the plant submerged, .Cw = clarity
/* of flood water, .Sp = length of submergence, and .pcryld =
/* percent yield reduction.
&if %.Cr% = 1 and %.Gr% = 1 and %.Ps% = 1 ~
   and %.Cw% = 1 and %.Sp% = 1 &then; &s .pcryld := 10;
&if %.Cr% = 1 and %.Gr% = 2 and %.Ps% = 1 ~
   and %.Cw% = 1 and %.Sp% = 1 &then; &s .pcryld := 10;
&if %.Cr% = 1 and %.Gr% = 3 and %.Ps% = 1 ~
   and %.Cw% = 1 and %.Sp% = 1 &then; &s .pcryld := 0;
&if %.Cr% = 1 and %.Gr% = 4 and %.Ps% = 1 ~
   and %.Cw% = 1 and %.Sp% = 1 &then; &s .pcryld := 0;
&if %.Cr% = 1 and %.Gr% = 5 and %.Ps% = 1 ~
   and %.Cw% = 1 and %.Sp% = 1 &then; &s .pcryld := 0;
&if %.Cr% = 1 and %.Gr% = 6 and %.Ps% = 1 ~
   and %.Cw% = 1 and %.Sp% = 1 &then; &s .pcryld := 0;
```

Program: rules.aml (contd...)

```
:
:
&if %.Cr% = 1 and %.Gr% = 6 and %.Ps% = 3 ~
   and %.Cw% = 2 and %.Sp% = 6 &then; &s .pcryld := 100;

/*Write outputs to the file.
&s writestat := [write %fileunit%[unquote [quote ~
[format '%1,-6%%2,-6% %3,-3%%4,-3%%5,-3%%6,-3%%7,-3%'~
%.farm_name% %.pcryld% %.Cr% %.Gr% %.Ps% %.Cw% %.Sp%]]]]
&r message 'Determining percent yield loss'
/*Close the file unit
&s closestat := [close %fileunit%]
&r message 'Output added to fxresult.out file.'
&return
```

Program: a+inter.aml

```
/***********************************************************
/* File name :   a+inter.aml
/*
/* Purpose    :  Creates interface with AEGIS+ and FLOODEX
/*
/* Called by  :  fxmain.menu
/***********************************************************
/* Confirm Exit
&s choice = [GETCHOICE YES NO -prompt '  Enter AEGIS+?']
&if %choice% = NO &then
&return
/* Remove all threads except a+.aml, and return control to
fx.aml.
q
&workspace /usr2/aegis+
&r a+
```

Program. exit.floodex.aml

```
/*****************************************************
/* Name          : exit_floodex
/* Purpose       : Exit FLOODEX, asks for confirmation.
/*
/* Date          : 3/01/95, S.G.  Hussain
/* Amls called : thread_del_all
/* Called by     : main.menu
/*****************************************************
/* Confirm Exit
&s choice = [GETCHOICE YES NO -prompt '  Exit FLOODEX?']
&if %choice% = NO &then
   &return
/* Remove all threads except fx.aml, and return control to
/* fx.aml.
&r thread_del_all
&thread &focus &on &others
&return
```

Program: copy_result.aml

```
/******************************************************
/* Name          : copy_result.aml
/* Purpose       : Renames fxresult.out file in
/*                 ../aegis_cov/data to fxresult_out.old and
/*                 copies current output of FLOODEX to
/*                 ..aegis_cov/data directory.
/* Author        :  S.G.  Hussain; 6/10/1995
/* Called by     :  fxmain_menu
/******************************************************

&workspace /usr2/sk.aegis+/aegis_cov/data
&sys mv fxresult.out fxresult_out.old
&sys rm fxresult.out
&workspace /usr2/sk.aegis+
&sys cp /usr2/sk.aegis+/floodex/floodex_out/fxresult.out/
usr2/sk.aegis+/aegis_cov/data/fxresult.out
&r message 'Copying FLOODEX output to AEGIS+'
&r message '     '
&workspace /usr2/sk.aegis+/floodex
&return
```

Program: Retrieve_scene.aml

```
/********************************************************
/* Name         :  retrieve_scene.aml
/* Purpose      :  Retrieves a selected scenario,
/*                 renames it to fxresult.out
/*                 and copies to ..aegis_cov/data directory.
/* Author       :  S.G.  Hussain; 6/10/1995
/* Called by    :  fxmain_menu
/*******************************************************
&s .scene_sel := [GETFILE [UNQUOTE 'floodex_out/*scn'] -FILE
_NONE]
&sys mv %.scene_sel% fxresult.out
&r copy_result
&return
```

Program: view_scenario.aml

```
/***********************************************************
/* Name         :  View_scenario
/* Purpose      :  To view the selected scenario
/* Author       :  S.G.  Hussain; 6/10/1995
/* Called by    :  fxmain_menu
/***********************************************************
&s  .scene_sel := [GETFILE [UNQUOTE 'floodex_out/*scn'] -FILE
_NONE]
&sys textedit %.scene_sel% -Wp 239 65 -Ws 595 635 &
  &return
```

Program: print_scenario.aml

```
/**********************************************************
/* Name         :  print_scenario
/* Purpose      :  To print the selected scenario
/* Author       :  S.G.  Hussain; 6/10/1995
/* Called by    :  fxmain_menu
/**********************************************************
&s.scene_sel := [GETFILE [UNQUOTE 'floodex_out/*scn'] -FILE
_NONE]
&sys lpr %.scnene_sel%
```

Program: thread_del_all.aml

```
/***********************************************************/
/* Name        : thread_del_all.aml
/* Purpose     : To remove focussed menus
/* Author :  S.G.  Hussain; 6/10/1995
/* Amls called : none
/* Called by   : exit_floodex
/***********************************************************/
/* to remove remaining menus
&if [show &thread &exist FACTORS]  &then
    &thread &delete FACTORS
&if [show &thread &exist FLOODEX2] &then
    &thread &delete FLOODEX2
&if [show &thread &exist RETRVSECENE] &then
    &thread &delete RETRVSECENE
&if [show &thread &exist SAVESCN] &then
    &thread &delete SAVESCN
&if [show &thread &exist VUSCENERIO] &then
    &thread &delete VUSCENARIO
&if [show &thread &exist PRINTSCENE] &then
    &thread &delete PRINTSCENE
&if [show &thread &exist COPYSCENARIO] &then
    &thread &delete COPYSCENARIO
```

Program: dialog_box.menu

```
/************************************************************
/* Name    : dialog_box.menu
/* Purpose : Display messages
/************************************************************
7
 %line
/* %dialog display .message_icon 6 ICON
%line INPUT .view_line 160 ROWS 2 SCROLL YES TYPEIN NO KEEP
INITIAL ~ %.dialog_line9% CHOICE ~
%.dialog_line1% ~
%.dialog_line2% ~
%.dialog_line3% ~
%.dialog_line4% ~
%.dialog_line5% ~
%.dialog_line6% ~
%.dialog_line7% ~
%.dialog_line8% ~
%.dialog_line9%
%FORMOPT SETVARIABLES IMMEDIATE
```

Program: fxmain.menu

```
/*************************************************************
/* Name     : fxmain.menu
/* Purpose      : FLOODEX main menus
/*
/* Author :  S.G.  Hussain; 4/10/1995
/*
/* Called by    : floodex.aml
/*************************************************************
1   Main menu
' Flood Scenario Menu'        &thread &create FACTORS
                                   &menu rules.menu
'              '
'              '
'  AEGIS+ Interface  '        &thread &create FLOODEX2
                                   &r a+inter
'            '
'            '
'  Scenerio Manager  '
     'Retrieve Scenerio'      &thread &create RETRVSECENE
                                        &r retrieve_scenario
     'Save Scenerio'          &thread &create SAVESCN &menu
                                   savescn.menu
     'View Scenerio'          &thread &create VUSCENARIO &r
                                   view_scenario
     'Print Scenerio'         &thread &create PRINTSCENE
                                        &r print_scenario
    'Copy Scenerio to AEGIS+' &thread &create COPYSCENARIO
                              &r copy_results
'            '
'            '
'  Utilities  '
    'Text Editor'             &sys textedit -Wp 230 100 -Ws
                                   600  650 &
    'Command Tool'            &sys cmdtool -Wp 230 100 -Ws
                                   700 500    &
    'File Manager'            &sys filemgr -Wp 0 450 -Ws
                                   1140 400   &
    'Print Tool'              &sys printtool -Wp 230 100 -Ws
                                   500  450 &
    '      '
'  EXIT   '                   &r exit_floodex
```

Program: flood_scenario.menu

```
/*****************************************************
/* Name     : flood_scenario.menu
/* Purpose :  Assign flood factors input menu
/*****************************************************
7  Assign factors menu
   ENTER THE POLYGON NUMBER %farm_name
______________________________________________________

   1.  SELECT ONE CROP
      %crops
______________________________________________________

   2.  SELECT THE GROWTH STAGE
      %growth
______________________________________________________
    3.  SELECT THE LEVEL OF SUBMERGENCE
      %level
______________________________________________________
    4.  SELECT THE CLARITY OF WATER

      %clarity
______________________________________________________

    5.  SELECT THE PERIOD OF SUBMERGENCE

      %period
______________________________________________________
        %ok                                %clear
/* field definition
%farm_name INPUT .farm_name 5 required INTEGER
%crops CHOICE .Cr PAIRS  Rice 1 Wheat 2 Jute 3
%growth CHOICE .Gr PAIRS '40 DAS/10DAT' 1  'Maximum
   Tillering' 2 'Panicle  Initiation' 3  'Heading' 4
   'Grain Filling' 5 'Physiological Maturity' 6
%level CHOICE .Ps ' 25 to 50 percent' 1 ' 50 to 75 percent'
   2 ' 75 to 100 percent' 3
%clarity CHOICE .Cw PAIRS Clear 1 Turbid 2
%period CHOICE .Sp PAIRS '5 days' 1 '7 days' 2 '10 days' 3
'15 days' 4 '20 days' 5 '> 20 days' 6
%OK  BUTTON return 'Assign to Polygon' &r rules.aml
%Clear BUTTON return 'Exit Menu' &return
%formopt SETVARIABLES IMMEDIATE
```

Program: Scenario_man.menu

```
/*************************************************************
/* Name     : Scenario_man.menu
/* Purpose      : Menu that asks for saving the output as
                flood scenario file.
/* Author       :  S.G.  Hussain; 6/10/1995
/*************************************************************
*
7 scenario.menu
   ENTER scenario NAME:
   Source scenario Name     : %1
   Target scenario Name     : %2
    __________________________________
   *                                  *
   *  File extension is automatically *
   *  'scn' for the scenario file.    *
   *__________________________________*
         %3                %4
%1 DISPLAY fxresult.out 23
%2 INPUT .new scenario 21 keep return ~
    &s .new scenario CHARACTER
%3 button ' OKAY ' &r save_scenario
%4 button "EXIT MENU' & return
%formopt SETVARIABLES IMMEDIATE
% forminit
&s .new scenario
```

GLOSSARY

Aus rice - This is a fixed maturing, photoperiod-insensitive group of rice varieties. In Bangladesh this crop is mainly rainfed and dry-seeded but when adequate rainfall and irrigation is available the crop is also transplanted. Aus rice seedling is transplanted during March-April and harvested during July-August. The field is usually transplanted with 30-day old seedlings.

Boro rice - Photoperiod insensitive winter irrigated rice transplanted in December to January and harvested in April - May.

Broadcast (B.) Aman rice - This rice is also known as deepwater rice (DW rice) in Bangladesh. Traditionally, this rice is direct-seeded under dryland condition during the premonsoon period (March to April) in the deepwater (1 to 4 m deep) areas. But, recently with changes in the cropping pattern, this rice is also transplanted during May to June. In both cases, after establishment of the crop, the plants grow with rising floodwater and settles to the ground when the water subsides. The rice crop is photoperiod sensitive and harvested during October to December.

Kharif season/crops - The monsoon season is from April to September in Bangladesh. Crops grown during this time are known as kharif crops. Examples are Aus rice, Aman rice, and jute.

NVI *(Normalized Vegetation Index)* - The most commonly used vegetation index in remote sensing study. The band ratio combinations for NOAA satellite sensors are- the numerator is the near infrared band and the denominator the red. Normalized Vegetation Index is given by the following equation (Schneider, *et al.*, 1985)

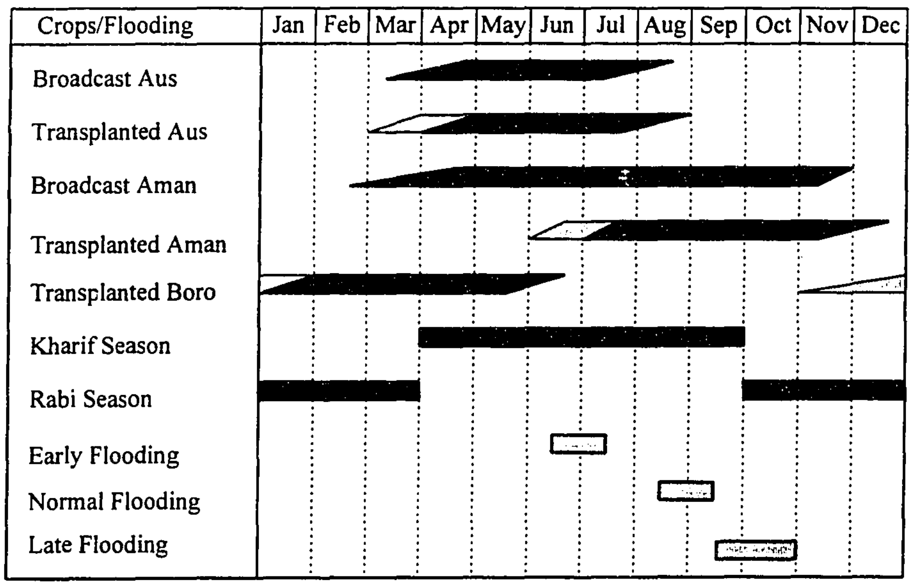
$$\text{NIV}= \frac{\text{AVHRR2} - \text{AVHRR1}}{\text{AVHRR2} + \text{AVHRR1}}$$

Rabi season/crops - The dry season is from October to March in Bangladesh. Crops grown during this time are known as rabi crops. Examples are wheat, chickpea, lentil, and mustard.

Thana - An administrative unit of Bangladesh comprising of several "unions" which in turn, are composed of several villages.

Transplanted (T.) Aman rice - A group of traditional photoperiod-sensitive rice varieties transplanted in July - August and harvested in November - December. Photoperiod-insensitive varieties have recently become available and are also cultivated during T. Aman season.

Crop and flooding calendar of Bangladesh.



= Seed bed

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