DEVELOPMENT OF DECISION SUPPORT SYSTEM FOR WATER RESOURCES PLANNING IN A WATERSHED

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **DEVELOPMENT OF DECISION SUPPORT SYSTEM FOR WATER RESOURCES PLANNING IN A WATERSHED** in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy and submitted in the Department of Water Resource Development and Management of the Institute is an authentic record of my own work carried out during a period from January, 2003 to July, 2006 under the supervision of **Prof. U. C. Chaube, Dr. Deepak Khare** and **Prof. P. K. Garg**.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other University/Institute.

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ABSTRACT

Watershed management is one of the promising approaches for management of water resources in arid and semi-arid Indian ecosystems. The gap between demand and supply of water in these areas is growing with the population. The real challenge on water resources planning at micro level is to assess the quantum of water demand and availability. This is due to unavailability of adequate database. Watershed based planning considering the availability of water resources and demand for all purposes is being considered as the most appropriate approach.

Watershed-based planning aims at management of water resources of area (often micro watershed). This approach as far as possible helps in meeting the local water requirement from available water resources. In-situ retention of rainfall, groundwater recharge, water harvesting in ponds and keeping balance between optimal water use and replenishment of water resources during the year are major activities proposed in this concept.

From the wide literature and other resources available on the Decision Support Systems (DSSs), it is found that most of the DSSs developed are either area specific or problem specific. Many DSSs have been reported on river basin and reservoir planning and management. Some of the DSSs available in the watershed concentrate on environmental problems, such as pollutant load and water quality. The watershed-based water resources planning approach can be implemented by demonstrating and developing software-based DSS with user friendly GUI so that, it is readily adopted by the decision makers. Keeping this in view, a DSS was developed in the present study for water resources planning in a watershed.

In accordance to the research objective, the essential characteristics of a DSS, as appropriate for water resources planning on watershed basis are first identified. A comprehensive search on models and methods of various components of watershed hydrology was done keeping in view their data needs and type of output generated. The NRCS CN and CELTHYM models have been used in the surface water assessment, while Rational method has been used for storm runoff estimation. For groundwater recharge assessment GEC norms of 1997 have been implemented in the DSS. The bunds and terraces have been used in the soil and water conservation structures module. The dugout type water harvesting ponds have been considered for retention of surface runoff in the watershed. The prototype DSS developed for water resources planning has been demonstrated for small hilly "Khadak Ohal" watershed in Nashik district of Maharashtra, India

An interactive DSS was developed using the object oriented programming language, MS Visual Basic (VB) 6.0. An ActiveX control, MapObjects was used to make DSS to input and assess spatial data in the interfaces of DSS. Before programing of DSS, various methods and models were selected from wide range of models available, depending on input data requirements, popularity and simplicity and output. The spatial and non-spatial database was created for the study area to form the database component of DSS. The interfaces were then developed separately for each model, called module in DSS. The various modules of Basic Data, Rainfall, Runoff, Evapotranspiration, Forecasting, Groundwater Recharge, Morphometry, Water Conservation and Water Use Planning were developed. The developed software platform is a prototype of the **Decision Support System for Water Resources Planning in Watershed**, which has been abbreviated and called as **DSS-WRPW**.

The study fulfils its objectives for the development of DSS for water resources planning considering the needs of the habitants. The DSS developed in the study is user friendly, and has capability to handle both the spatial and non-spatial data as input. A methodology for ordering of streams (Strahler's configuration) has also been developed and implemented in the separate GUI, which takes the vector format of spatial data as input. On the basis of this, geomorphological parameters of the watershed have been extracted. Water resources assessment (Surface & Groundwater) models have been implemented in GUIs and applied for the watershed. Two modules in each part i.e. surface (NRCS CN and CELTHYM) and ground water (Rainfall Infiltration and Water Table Fluctuation) have been developed further.

An interactive module has been developed for habitant population forecasting. This module also gives water and food/fodder demand for the year of forecast. Two modules have been developed to estimate the potential evapotranspiration in the watershed, based on the data input, i.e. one, which needs detailed climatic data (Penman-Montieth) and the other, which requires minimum input data (Hargreaves-Samani). The module for estimating agricultural water demand has been developed and demonstrated. A decision module has been developed for suggesting the water conservation structures, which gives the length of contour bunds, graded bunds and bench terraces.

A policy for operational planning (fortnightly) of water resources has been formulated and implemented through integration of all GUIs and modules in a separate decision making module. The working of this module has been demonstrated with different scenarios in the existing and future conditions. In the exiting conditions combination of Water Table Fluctuation and Penman-Montieth models produced the maximum water surplus after fulfilling all water demands. In the future system of watershed the combination of NRCS CN, Penman-Montieth and Rainfall Infiltration models produced the maximum water surplus after meeting all water demands in the watershed.

The study has integrated spatial technologies, hydrological models and water resources decision policies in the form of platform independent software, which does not require any conventional GIS package. In general, study has successfully demonstrated the application of DSS for water resources planning in a watershed, which may be useful to agriculturists, water resources planners and decision makers.

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(Kishor Anil Dhore)

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ABBREVIATIONS USED

.shp	Shape File
AGNPS	Agricultural Non Pollution Source
AI	Artificial Intelligence
AMC	Antecedent Moisture Condition
AML	Arc Macro Language
API	Application Programming Interface
BA	Bottom Area
BIS	Bureau of Indian Standards
CAD	Computer Aided Design
CLETHYM	Cell-based Long-Term Hydrological Model
CN	Curve Number
COM	Component Object Model
CWR	Crop Water Requirement
DBMS	Database Management System
DEM	Digital Elevation Model
DGMS	Database Generation System
DSS	Decision Support System
E	East
EC	European Commission
EDP	Electronic Data Processing
EDSS	Environmental Decision Support System
EML	Executable Modelling Language
ES	Expert System
ESRI	Environmental System Research Institute
ET	Evapotranspiration
ET_0	Reference Crop Evapotranspiration
FAO	Food and Agriculture Organization
FC	Field Capacity
FID	Field ID
GEC	Groundwater Estimation Committee
GIS	Geographical Information System
GML	Grass Modelling Language

GMS	Groundwater Modelling System
GUI	Graphical User Interface
GW	Groundwater
ha	hectare
ha-m	hectare meter
HDT	Hasse Diagram Technique
HEC	Hydrologic Engineering Corps
HI	Horizontal Interval
hr	hour
HS	Hargreaves-Samani
HTML	Hyper Text Mark Up Language
IARI	Indian Agricultural Research Institute
ICMR	Indian Council of Medical Research
IMP	Irrigation Management Plan
IRS	Indian Remote Sensing Satellite
IWRM	Integrated Water Resource Management
KINEROS	Kinematic Runoff and Erosion Simulation Model
km	kilo meter
km^2	kilo meter square
LISS	Linear Imaging Self Scanner Sensor
Lit	litre
LSU	Live Stock Unit
m	meter
m^2	meter square
Max	Maximum
MCA	Multi Criteria Analysis
MCDM	Multi Criteria Decision Making
mDSS	Mulino DSS
Min	Minimum
MIS	Management Information System
MS	Microsoft
MSFlexGrid	Microsoft Flexible Grid
N	North
NBSSLUP	National Bureau of Soil Survey and Planning

NRCS	Natural Resource Conservation Service
ODBC	Open Database Connectivity
OFR	On Farm Reservoir
OLE	Object linking and Embedding
OOP	Object Oriented Programming
PET	Potential Evapotranspiration
PSE	Problem Solving Envoirnment
RDBMS	Relational Database Management System
RF	Rainfall
RH	Relative Humidity
SCS	Soil Conservation Service
SDSS	Spatial Decision Support System
SFR	Small Farm Reservoir
SOI	Survey of India
SW	Surface Water
SWAT	Soil and Water Assessment Tool
SWMM	Strom Water Management Model
TA	Top Surface Area
TIN	Triangulated Irregular Network
TSA	Total Side Area
TUI	Technical User Interface
UK	United Kingdom
URL	Universal Resource Locator
USA	United States of America
USLE	Universal Soil Loss Equation
V	Volume
VB	Visual Basic
VBA	Visual Basic for Applications
VC^{++}	Visual C++
VI	Vertical Interval
WHP	Water Harvesting Pond
WMDSS	Watershed Management Decision Support System
WP	Wilting Point

CHAPTER 1

INTRODUCTION

1.1 Watershed Based Water Resources Planning

The gap between demand and supply of water in arid and semi-arid areas is growing with increasing population. This is the scenario at macro level. The challenge on water management at micro level is to make reliable assessment of water demand and availability with inadequate data. Developed and developing countries have different perception about objectives of watershed management (Reddy, 2000). Developed countries usually focus on environmental concerns, while later focus on resources generation and their management.

Watershed based management is a common approach for management of water resources in arid and semi-arid Indian ecosystems (Sarangi et al., 2003). Properly executed watershed management programmes can lead to an increased availability of utilizable natural resources. Retaining rainwater which would otherwise become runoff can improve the soil moisture availability for crops and other plants or recharge groundwater aquifers and provide life saving supplementary irrigation as well as increase dry season stream flows. This is generally achieved by conservation of runoff through either constructing physical structures (bunds, check-dams etc.) or through agronomic measures. This can significantly improve water retention by enhancing infiltration capacity of soils, in addition to the reduction in sediment load (Singh, 1994).

It is important to recognize that the problems of managing resources within a watershed do not arise necessarily from physical limitations or from lack of technical knowledge. Over exploitation of resources, deforestation practices, shifting cultivation and uncontrolled livestock grazing are well known to have adverse impacts on soil and water resources. Such problems have often been attended using adhoc approach and only after severe degradation of resources have taken place in a watershed. Substantial decrease in productivity of land is an indication of degradation of soil, while water table depletion is related to groundwater. Deforestation and livestock grazing result in loss of natural vegetation, thereby failing to trap the rainfall in watershed boundary (Singh, 2000). The further impact of this is flood aggravation and heavy siltation in reservoirs in downstream. As a result of which inadequate drinking water supply also becomes acute in the non-monsoon period.

It has been demonstrated through a number of watershed management projects that the requirements of water, fuel, fodder and food can be better managed locally in the watershed (Singh, 2000). This requires a unified approach with technology, vision and commitments towards watershed development. The development of land and water resources within the watershed to meet water, food and fodder requirements may take a long period. Unfortunately, watershed management programmes as perceived in India often have short-term project-based objectives. They focus on immediate and popular concerns such as employment generation and drought relief measures. However production and conservation of the resources on watershed lands are dependent upon long-term and extensive commitments.

Technology is available to solve many watershed problems. However, methods are further needed to effectively demonstrate the benefits of instituting environmentally sound watershed management programmes. The major problem is faced related to availability of adequate database and methodology (Sarkar and Singh, 1997). Watershed based water resources planning considering the availability of water resources and demand for all purposes is being advocated as most appropriate approach (Singh, 1997; Singh and Bhattacharya, 1998).

Watershed based water resources planning aims at management of water resources of the area (often micro watershed) in such a way, so as to meet the local water requirement from the available water resources within the watershed. In-situ retention of rainfall, groundwater recharge, water harvesting in ponds and keeping balance between optimal water use and replenishment of water resources during the year are major activities proposed in this concept. Temporal assessment of water availability and demand during the year and planning conservation strategies are major tasks in the watershed planning and management. These tasks are often ill-structured which makes the decision making problem complicated. Effective solution of these problems requires the integration of theory, data, simulation models and expert judgement. This provides a scientific basis for decision making at watershed level due to its holistic nature of resource management system comprising of inter-related elements of soil, water and social factors. The need of computerized Decision Support System (DSS) is clearly emerging to support the decisions regarding the planning of water resources at watershed level.

1.2 Decision Support System

Several definitions of DSS have appeared in literature. Andriole (1989) has defined decision support as consisting of "any and all data, information, expertise or activities that contribute to option selection". Adelman (1992) has defined DSS as interactive computer programs that utilize analytical methods, such as decision analysis, optimization algorithms, program scheduling routines, and so on, for developing models to help decision makers to formulate alternatives, analyze their impacts, and interpret and select appropriate options for implementation.

DSS is a computer based system of integration of database, models and user interface which are programmed for easily interpretable results to aid the decision makers (Walsh, 1993). DSS is essentially a system that consists of information and tools which interprets that information in a form more readily integrated into decision-making processes (Zhu et al., 1996). Most recently DSS has been defined as a computer based information system whose primary purpose is to provide knowledge workers with the information on which informed decisions are based (Mallach, 2002).

A DSS is both a process and a tool for solving problems that are too complex for human alone, but usually too qualitative for only computers. Multiple objectives can complicate the task of decision-making, especially when the objectives conflict. As a process, a DSS is a systematic method which considers all objectives and evaluates options to identify a specific solution that best solves an explicit problem while satisfying as many objectives as possible.

DSS have been used to develop water resources management plans, adaptable operating rules for water and wastewater systems, and in formulating regional policies. Many local governments and authorities often derive their water supplies from several sources, which may include surface reservoirs, rivers, groundwater wells or combinations of these sources. To identify the best combination of supply sources in long term, or to determine the most effective way of managing existing systems, decision-makers need a large amount of information to account for hydrologic, hydraulic, water quality, economic, and other aspects within the system.

As a tool, a DSS consists of mathematical models, database, and graphical user interfaces that connect decision-makers directly to the models and data and scientific decisions. A DSS collects, organizes, and processes information, and then translates the results into comprehensive management plans (Walsh, 1993).

A DSS is much more comprehensive than the traditional methods of decision-making in water resources management. DSS recommendations are based on scientific data and models depending on the objectives, cause-effect relationships, risks, costs, and reliability, whereas traditional decision processes have had difficulty aggregating all of these considerations (Watkins and McKinney, 1995).

DSS programs are adoptable; they are custom-designed for specific systems to achieve management objectives. Since a DSS is a reproducible method of decision-making, it can be used in the repetitive decision making processes. A computer model is often seen as a black box, but in the case of a DSS, a graphical interface links the decision-makers with the models. Decision-makers can set up scenarios and even view the modelling relationships. Finally, a DSS may present management plans in a tabular, graphical or spatial format rather than generating it in cryptic form (Mallach, 2002).

A Geographical Information System (GIS) is considerably more than what most people would think of as a single computer program, it is in fact a whole system that organizes the various activities of acquiring, storing, manipulating and displaying spatial data. These capabilities along with analytical capabilities make the GIS as a Decision Support System (Murphy, 1995). The integration of GIS into DSS has been termed as Spatial DSS (SDSS) (Walsh, 1993).

1.3 Background of the Study

The watershed management tasks required at the planning stage can be classified by management activities and management system elements. The management activities involve land use assignment, on site resources utilization and management practices. The management system consists of resources management actions, implementation tools, institutional assignments. Choosing the right combination of all activities is key to planning and involves a complex decision making. Most of the available DSS are either area specific or problem specific. Many DSS have been reported in literature on river basin and reservoir planning and management. A few watershed related DSSs are also available which concentrate on environmental problems, such as pollutant load and water quality assessment.

The common approach to watershed management in India is based on utilization of natural resources within the watershed. Objectives of watershed management may vary according to interest groups and implementing agencies (water users, agriculturists, foresters). The watershed based water resources planning approach can be implemented by demonstrating and developing software based DSS with user friendly Graphical User Interface (GUI) if it is to be readily adopted by the decision makers.

1.4 Objectives

The main objective of the study is to develop the DSS for water resources planning in a watershed. This can be divided into various parts (i) water availability assessment, (ii) water demand estimation and, (iii) operational planning of water resources. Besides these a module can be included to suggest the length of contour bunds, graded bunds and bench terraces. A watershed geomorphology module can form a supplementary module, which can be useful in the characterization watershed. The specific tasks or objectives of the study can be outlined as follows:

1. Development of graphical user interface to extract the geomorphological characteristics of a watershed.
2. Development of graphical user interface for assessment of water resources in a watershed.
3. Interactive assessment of water demand for all sectors in a watershed.

4. Development of module for operational planning of water resources.
5. Development of DSS by integrating all interfaces and modules.
6. Demonstration of developed DSS for a selected watershed.

1.5 Scope of the Study

The study is focused on the development of DSS for water resources planning in a watershed. The watershed based water resources planning comprise three major tasks viz; assessment of available water resources, assessment of water demands and allocation of water between various demand sectors. To implement these three tasks different GUIs or modules are needed. Prior to this various alternatives of DSS development were explored and embedded coupling approach has been used with VB 6.0 and MapObjects. This makes the DSS compatible for assessing and displaying the spatial data. The conceptual diagram framed for the study is given in Chapter three (Fig 3.7). The various modules proposed in this study are as given below.

1. The GUI for geomorphological characterization of watershed is to be developed. This is needed as supplementary module to the user. This will be helpful in the runoff assessment from unguaged watershed and deriving watershed prioritization indices.
2. The water resources availability assessment part comprises of two different modules for surface runoff estimation and groundwater recharge assessment. The runoff module has two sub-modules (NRCS CN and CELTHYM). Similarly groundwater recharge module has two sub-modules (Water Table Fluctuation and Rainfall Infiltration).
3. The GUI has to be developed for population forecasting and for estimation of water, food/fodder requirement. Two sub-modules of PET estimation i.e. Penman-Montieth and Hargreaves-Samani are implemented in evapotranspiration module. These are further used in the estimation of agricultural water requirement.

4. The water use allocation policy is required in the final decision making for water resources planning. Therefore a module is required for this purpose.
5. Besides these modules, a module is employed in the DSS for suggesting the length of contour and graded bunds, bench terraces. It also contains a sub-module for water harvesting ponds.

The Khadak Ohal watershed is considered to demonstrate the applicability of developed DSS in the present study. A GIS database generated for this watershed is used as input. Several scenarios can result from different combination of models. In present study model combination provide four scenarios in the context of data availability.

1.6 Organization of Thesis

Thesis has been divided according to the structure of the DSS i.e. model base, database, and user interface developement. The contents of the each chapter are briefly described below:

Chapter two presents the literature review related to the DSS applications in the water resources management. This chapter covers watershed planning and management, use of Remote Sensing (RS) and Geographical Information Systems (GIS) in watershed studies and GIS based interfaces of hydrological models.

Chapter three is devoted to various alternatives of the DSS developement and architectures, methods of coupling of models and GIS with the interfaces. Conceptual framework of proposed DSS has also been given at the end of the chapter.

Chapter four describes the profile of study area. The general characteristics have been described in detail.

Chapter five gives the details of models and methods used in development of the interfaces of DSS. Each model used in the study has been described with their formulae, associated data and the assumptions.

Chapter six presents the methodology of generation of spatial database with source of particular data and software used. Various thematic layers needed as an input to various models and methods have been discussed.

Chapter seven enumerates the methodology for GUI development for all models used in the study.

Chapter eight illustrates the scenario analysis approach; two cases have been presented in the demonstration part of the developed DSS. At the end, conclusions drawn and recommendations made are presented in the chapter **nine**.

Extensive programming has been done to develop the DSS for water resources planning in watershed using Visual Basic 6.0 with MapObjects. The programming source codes have been given in appendices of the thesis (Compact Disc).

CHAPTER 2

LITRATURE REVIEW

2.1 Prelude

This chapter deals mainly with the available literature on application of DSS in the water resources management. Emphasis has been placed on discussion of various general aspects of DSS, watershed management and use of remote sensing and GIS in watershed studies. Many hydrological models have come up with the interface to handle the GIS data, which relevant to the present study have also been included.

2.2 Watershed Planning and Management

There are two area developement approaches in the field of rural and agricultural development (i) command area developement and (ii) watershed area development (MoA, 1990) or watershed management. In other word there can be two approaches in particular to the water resources development (i) at macro level and (ii) another at micro level (Sharma and Singh, 2002). The watershed area developement approach is suitable in the rainfed areas, which can be termed as micro level approach. Watershed management aims to establish a workable and efficient framework for integrated use, regulation and development of land and water resources in a watershed for socio-economic growth. For an equitable and sustainable management of shared water resources, flexible and holistic approach of Integrated Water Resources Management (IWRM) is required, which can cater to hydrological variations in time and space and changes in socio-economic needs along with societal values. Watershed is the unit of management in IWRM, where surface water and groundwater are inextricably linked and related to land use and management (Kumar et al., 2005).

IWRM approach is often considered as holistic approach of watershed management and development. There are few watersheds in India, which have been developed considering IWRM approach. The Sukhomajri/Nada (Haryana), Facot (Uttaranchal), Ralegoan Siddi (Maharashtra) and G. R. Halli (Karnataka) have popularised the watershed approach. The actual work involved plantation, erosion control, water harvesting and adoption of appropriate cropping systems and water management practices (Druva Narayana et al., 1997). Besides this, many researchers across the nation have reported watershed management studies. Few of them in particular to water resources developement and planning in a watershed have been discussed below.

In–situ retention of rainfall in the catchment areas is the first step in the process of water resources development. Soil and water conservation measures such as mechanical and vegetative are very helpful in the retention of rainfall in the watershed (Tejwani and Dhruva Narayana, 1960). These measures help in retention of runoff water, resulting in maintaining the hydrological phenomenon/soil moisture regime and create the same situation provided by natural vegetation (Singh, 2000). Hydrological behaviour, under different watershed based land use systems are reported to behave alike at contrasting situations, attributing efficacy of soil and water conservation measures that resulted in enhancing the process of in-situ retention of rainfall (Singh, 1994; Singh and Solanki, 1994). Hazra (1990) reported significant change in water resources availability for irrigation in a watershed at Tejpura as result of adoption of soil and water conservation measures in 776 ha area.

Dhyany et al., (1993) showed the possibility of integrated development that has potential of water resources developement at micro level integrating it with the production activity within a watershed. Satapathy (2000) reported a water resources developement in hilly micro watershed in the Meghalaya through retention of runoff in the water harvesting ponds. He further gave the water balance in the water harvesting ponds. Mishra et al., (2002) identified and proritised the natural resources management problems in the same watershed. Bangar and Sthool (2004) studied the impact of watershed developement programme in a village of Maharashtra state, India through number of soil and water conservation structures and increase in groundwater availability after implementation. Das (2005) assessed the hydrological status of the watershed from the land retention and groundwater recharge in the Gujarat. This provided an approach and some principles used in the assessment of hydrologic condition of the watershed after implementation of conservation measures.

Water harvesting, though an old age practice, is emerging as a new paradigm in water resources development and management in the rainfed areas. The success of Sukhomajri, Ralegaon Siddi and Tarun Bharat Sangh are telling us loud and clear about the importance of water harvesting and watershed management (Samra et al., 2002). The term water harvesting was probably first coined by Geddes (1963) as "the collection and storage of any form of water either runoff or creek flow for irrigation use". Water harvesting systems though initially developed for arid and semi-arid regions, now being extended to sub-humid and humid regions (Verma and Tiwari 1995).

In India, a lot of work has been done on evaluation of farm pond for irrigation purposes using different crops in different part of the country. However, little efforts have been made on its design. As a result, no suitable design criteria are available to the farmer in different rainfed-areas in the country (Sharma and Bhattacharya, 2005).

Water harvesting ponds (WHP) are suitable in mildly rolling landscape with heavy soils where runoff collection and storage are convenient and where the lower fields can be irrigated by gravity flow. However, the technology can also be adopted in flat areas using suitable and economic water lifting devices, (Moya et al., 1994). Excavating type WHP can be constructed in varying top sequence, which is a common situation prevailing in farmer's field. It is generally constructed at the lowest area of micro watershed where a higher water storage capacity per unit volume of earthwork is achievable (Sahu, 1999). The ponds located at such places may have storage and excavation ratios ranging from 5 to 20 (Singh, 1983). The ideal location of WHP is in the middle of watershed so that a sizable amount of runoff collected in WHP is used for irrigating lower areas by gravity flow (Radder et al., 1995). Tanks designed with elevated inlet store water partly in the excavated portion and partly above ground. It increases the storage to excavation ratio, reducing the cost of construction (Helweg and Sharma, 1983).

The most economical shape of the WHP is an inverted truncated cone with circular cross section, as it gives least surface area for evaporation and minimum wetted perimeter for seepage when compared to other shapes (Helweg and Sharma, 1983). The rectangular shape of pond is more practical because it is easy in construction and lining. The circular ponds have the highest storage capacity and have least circumferential length for a given surface area and side slopes (Radder et al., 1995). Helwag and Sharma (1983) developed a nonlinear optimization model to design the capacity of tanks for semi arid tropics of India. The model is based on the considerations of tank shape as an inverted truncated- cone and trapezoidal dyke, annual amount of irrigation application, elevated inlet and minimization of the total cost of excavation.

Verma and Sarma (1990) developed a procedure to design a tank for water harvesting and compute its benefit cost ratio for a region in northern Punjab. It was observed that the total cost of tank per unit capacity decreased with increasing tank capacity. They found that as probability level increases, the tank size decreases and available water per unit of tank capacity increases. The best probability levels were selected for optimum tank design corresponding to the lowest cost of unit available water at the time of irrigation and it was found to vary from 40 to 80% for various size of catchments. Bhandarkar and Nimje (1996) found that the dugout pond of 3 m depth having 2.2 ha-m storage capacity was economically viable for a watershed area of 6 ha in vertisols areas of Bhopal With the water stored in pond, 50% of watershed area could be irrigated twice during *kharif* and two irrigations could be given to the entire watershed area during *rabi.* The loss through evaporation and seepage varied from 38 to 68% of stored water depending on storage time of 3.5 to 6.5 months.

Panigrahi et at., (2000) developed a daily simulation model to determine the size of on farm reservoirs (OFR) that enables the farmers to provide supplemental irrigation to paddy. Sahu (2000) proposed alternative designs of small farm reservoir (SFR) at four levels of probability of exceedence viz. 80, 75, 60 and 50% using model (CN method) outputs (runoff) and other hydrologic parameters of micro watersheds. The water-spread area of SFR with 3.0 m depth was found to be 10 to 12.5% and 13.5% of the micro watershed (MW) for plains and plateau, respectively. Srivastava (2001) gave the methodology for design of water harvesting system for high rainfall areas in India.

Water losses from WHP comprise mainly of seepage, both horizontal and vertical, and evaporation losses. Of these, seepage loss is the main problem especially in the regions where the sub-soil is permeable. Seepage control under such condition is essential to store water in WHP for supplemental irrigation. In new dugout pond in laterite soil, seepage losses may be as high as 18.56 lit/hr/m^2 (Kale et al., 1986).

The micro-watershed based management and maintenance of water harvesting structures was widely accepted practice in India. But the introduction of private land ownership through various settlements by the British Government in the eighteenth century alienated local community from collective efforts towards the betterment of these structures (Prasad and Sharma, 1994). Mbajiorgu (1995a) developed a Watershed Resources Management (WRM) and applied it to a Upper Wilmot Watershed (Mbajiorgu, 1995b). Traditional knowledge and experience in managing and developing water resources within a watershed were, thus, lost as a result of adopting a developemental strategy to make quick gains without considering adverse impact on environment (Sharma, 1998). Experiences during the last one decade indicate the possibility of watershed based water resources developement and management considering the availability, demand, and water use systems in an integrated manner (Sharma and Singh, 2002). This concept has been proved successful for the urban watershed (with an area of 1032 ha) in IARI, New Delhi, where water demand of 942 ha-m can be met out from the 1132 ha-m of total available water. Reddy (2000) demonstrated the watershed based water resources developement concept for watershed in Nagpur, Maharashtra. Ingle (2001) reported that water demand could be met out similarly from the available water resources in the Shikohpur watershed in Haryana.

2.3 Use of Remote Sensing and GIS in Watershed Studies

Remote sensing and GIS are playing a rapidly increasing role in the field of hydrology and water resources development. GIS in combinations with the space technology or remote sensing inputs have been particularly successful in the area of water resources assessment, flood management (Mason et al., 2003) and irrigation water management (Sah et al., 1997; Goel 2002). The relational database management, spatial data visualization and spatial and non spatial data handling capabilities have been instrumental in the increased use of GIS in watershed studies (Wilson et al., 2000). The remote sensing data in combination with GIS is being used in India for long time. The applications of these techniques have been found in nearly all fields of watershed hydrology, such as estimation of soil erosion (Chandramohan and Durbude, 2002; Jasrotia et al., 2002; Jain and Kothyari, 2000; Jain and Goel, 2002), watershed prioritization and geomorphologic studies (Raju et al., 2002; Kaur and Datta, 2002; Katpayal and Dube, 2003), rainfall runoff modelling (Tripathi et al., 2002; Pandey and Dabral, 2004; Shrivastava et al., 2004). The GIS and remote sensing applications have also been reported in the area of groundwater prospects zoning (Anbazhagan, 2005; Khan and Mahorana, 2002).

Remote sensing provides very useful methods of survey, identification, classification and monitoring of several forms of earth resources, and also helps in acquisition of short time at periodic intervals (temporal), at different wavelength bands (spectral) and covering large area (spatial) (Tripathi et al., 2002).

The GIS has got the two basic data types (i) vector data and (ii) raster data. There are other data types such as Digital Elevation Model (DEM), Triangulated Irregular Network (TIN), which have been found extremely useful in hydrological modelling studies (DeVantier and Feldman, 1993). The advantages and disadvantages of these three data types with application in terrain analysis have been discussed by Moore et al., (1991).

2.3.1 Watershed Delineation and Characterization

For giving a practical shape to the systematic, scientific and rational approach of watershed as a unit of planning, a proper delineation of watershed is pre-requisite. An approach to automatically extract the, map and encode the spatial structure of drainage basins from standard elevation files or DEM has been given by Band (1986). The river catchment has been divided into many micro watersheds using this approach. Kaur and Datta (2002) compared the GIS based digital delineation of watershed with manual conventional approach for watersheds in Hazaribagh and Bankpura districts of Indian state of Jharkhand. The stream generation and flow direction determination is equally important for watershed. Ahamed et al., (2002) presented an approach for automatic extraction of tank outlet in sub-watershed with the DEM. Tarboton (1997) presented a method for determination of flow directions and upslope area in the DEM. Similarly use of contour based DEMs for deriving and mapping of topographic attributes of watershed has been given by Mizukoshi and Anjya (2002). Martz and Garbrecht (2003) demonstrated the channel network delineation and watershed segmentation in TOPAZ digital landscape analysis system. They have further assessed performance of automated watershed delineation. Solanke et al., (2005) used remote sensing and GIS techniques for the watershed characterization in Ganeshpur watershed in Maharashtra state. Arun et al., (2005) used these techniques for rule based physiographic characterization in drought prone watershed in West Bengal.

2.3.2 Morphometric Analysis

Watershed geomorphology is another important aspect in the preliminary planning of watershed management projects (Raju et al., 2002). Tachikawa et al., 2003 developed basin geomorphic systems for geomorphological characterization of watersheds. The system used the TIN-DEM data structure to compute the parameters. The Basinsoft, computer program to quantify the drainage basin characteristics has been reported by Harvey and Eash (2003). Miller et al., (2003) derived stream channel morphology using GIS based analysis in Walnut Gulch experimental watershed. In literature, the term morphometry has been used frequently as an alternative to geomorphology. The morphometric analysis provides quantitative description of watershed geometry (Stahler, 1957). Remote sensing techniques have been found a convenient tool for morphometric studies.

Many workers, especially in India, have carried out the morphometric analysis using remote sensing and GIS techniques. Shrivastava (1997) carried out drainage pattern analysis in the Jharia coalfields of Bihar, whereas Nag (1998) applied these techniques in Chaka sub-basin in Purulia, West Bengal. The influence of rock types and structures in the development of drainage pattern in the hard rock areas was studied by Nag and Chakraborty (2003). All these studies have reported the efficient use of remote sensing and satellite data. Srinavasa et al. (2004) and Chopra et al. (2005) have used remote sensing and GIS techniques for morphometric analysis of the sub-watershed in Tumkur district of Karnataka state and Gurdaspur district of Punjab respectively. The morphometric parameters in combination with the surface runoff and sediment yield have been used in the prioritization of watersheds (Suresh et al., 2004; Raju et al., 2002). This approach has been used in cases where analysis is carried out at the basin level, and for developing individual watershed prioritization index. Tiwari et al., (1997) extracted watershed parameters to develop an empirical model for seasonal runoff estimation using both the techniques.

2.3.3 Rainfall-Runoff Modelling

Prediction of runoff is one of the most useful hydrologic capabilities of GIS (DeVantier and Feldman, 1993). Garbrecht et al., (2001) provided integrated overview of multiple facets of data-GIS modelling issues and source of background information for selection and application of GIS in watershed modelling. The selected spatial data issues, data structures and projections, data sources, resolution and uncertainties have been addressed in this paper.

The GIS and hydrological modelling example have been further provided with recommendation of integrated use of spatial data, GIS and distributed watershed models. Moore and Grayson (1991) used vector elevation data for catchment partitioning and runoff prediction. With this approach, they demonstrated the utility of such a partitioning for runoff prediction subsurface flow saturation overland flow and Hortonian overland flow models. This was shown with the runoff hydrographs and surface flow velocities on small rangeland catchment in United States. An urban watershed runoff modelling was demonstrated for Baton Rouge, Louisiana. USA, with the help of Arc Info with HEC -1 model (Greene and Cruise, 1995). The study further has shown the effect of scalar and spatial changes on discharge. Schuman et al., (2000) applied GIS for conceptual rainfall runoff modelling in some catchments in Germany with three process based semi-distributed models (runoff generation, runoff formation and concentration). Some ideas regarding how conceptual models can benefit from the new possibilities were presented in this study.

Fortin et al., (2001) developed a GIS and remote sensing data compatible distributed watershed model into a user friendly GUI, with the help of modular system HYDROTEL. This model could be applied to a wide range of water with due account of available data. Sun et al., (2002) employed rainfall-runoff model based on DEM in small catchment in Southern Australia. They found that study improved the existing model, THALES, by further modification with time variant, spatially distributed watershed moisture representation. Nyabeze (2003) modified a hydrological model (GWBasic Wits Rainfall-Runoff Erosion Model) for distributed rainfall runoff modelling in a GIS. Modifications enabled better estimation of low flows, which are typical in drought conditions. Jacobs et al., (2003) suggested the improved rainfall runoff estimate using the remotely sensed soil moisture data. Hydrologic modelling and change detention, scenario testing was demonstrated with the automated geospatial watershed assessment tool (Semmens and Kepner, 2004).

Impact of landuse change resulting from urban development in a Reesor Creek watershed has been studied by Smith et al., (2005) by implementing model SWMM in GIS environment.

In Indian context, number of studies have been carried out for estimation of runoff from the watersheds. Pandey and Dabral (2004) used satellite data for estimation of annual runoff from the hilly watersheds in the North Eastern region. Shrivastava et al., (2004) used satellite date with GIS technique for hydrological modelling of small watershed in Eastern region. They used hydrological SWAT for runoff and sediment yield estimation. Similar study was reported by Jasrotia et al., (2002) in four sub-watersheds of Tons watershed in Yamuna basin. They used NRCS CN model for rainfall runoff estimation, while annual soil loss was estimated by Morgan, Morgan and Finney model. Tripathi et al., (2002) used IRS IB-LISS-II satellite data in the EASI/PACE GIS for runoff modelling of Nagwan watershed in Damodar valley. Durbude et al., (2001) used IRS – IB-LISS- II satellite data for estimation of surface runoff potential of semiarid watershed in the Rajasthan state. The NRCS CN model was used in the estimation of surface runoff. Suresh et al., (2004) used remote sensing technique in the assessment of surface water potential in the Himalayan watersheds in West Bengal. This information has been further used in the prioritization of watersheds with the morphometry of the watersheds and annual sediment production rate. The NRCS CN model has been used for the runoff assessment. Chowdary et al., (2004) used AGNPS model with remote sensing and GIS for non point source pollution modelling of Karso watershed of Jharkhand state.

2.3.4 Soil Erosion and Sediment

The remote sensing and GIS techniques have been used for sediment and erosion modelling across the globe. Sun et al., (2002) used a contour based DEM for the development of erosion and sediment estimation tool. The application of tool has been discussed for the watershed in the Happy Valley of southern Australia. The model simulates the dynamics of event runoff, soil detachment and transport processes. Jain and Kothyari (2000) demonstrated the utility of GIS and satellite data in identification of source areas and prediction of storm sediment yield from catchments. The concept of sediment delivery ratio with USLE was used in the study for Karso and Nagwan watersheds in Jharkhand. With the same watersheds and concept of sediment delivery ratio, Kothyari et al., (2002) estimated the temporal variation in sediment yield. Jain and Goel (2002) used these techniques for the assessment of vulnerability of 16 watersheds in the Western India to the soil erosion. The study was reported for catchment of Ukai dam in Gujarat. Chandramohan and Durbude (2002) used IRS IC–LISS-III data for soil erosion potential mapping for Hire Nadi watershed in Karnataka state. The USLE approach was used to identify the erosion potential zones in the watershed. Srinivas et al., (2002) carried out similar analysis for Nagpur district of Maharashtra, which has been further used in prioritization and delineation of conservation units. Sikka et al., (2003) similarly produced the soil erosion map of entire state of Kerala.

2.3.5 Groundwater Studies

High resolution satellite data with spatial analysis capabilities of GIS have been used in the groundwater studies for long time. Khan and Moharana (2002) used IRS ID-LISS-III satellite data for delineation and characterization of groundwater prospect zones. The study was carried out for the watershed in the state of Rajasthan. Jothiprakash et al., (2003) reported the delineation of potential zones for groundwater recharge in the river basins of Tamilnadu. Rao et al., (2004) carried out an integrated study of Pedda Gedda watershed in Andhra Pradesh. The IRS IB-LISS-II and IRS ID-LISS –III data have been used to identify the location of groundwater zones. Rao et al., (2001) identified the groundwater potential zones in and around Guntur town of Andhra Pradesh. Gopoinath and Seralthan (2004) identified groundwater prospective zones Muvattupuzha basin of Kerala state using LISS-III and pumping test data. Similar study has been reported by Srinivas et al., (2005) in the north Pennar basin of Karnataka.

Among the other aspect of watershed management, irrigation water requirement estimation (Rao et al., 2001; Nandagiri and Shetty, 2003), water resources development action plan (Rokade et al., 2004), site suitability analysis of soil and water conservation structures (Durbude and Venkatesh, 2004), land use/ land cover mapping have reported in India using the remote sensing and GIS techniques.

2.4 Decision Support Systems and Spatial Decision Support Systems

DSS is a set of computer based interactive programs, often with the graphical user interface (GUI), that incorporates simulation and optimization models to assist the decision making process (Loucks and deCosta, 1991), while Spatial Decision Support System (SDSS) are new class of computer systems that combine the technologies of GIS and DSS (Walsh, 1993).

Water resources planning and management mostly depends on the information derived from the hydrological models. Implementation of these models becomes convenient when, they are developed with interactive graphical user interface. This interface gives, user control, over the model operation as well as data input, editing and output. These computer based models in combination with interactive interfaces are typically called as DSSs (Loucks et al., 1996). In order to develop SDSS, there has to be spatial data component in the DSS. Fundamentally, DSS assisted in developing semi-structured and unstructured decisions in multidisciplinary fields of decision theory, such as artificial intelligence (AI), operation research, management information systems, organizational studies, and others (Hess et al., 2000). However, advancement in research from different areas of technical and engineering applications have been easily adopted into the principal components of DSS, namely, the dialog generation management system (DGMS), the model base management system (MBMS), and the database management system (DBMS) (Sprague and Carlson, 1982). Recent advancement in programming has introduced visual interfaces and many other usability features in DGMS, while the open database connectivity (ODBC) technology has improved the functionality of DBMS.

2.4.1 Historical Perceptive

DSS evolved early in the era of distributed computing. The history of such systems begins in 1965 (Power, 2003). Evolutionary characterization and development can be traced from Electronic Data Processing (EDP) at the beginning of computing age to Management Information System (MIS) and to modern DSS (Guariso and Werthner, 1989). The term DSS was coined in early 1970s to describe the computer programmes developed specially to assist with the solution of semistructured and unstructured problems faced by senior managers of commercial and government organization (Sprague and Carlson, 1982). DSS is an extension of MIS. This has given rise to the new discipline, which gives the emphasis on the design and development of DSS, which have strong theoretical background and large number of applications in management of sectors ranging from commercial business to natural resources (Andriole, 1989). The DSS has advantage over the MIS, which merely retrieves the data from database on selected queries, whereas DSS has more features of models and user interface with the database. Till mid 1980s, DSS has found little application in water resources although one of the first DSS to be widely described was developed for catchment management (Holsapple and Whinston, 1976).

2.4.2 Classes of Decision Support Tools

Bardos et al., (2001) gave the four categories to describe the decision support tools as follows:

a) The decision-making role of the approach: This describes the type of decision making being supported i.e. managing single site, or prioritising number of sites. This deals with the overarching decisions made at the site.

b) Functional application: This includes whether the decision support is for risk management, remediation, monitoring and aftercare, sustainable development and planning.

c) The analytical technique used: Several techniques can be employed to assist the decision-making. There can be optimization, multi criteria analysis, and cost benefit analysis or impact assessment. In practice many of the DSS use these techniques or combination of different parts of them.

d) The nature of decision support product: This describes the whether decision support is written guidance; a map of some sort, a series of procedures or a software based system. In practice many of the DSS address the multi criteria with the software base an essential base.

2.4.3 Concept and Components of DSS

Standard set of the components are essential to have an efficient DSS. The DSS traditionally consists of three essential components; (1) Data base, (2) Models and (3) User interfaces (Densham and Goodchild, 1990). The user interface is an interactive program developed in a suitable programming language so as to have the user friendly way of presentation. The recent development in information technology especially in GUI has given the DSS developers an advantage to understand and develop the human–computer interaction (Walsh, 1993). Database is important in any decision making activity. In DSS, it forms a core component. The model base is developed as an essential component of DBMS so as to keep a track of models and methods used in the decision making process. The models in a DSS can be both procedural (i.e. algorithmic) and non-procedural (e.g. heuristic). The procedural models are typically built around a mathematical algorithm that is efficient but opaque to users. The object oriented programming has given a new twist to the DSS development. The object-oriented approach crosses the neat lines of the user interface, database and model base for existing and traditional DSS concept (Denshan and Goodchild 1990, Walsh 1993).

SDSS is a new concept that has emerged with the development of GIS. This is the result of integration of DSS, GIS and models. An extension of DSS concept offers unifying framework for integrating GIS and DSS, including models within DSS. This combines the technologies of DSS and GIS. The modelling capabilities of GIS allow users of SDSS to simulate the changes in the object and the attribute data. The database component supplies the input data and running models provide output, which can be displayed at the GUI via SDSS in the form of a map or a table.

2.4.4 DSS/SDSS Applications in Water Resources

Several efforts have been made to develop and sustain water resources decision support systems. Some of these systems are aimed at research applications, while others are designed to support specific decision and management goals. Some of the DSS are reviewed here to illustrate the accomplishments and shortcomings with the use of these systems. Table 2.1 gives the summary comparison of various DSSs along with their applications.

Implementation of DSS for water resources management-related decision making can be found in the literature with number of case studies. TERRA (Reitsma et al., 1994) is an operational water resources management DSS developed using a problem-centered design, and is capable of analyzing the scheduling problems in reservoir operation, power plant operation, water quality analysis, and others, handling various constraints associated with these activities. NELUP (Dunn et al., 1996) is a DSS that provides quantitative description of the economic and environmental impacts arising out of rural land use changes, integrating models of economy, ecology, and hydrology.

AQUATOOL (Andreu et al., 1996) is a generic DSS capable of assisting decision makers both at the planning and operation stage of a complex river basin with provisions for accessibility to geographically referenced database and knowledge bases, along with modelling capabilities for basin simulation, optimization, aquifer flow, and risk assessment. Water Ware (Jamieson and Fedra, 1996) is a river basin planning and management DSS incorporating various modelling, optimization, GIS, and expert system technologies. The Murray–Darling Basin in Australia is severely environmentally degraded as a result of a range of anthropogenic changes, most notably the regulation and extraction of surface water resources for irrigated agriculture (Young et al., 2000). To facilitate the on-going trade-off process between competing users of this resource, a DSS is being developed which will enable explicit prediction of the likely response of key features of the riverine environment to proposed flow management scenarios. The DSS is being developed using the RAISON shell. CTIWM (Ito et al., 2001) is a DSS, which integrates hydrologic processes modelling with risk estimation to evaluate surface water management alternatives in a river basin. Shim et al., (2002) presented a prototype SDSS for integrated, real-time river basin flood control in a multipurpose, multireservoir system. The SDSS integrates a GIS with a database management subsystem, a real-time meteorological and hydrological data monitoring system, a model-base subsystem for system simulation and optimization, and a graphical dialog interface allowing effective use by system operators. The SDSS for flood control is applied to the Han River basin in Korea and demonstrated through simulated application to a severe 1995 flood event.

Mysiak et al., (2002) reported a DSS, targeted at solving decision problems in the management of water resources. The application-driven approach to developing the MULINO-DSS (mDSS) combines the scientific background of the consortium members with local knowledge and decision support needs, expressed by five user groups. MULINO-DSS prototype is presented through an application example in the Vela catchment that belongs to the Venice Lagoon watershed (north-east Italy). Westphal et al., (2003) provided an example of the development of a real-time DSS for adaptive management of the reservoir system that provides drinking water to the Boston metropolitan region. The DSS uses a systems framework to link watershed models, reservoir hydraulic models, and a reservoir water quality model with linear and nonlinear optimization algorithms. The DSS offers the ability to optimize daily and weekly reservoir operations towards four objectives based on short-term climate forecasts.

Liu and Stewart (2004) discussed the object-oriented modelling of DSSs for multicriteria decision making (MCDM) in natural resource management. This approach of DSS modelling is integrated into the uniform framework based on object orientation for both MCDM and DSS modelling. The system development of a DSS for water resources management based on the DSS model has demonstrated both efficiency of the development process and effectiveness of the system developed. Mysiak et al., (2005) described the development methodology and progress of mDSS, a decision support system for water resource management that has been developed under the European research project MULINO. The mDSS tool is designed to integrate environmental (especially hydrological) models with multiple-criteria evaluation procedures. The main aim of the DSS is to help with increasingly complex decisions of general water management, the concepts of sustainable river basin management introduced by the water framework directive are addressed as well.

Use of interactive computer technologies can be beneficial for water resources planning (Friedman et al., 1984). Legal, political, economic and ecological complexities caused by water transfer result in the difficult decision making problem for water planners (Nunn, 1988). Stanbury et al., (1991) developed a DSS for water transfer evaluation. The DSS consisted of three main modules; (i) conjunctive surface and groundwater module, (ii) impact analysis segment which uses the GIS and integrates the model output, (iii) multi criterion decision making algorithm that ranks the transfer schemes. The DSS was tested and implemented for number of case studies of different water transfer alternatives.

Policy analysis is key issue in water resources planning and management which involves the interactive process generation, evaluation and exploration of possible solutions. The policy analysis DSS needs to be effective so that it analyses the proposed alternatives, examines the reason for conclusions, checks evidences and determines the reliability of results (Davis et al., 1991). Prototype DSS that estimates the effect of policies on water quality and cost implementing the policies were developed. The DSS consisted of three modules; (i) policy module that builds up the suite, (ii) catchment module estimates the effect of these policies on pollutants, (iii) a display module gives the policy alternatives. The DSS was programmed in Prolog language. This was evaluated for the south Australian engineering and water supply department.

Feick and Hall (1999) described a prototype SDSS that satisfies community participation needs through a tight-coupling of GIS functionality and Multiple Criteria Analysis (MCA) techniques. The potential benefits of adopting this approach and future extensions to the prototype are discussed in light of a land use-planning example.

Davis (2000) offered the concept of complete agents as a theoretical basis for designing computational architectures of use in modelling intelligent behaviours. A framework was proposed for use in decisions making about water supply infrastructure rehabilitation and development. The framework supports database reclamation, data warehousing, water mains pipe-failure prediction and strategic overview information based on customer complaints and chemical analysis of supplied water. Vacik and Lexer (2001) reported the development and application of a SDSS for silvicultural planning in forests managed for sustained yield of water resources. The implementation of core components of the SDSS is described. As an example, the development of a decision model for selecting the best silvicultural treatment option for scheduled for natural regeneration is discussed. The decision problem is factorized into decisions on the future species mixture i.e GSO and on an appropriate Regeneration Method (RM). The combination of GSO and RM which simultaneously maximizes the expected utility and satisfies all constraints of the forest decision maker is selected as the overall best solution.

Sample et al., (2001) reviewed application of GIS technology to the field of urban stormwater modelling. Then a GIS application in urban storm-water management is presented at a neighborhood scale. A single site example is presented illustrating the value of GIS tools to provide more complex on-site hydrologic analysis. Collentine (2002) produced the CATCH-model, a DSS for catchment-based water management, built on the use of 'discourse and deliberation' within stakeholder groups to define relevant socio-economic parameters and the relationships between these parameters. The sets of matrices that describe these parameters and their interrelation serve as the basis for evaluation of alternative management strategies and evaluation of specific measures for improving water quality.

Segrera et al., (2003) reviewed the evolution of DSS architectures, particularly as they apply to natural resources. DSSs have evolved; their architecture, mode of implementation, as well as their functionality, whereas incorporation of new computational techniques have advanced lately. In the particular case of Cuba, the first step in materializing this evolution have begun. They proposed the development and building of a dedicated DSS for sugar cane cropping.

Koutsoyiannis et al., (2003) presented main components of a DSS developed to support the management of the water resource system of Athens. The DSS includes information systems that perform data acquisition, management and visualisation, and models that perform simulation and optimisation of the hydro-system. This has been utilised to support the master plan of the hydro-system management.

Simon et al., (2004) demonstrated the evaluation of water management strategies in the cities of Berlin and Potsdam (Germany) with respect to their ecological effects in 14 sections of the surface water system. Two DSSs were compared in this study, namely PROMETHEE, which is designed to obtain a clear decision (linear ranking), and Hasse Diagram Technique (HDT), normally providing more than one favourable solution (partial order).

Environmental Decision Support Systems (EDSSs) are among the most promising approaches to confront decision complexity (Poch et al., 2004). The flow diagram used to build the EDSS is presented for each of the systems, together with a discussion of the tasks involved in each step (problem analysis, data collection and knowledge acquisition, model selection, model implementation, and EDSS validation). In addition, the architecture used is presented.

According to Holmes et al., (2004), in the United Kingdom, the Environment Agency of England and Wales has developed a number of initiatives to assist in implementing the European Water Framework Directive (2000/60/EC) including catchment abstraction management strategies and the resource assessment management framework. This paper describes the system components and how low flows 2000 has been implemented within the United Kingdom to address real-world water resource issues associated with the Water Framework Directive's over-arching strategic initiatives.

Irrigation management is another important segment of water resources sector. The critical decisions are involved in irrigation management. The various components are associated with large datasets e.g. evapotranspiration (ET). The decision making is often complex and hence requires a comprehensive approach. The DSS, as defined earlier, could be suitable in handling the decision making process. A DSS has been widely applied in the field of irrigation such as irrigation district planning, crop water requirement estimation, etc.

The term DSS and expert system are used synonymously though conceptually both are different. Mohan and Arumugam (1995) proposed an expert system (ES) to aid in selection of a suitable ET estimation method. In this, an intelligent front-end expert system that has been developed to select suitable ET estimation methods under south Indian climatic conditions. Ten meteorological stations located in different climatic regions and thirteen ET estimation methods have been considered in this ES. Like a human consultant, the system asks the user for information regarding the details of the project site such as location, season, climatic zone and data availability. It then makes a recommendation based on this information and the systems own knowledge of such a situation. Tank irrigation system operation DSS (Arumugam and Mohan, 1997) facilitates operation of a reservoir irrigation system, incorporating optimization and irrigation engineering techniques along with a knowledge base developed with field experts. MODSIM DSS (Fredericks et al., 1998) is a DSS for conjunctive management of surface and groundwater, constructed around the generalized river basin network flow model MODSIM, having interfacing capabilities to spatially referenced databases.

Lilburne et al., (1998) promoted the improved irrigation practices by making this information more readily available in the form of a DSS linked to the water allocation process. Under this approach, growers would be required to submit to the local authority an Irrigation Management Plan (IMP) which details how they intend to irrigate the crop in each of their management blocks. Sufficient information about the soil, crop, irrigation system and scheduling mechanism would have to be supplied in the IMP to evaluate for environmental impact. The IMP is evaluated by a water allocation consent officer with the help of the DSS, which is incorporated environmental impact knowledge. Irrigation-scheduling model consisting of the graphical user interface based on the daily water balance approach that uses the climatological data, crop and soil parameters was developed. The model was compared with the CROPWAT program developed by FAO (George et al., 2004).

An Irrigation District Decision Support System (IRDDESS) to a large irrigation scheme in the Middle Awash Valley of Ethiopia has been described and applied by Endale and Fipps (2001). IRDDESS is a crop growth and irrigation district simulation model capable of predicting biomass development and yields for fields varying in soil type and irrigation management scenarios. IRDDESS also accounts water demand in the distribution system. Ostfeld et al., (2001) developed a decision support system (HANDSS) to assist system managers select diversion rates and operate the Lake Hula canal system. HANDSS consists of; ArcView for visualizing the impacts of alternative operations, groundwater simulation models for computing the impacts, and optimization models for developing optimal operation plans for steady and unsteady conditions. The Groundwater Modelling System (GMS) is imbedded in HANDSS to provide data manipulation, groundwater simulation using MODFLOW, and link to ArcView.

Mateos (2002) described the Scheme Irrigation Management Information System (SIMIS) as a decision support system for managing irrigation schemes. The SIMIS approach is based on simple water balance models with capacity constraints. The user can simulate management alternatives, assess the results and try out new alternatives, until a satisfactory solution is found. SIMIS also helps in the administrative aspects of managing irrigation schemes (accounting, calculating water charges, and controlling maintenance activities) and in assessing their performance

Cliburn et al., (2002) discussed a software application for visualizing the results of a water balance model and its associated uncertainty. The effectiveness of the application and its visual presentation methods were incrementally tested and improved through usability engineering principles. Chowdary et al., (2003) reported the GIS based DSS for groundwater recharge assessment in large irrigation projects of India. GIS has been used to map the spatial distribution of recharge which then serves as input to a regional groundwater flow model for simulating the behavior of the underlying aquifer. A daily field soil water balance model and a simple canal flow model are used to estimate the percolation and seepage losses, respectively. The combination of models and GIS can be used as an integrated decision support system to assess the groundwater resources and derive strategies for integrated management of canal and groundwater resources in the project area.

Bazzani (2005) described DSS for Irrigation (DSIRR) for the economic-environmental assessment of agricultural activity focusing on irrigation, designed to answer both public and private needs. The DSS simulates the economically driven decision processes of farmers, permitting an accurate description of production and irrigation in terms of technology and agronomics. Distinct farm models can be constructed to describe the relevant production system in the catchment. DSIRR is a useful tool for more sustainable agriculture and the definition of a sound water policy.

2.4.5 DSS/SDSS Applications in Watershed Hydrology

Watershed hydrology is complicated due to large number of parameters and variation on spatial and temporal scale of spatially distributed data. Hence, the modelling and data processing become a difficult task. For processing the large volume of data, GIS, DSS, graphic and visual design tools have been found to be efficient (Singh and Fioerentio, 1996). Integration of these techniques with the watershed hydrology models accomplishes a number of significant functions, viz, designing, calibration, modifying, evaluation and comparing watershed hydrology models. Many authors have reported the use of GIS in modelling of watersheds. Very few attempts have been made to develop DSS and information systems for the specific use. Some of them are described below. Paniconi et al. (1999) reviewed the strengths and weaknesses of GIS and explained why distributed hydrologic models typically rely on GIS, data visualization, and other software tools for pre- and post-processing, and as complementary components of DSSs. They developed a DSS to estimate the soil moisture from satellite measurements and validate these estimates using ground truth measurement and catchment scale hydrologic modelling.

Eskandari et al., (1988) presented a DSS for watershed management which formulated a discrete multi-objective programming problem with four decision alternatives and fourteen criteria. This is a typical old style example of DSS in which a linear or dynamic programming was used for decision making, without the use of either spatial model or GIS. The output was presented in the form of numerical values. As the cartographic software lead to the development of GIS, the overall application of spatial tools in DSS has changed the concept drastically. Earlier approach of optimization was taken over by cartographic tools and then by GIS.

The ITC Netherlands had developed the first Integrated Land and Water Information System (ILWIS) in 1990s with the integration of GIS which is extremely helpful in spatial modelling. Briham Young University released the package Watershed Modelling System in 1999, which may be called as DSS, as it contains the use of GIS and various models programmed in GUI, in which most of the spatial analysis can be carried out. Wilson and Droste (2000) outlined the design of a watershed management decision support system (WMDSS). The WMDSS requirements are analyzed and ranked in order of priority. This gives a ranking for development of tool and information functional groups to support the following assessment types; surface water quality, surface levels and flows, integration, groundwater flows/levels, rainfall- runoff modelling and time series analysis. Functional analysis then provides the architecture and data flows necessary to meet system requirements. The WMDSS functional analysis is concluded with a recommended architecture for design of such a system. This sets the foundation for programming and validation of the system.

Integration of GIS into DSS, has given the researchers advantage for spatial analysis and visualization (Deshman and Goodchield, 1990). Hallenger and Maidment (1999) developed an automated procedure in ARC Macro Language (AML), ARC/INFO and ARC/View Avenue prgrammes to produce the connection of hydrologic elements using the geographic data, which was used to identify the hydrologic elements in Tenkiller reservoir watershed in Oklahoma, USA. Theodore (2000) developed a GIS based decision support tool with an ARC View application named LORELEI to rapidly develop and compare the management alternatives for urban watershed with hundreds of best management practices.

Dutta (2003) integrated ARC View GIS with model SWAT (Soil and Water Assessment Tool) to develop the SDSS for land water management and its application of watershed management.

The tool was applied in digitally delineating the watershed in Bankpura District of West Bengal, India and then it was used for estimating potential water, silt and crop yield from each of the watershed. The potential users for this are district level decision makers. Watson et al., (2002) have given an introductory concept of advancement in DSS technology, a Problem Solving Environment (PSE), which has overcome the limitation of traditional DSS of stand alone working on PCs. This has focused on the distributed integration of personal and models through internet. PSE was developed and demonstrated for impact of land use change analysis on watershed. Technical challenge of providing scientific linkage to decision making remained unclear.

Rao et al., (2003) developed the Intelligent Decision Support System for small watershed management which takes the Expert system as the core. Several functions were designed including information management, knowledgebase management, expert decision-making, visualization analysis, sustainable development assessment etc. The application of the system in the small watershed management in Beijing mountain areas is discussed taking the Shixia small watershed as a case.

Dai et al., (2003) described a knowledge base for Watershed Assessment for Sediment (WAS). The knowledge base was designed for protection of fish habitat and control of excessive sediment, and was evaluated in the Ecosystem Management Decision Support (EMDS) system. The WAS model allows experts from diverse fields to contribute to an integrated assessment of watershed condition. As a decision support tool, the model provided a means to assemble information and reasoning that support land use or regulatory decisions, and to communicate among diverse audiences the basis for those decisions. System was applied of the model to assess the condition of a coastal watershed in northern California. Major lacuna observed in this case was hydrological models that form a core to watershed.

Lam et al., (2004) developed a DSS by multi model integration. This is latest development in DSS by integration of number of models into Technical User Interface (TUI). The DSS was applied and tested for Seymour watershed in Canada for hydrological, hydrodynamic and water quality monitoring and planning of watershed. Through this exercise it was found that new models and data can be implemented and linked to existing modules in TUI easily as compared to the conventional approaches.

De la Rosa (2004) reported the evolution of Mediterranean Land Evaluation Information System (MicroLEISDSS) towards an agro-ecological decision support system. MicroLEISDSS is a set of useful tools for decision-making which in a wide range of agro-ecological schemes. The design philosophy follows a toolkit approach, integrating many software tools: databases, statistics, expert systems, neural networks, Web and GIS applications, and other information technologies. This is aimed to provide opportunities for greater cooperation in interdisciplinary research and in the application of knowledge to solve problems of soil protection. Dragan et al., (2003) applied SDSS based on multi-criteria and multi-objective decision analysis in a case study in Ethiopia to reduce soil erosion on the basis of reallocation of crops according to their capacity to protect the soil. The SDSS has been implemented using the GIS software IDRISI 3.2 (release 2) and with the direct involvement of local stakeholders in defining factors and constraints. These are based on land cover-land use, altitude, potential erosion, proximity to roads, water and the relative soil protective capacity of each crop species.

Rao and Kumar (2004) presented a prototype SDSS for watershed management. The SDSS integrates landuse/landcover derived from the remote sensing data, real-time hydrological data, geographic information system, and a model-based subsystem for computing soil loss, land capability classification and engineering measures Computed pixel based soil loss information is an input to the land capability classification and watershed management modules. The developed SDSS can help the end users in avoiding the laborious procedures of soil erosion calculations and analysing various thematic layers to get suitable watershed management practices.

Knowledge and information from several disciplines are integrated into a functional computer-based watershed management decision support system (WAMADSS). WAMADSS consists of three components: (1) a GIS, (2) an economic model, and (3) an environmental simulation model. A graphical user interface enables decision makers to generate scenarios, change LUMPs, run the models, and view results within GIS environment (Fulcher et al., 1999).

Watershed analysis and watershed management are developing as tools for integrated ecological and economic study. The new technology and thinking offered by the advent of the Internet and the World Wide Web is highly complementary to some of the goals of watershed analysis. In this respect the Web offers a wealth of opportunities for the decision-making process, but still few questions are to be answered e.g. at what scale and how widely will the Web be accepted as a management tool, and how can watershed management benefit from web applications. They used Patuxent River as study area to illustrate the web-based approach to watershed management.

Table 2.1 Summary of DSS and SDSS applications

Author	Focus	Application Area
Al-Shemmeri et al.,1997	Water Strategic Planning	Jordan
Adinarayana, 2002	Identifying Priority Sites gor Watershed Management Schemes	India
Andrue et al.,1996	Water Resources Planning and Operational Management	Segura and Tagus Basin, Spain
Arnold and Orlab,1989	Estuarine Water Quality Management	-
Arumugan and Mohan, 1997	Tank Irrigation System Operation	Tamilnadu, India
Aziz et al.,2002	Optimizing Groundwater Monitoring Plans	Washington, USA
Banai, 2005	Land Resource Sustainability for Urban Development	USA
Bardos et al., 2001	Contaminated Land Management	Europe and America
Bazzani, 2005	Irrigation and Water Policy Design	-
Chowdary et al., 2003	Groundwater Assessment in Large Irrigation Project Areas	Andhra Pradesh, India
Cliburn et al.,2002	Water Balance Application with Uncertainty	Various Countries
Collentine et al., 2002	Decision Support for Stakeholders in Catchment Areas	Sweden
Davis et al., 1991	Analyzing Impacts of Catchment Management	Australia
De et al., 2004	Comprehensive Nutrient Management	USA
de Kok and Wind, 2003	Design and Application of DSS for Integrated Water Management: Lessons to be Learnt	-
De la Rosa et al., 2004	Land Evaluation for Agricultural Soil Protection	Mediterranean Region
Denzer, 2005	Generic Integration of Environmental Decision Support Systems- State of Art	-
Dragan et al.,2003	To Reduce Soil Erosion	Northern Ethiopia
Dunn et al., 1996	Hydrological Component of NELUP DSS	Cam Basin, UK
Dutta 2004	Land and Water Management in Watershed Management	West Bengal, India
Dymond et al.,2004	Interdisciplinary Watershed Management	USA
Engel et al., 2003	Hydrologic Impact Evaluation of Small Watershed Land Use Changes	USA
Eschenbach et al.., 2001	Multi-Objective Operation of Reservoir Systems	USA

Eskandri et al.,1995	Watershed Management	Arizona, USA
Fassio et al., 2004	Simulating Effects of Alternative Policies Affecting Water Resources	Europe
Fedra and Jamieson, 1996	River Basin Planning	Thames Basin, England
Fredericks et al.,1998	Conjunctive Stream Aquifer Management	Colorado USA
Froukh, 2001	Domestic Water Demand Forecasting and Management	Swindon Demand Zone of Thames Water Utility, UK.
Frysinger et al., 1993	Hydrological Characterization and Design of Monitoring Well Network	-
Furst et al., 1993	Application of DSS for Groundwater Management	Austria
Ghayoumian et al., 2004	Identification of Suitable Areas for Artificial Recharge, Case Study	Meimeh Basin, Iran
Gu and Tang, 2000	Design of Water Resources Management Decision Support System, WSR Approach	China
Halls, 2003	Exploratory Data Analysis of Water Quality Parameters	Cape Fear River, USA
Holmes et al., 2005	Catchment Abstraction Management Strategies and Resource Assessment Management	England and Wale
Ito et al., 2001	Surface Water Planning in River Basins	Chikugo River Basin, Japan
Janssen et al., 2005	Integrated Wetland Management	Netherlands
Jeunesse et al., 2003	Implementation of Participatory Approach at The Catchment Scale	Dyle Catchment Belgium
Koutsoyiannis et al, 2003	Masterplan of Hydrosystem Management.	Athens Greece
Kumar and Singh, 2003	Regional Water Management Modelling in Irrigated Agriculture	Haryana, India
Labadie and Sullivan, 1986	Documentation of Benefits and Values Of DSS for Wide Application Areas	-
Lam et al.,2004	Watershed and Lake Management Scenarios	British Columbia, Canada
Lisson et al.,2003	Costs and Benefits of on Farm Water Storage Based Production Systems	Australia
Liu and Stewart, 2004	Water Resources Management	South Africa
Liu, 2004	Managing Ground Water Resources	Choushui River Alluvial, Taiwan
Manos et al., 2004	Monitoring and Management of Strymon River	Southern Balkans
Markopoulus et al., 2003	Urban Water Management	USA
Martens and DiBiase, 1996	Total Catchment Management	-

Mateos et al., 2002	Irrigation Schème Management	-
Miller et al., 2003	Rangeland Watershed Management	USA
Muleta, and Nicklow, 2005	Watershed Management using Evolutionary Algorithms	Illinois, USA
Murphy, 1995	GIS as DSS	-
Mysiak et al., 2005	Sustainable River Basin Management	-
Nauta et al., 2003	Set-Up of a Decision Support System for Sustainable Development	Laguna de Bay, Philippines
Ostfeld et al., 2001	Operation and Diversion Rates in Canal System	Lake Hula, Israel
Pallottino et al., 2005	Water Resources Management Under Uncertainty by Scenario Analysis	Sardinia, Italy,
Pereira et al.,2005	Groundwater Governance Issues	-
Pieterse et al., 2002	Restoration Planning of Stream Valley Ecosystems	Border between The Netherlands and Belgium.
Poch et al., 2004	Design and Building of Real Environmental DSS	Spain
Power 1993	Object Oriented Design of DSS for Natural Resources Management	-
Rajasekaram and Nandalal 2005	Reservoir Water Management Conflict Resolution	-
RAO and KUMAR, 2004	Watershed Management (Soil Erosion Estimation)	Yamuna Basin, India
Rao et al.,2001	Interactive Management System for Operational Control of Kirazdere Reservoir	Turkey
Richards, 2003	Need of DSS Maintenance of Water Quality and Safety Standards.	-
Ritsma, 1996	Structure and Support of Water-Resources Management and Decision-Making	Colorado River Basin, USA
Salewicz and Nakayama, 2004	Managing Large International Rivers	Ganges River, India
Sample et al., 2001	Urban Storm Water Management	USA
Sarangi et al., 2004	Soil and Water Conservation Measures on Agricultural Watersheds	St Lucia
Segrera et al., 2003	Land Planning and Management in Sugarcane Area	Cuba
Sharifi, 2002	Supporting the Ground Water Rehabilitation	La Mancha Region Spain.
Shim et al.,2002	Integrated River Basin Flood Control	Han River Basin South Korea
Simon et al., 2004	Aspects of Decision Support in Water Management-Spatially Differentiated Evaluation	Berlin and Potsdam,Germany

Singh et al., 1999	Irrigation Optimisation System (IOS) to Major Irrigation Project	India
Soncini-Sessa et al., 2003	Planning and Management Water Reservoir Systems	Verbano Water System, Italian–Swiss border
Stanbury et al., 1991	Water Transfer Evaluation	Nebraska, USA
Sugumaran et al., 2004	Environmental Planning and Watershed Management	Missouri, USA
Theodore et al., 2000	Urban Watershed Management in Fulton County, Georgia	USA
Twery, et al., 2005	Integrated Forest Ecosystem Management	-
Vacik and Lexer 2001	Protection Forests for Sustained Yield of Water Resources	Vienna
Walsh, 1993	SDSS Concept Development and Challenges	-
Weintraub et al.,2001	Watershed Analysis, Risk Management in Catamba Basin	Carolina, USA
Westphal et al., 2003	Adaptive Water Supply Management	Massachusetts
Yeh and Qiao 1999	Intelligent Solution Support System for Spatial Modelling and Decision Support	-
Young et al., 2000	Prediction of Likely Response of Key Features of Riverine Environment to Proposed Flow Management Scenarios	Murray–Darling Basin Australia
Zhu et al., 1996	Strategic Land Use Planning	Scotland

2.5 GIS Based Interfaces for Models

The use of GIS has grown dramatically since 1980s. Its use in planning and other studies has been seen across the academic, government and commercial agencies with diverse applications (Bennett, 1997; Djokic and Maidment, 1993) In the field of hydrology and water resources, GIS have been introduced in past 15-20 years. The lack of sophisticated analytical and modelling capabilities was recognized by GIS researchers and hydrologists as one of the major deficiencies of GIS technology (Maidment, 1993; Wilson, 1996).

Many attempts have been made in integrating GIS with hydrological models in Information Systems (IS), Decision Support Systems (DSS) and Expert Systems (ES) in the management related problems (Fedra, 1993; Bantayan and Bishop, 1998; Wu, 1998; Goodchild, 1993; Goodchild et al., 1996). The ongoing efforts of GIS capabilities integrated with hydrologic models provides a powerful way to understand, to visualize and to analyze hydrologic processes (Singh and Fiorento, 1996).

The incorporation of analytical models into GIS can be termed as the coupling or integration. However two terms are different from each other. Coupling means the linkage of two stand-alone systems i.e. GIS tool and simulation model by data transfer. Integration means the implementation of GIS tools and simulation models on top of a common data and method base. There are four different approaches have been widely used to integrate GIS with hydrological modelling (Sui and Maggioet al., 1999). These approaches have been given in Fig. 2. 1

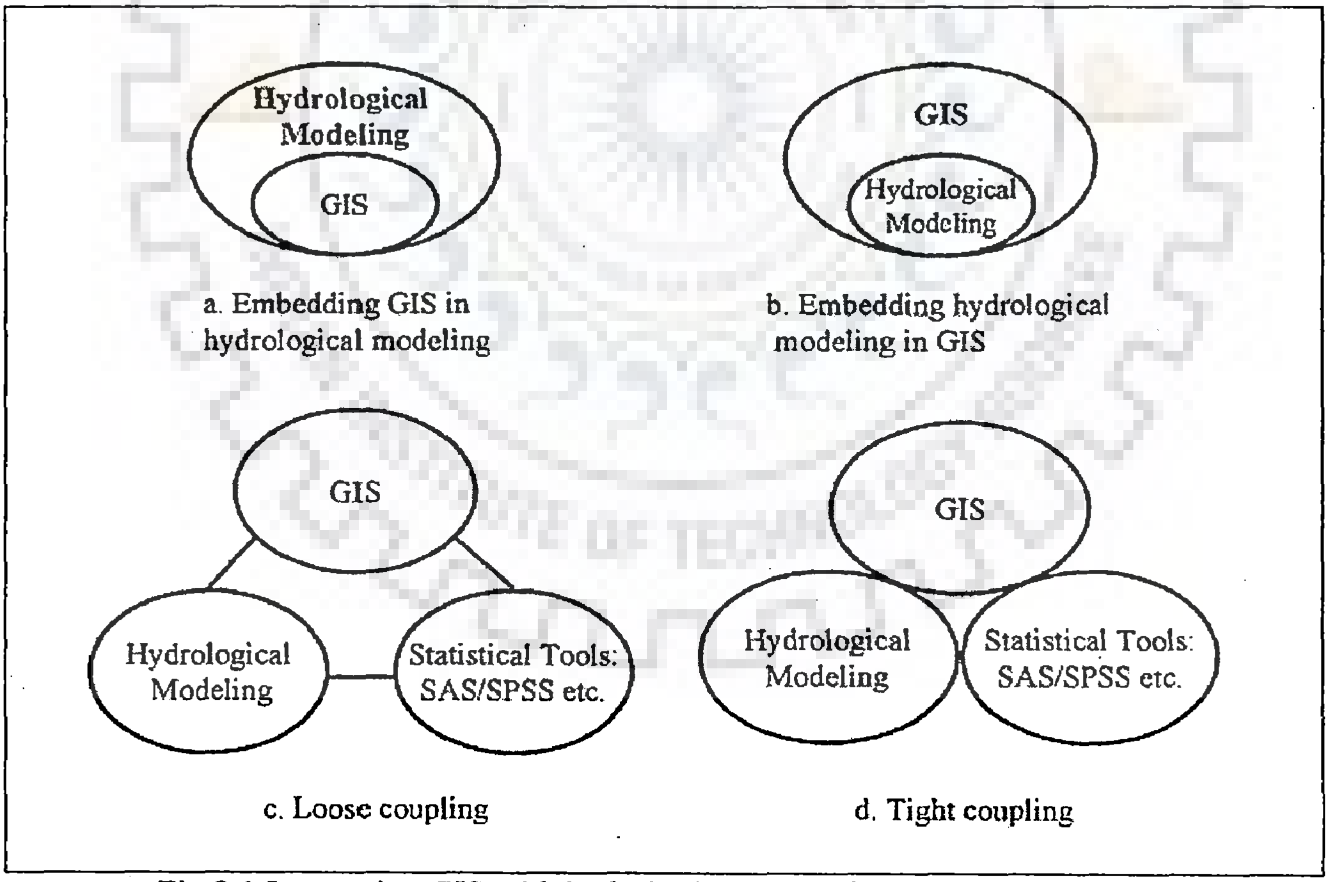


Fig 2.1 Integrating GIS with hydrological modelling: current practices

(After Sui and Maggio, 1999)

The embedded approach aims to embed GIS functionalities in hydrological modelling packages, and has been used primarily by hydrological modelers. This approach usually gives system developers maximum freedom for system design (Sui and Maggio, 1999). The linking of GIS and several hydrologic process models (beyond creating preprocessed data files within the GIS) is examined by Charnock et al., (1996) and DeVantier and Feldman (1993).

The way of data transfer in the coupling of models and GIS, differentiate the coupled systems (Nyerges, 1992; Fedra, 1996). The types of these systems can be of loose coupling or tight (deep) coupling. Most of the integrated models and GIS are in loose coupling category (Singh et al, 1996; Bell et al., 2000). In the tight coupling approach GIS and simulation models are linked with a common user interface. While it appears to user as one system, GIS and simulation elements remain separate (Fedra, 1996). A tight coupling approach requires significant amount of software engineering to either add GIS functions to analytical models or to add modelling capabilities to a GIS.

The object oriented programming approaches have been used in the recent studies to integrate the hydrological models with the spatial data or GIS (Raper and Livingstone, 1995; de Oliveira et al., 1997; Huang and Lin, 2002; Smiatek, 2005; Papajorgji and Shatar, 2004).

Using these approaches many studies have been reported in the recent years on hydrological model integration with GIS. The studies range from simple hydrological data visualization (Furmann, 2000), hydrological parameter estimation (Bhaskar 1992, Smith & Vidmar, 1994; Shumann, 1993) to distributed hydrologic modelling (Krummel et al., 1996; Srinivasan and Arnlod, 1994; Johnson and Miller 1997). Selected studies have been summerised in Table 2.2. This is a demonstration of recent advances in the integration of GIS to the hydrological of models and popularity of approach amoungst the research community.

Table 2.2 Summary of selected studies on integration of GIS and hydrological models

Author	GIS	Hydrological Model	Focus
Calijuri et al., 2002	MapObjects	-	Digital Land Use Cartography
Dai et al., 2003	ArcView	EMDS	Knowledge-Based Model of Watershed Assessment for Sediment
Dikshit and Loucks, 1996	ERDAS	CNPS NPS Pollution Model	Prediction of Land Use Change on N and P Loading
Djokic, 1996	ArcInfo	HEC-1	Rainfall-Runoff Modelling in a Watershed
Engel et al, 1993	GRASS	ANSWERS AGNPS, SWAT NPS	Comparison of Coupled Models to Monitored Runoff
Facchi et al., 2004	-	SVAT MODFLOW	Water Resources Simulation in Irrigated Alluvial Plains
Furhrmann, 2000	MapObjects	-	Visualization of Hydrologic Data
Garnier et al., 1993	GRASS and IDRSI	NASA EOS Distributed Model	Integration of GIS to Physically Distributed Models
George et al.,2004	GeoMedia	ET and Paddy Water Balance	Irrigation Scheduling Model
He, 2003	ArcView	AGNPS	Runoff and Sediment Modelling
Hellweger and Maidment, 1999	ArcInfo/Arc View	HEC-HMS	Definition and Connection of Hydrologic Elements using Geographic Data
Huang and Lin, 2002	ArcView IMS	-	Geographic Virtual Reality Toolkit on the Internet
Joao and Walsh, 1992	ArcInfo	ANSWERS	Simulation of Non-Point Pollution Generated as a Consequence of Watershed Development Scenarios
Kim and Ventura, 1993	ArcInfo	SLAMM	Modelling Heavy Metal, Nutrients And Sediment
Krummel et al., 1996	ArcInfo	ANSWERS	Analysis of Land Cover Change on Hydrologic Parameters
Laio and Tim, 1997	ArcInfo	AGNPS	Agricultural Runoff and Pesticide Pollution Modelling
Leavesley et al., 2002	ArcInfo	WARSMP	Modular Approach Addressing Model Design, Scale and Parameter Estimation Issues in Distributed Hydrological Modelling
McKinney and Cai, 2002	ArcView	Water Balance	Object Oriented Water Resources Modelling
Morari et al., 2004	ArcInfo	NPS	Selecting Criteria of Best Management Practices
Naoum et al., 2005	Arc View	IDOR3D	Pollutant Transport Modelling
Newham et al., 2004	ArcInfo	IHACRES	Integrated Hydrologic, Sediment and

		SedNet	Nutrient Export Modelling
Nyarko, 2004	ILWIS	Rational	Flood Risk Assessment
Portoghese et al., 2005	Arc View	Distributed Soil Water Balance Model	Hydrogeological Water Balance Evaluation on a Regional Scale in Semi-Arid Environments
Prisloe et al., 2001	ArcView	-	Impervious Surface Model
Remortel et al., 2004	ArcInfo	RUSLE	Computing the LS Factor for The Revised Universal Soil Loss Equation
Renschler, 2003	ArcView	WEPP	Geo-Spatial Interfaces to Scale Process Models
Ross and Tara, 1993	Tydac SPANS	FHM	Integrated Hydrologic Modelling
Sarangi et al., 2003	ArcGIS	DEM	Estimation of Watershed Geomorphology
Schluter and Ruger, 2005	ArcView	TUGAI	Illustration Implications of Uncertainties for Water Management
Srinivasan and Arnold, 1994	GRASS	SWAT	Non Point Pollution, Sediment And Pesticides Transport
Srinivasan and Engel, 1994	GRASS	AGNPS	Non Point Pollution, Sediment and Pesticides COD
Tim and Jolly, 1994	ArcInfo	AGNPS	Modelling Stream Runoff in Agricultural Watershed
Tsou and Whittemore, 2001	ArcView	MODFLOW	Groundwater Modelling
Wang et al., 2004	ArcView	Optimization	Land Allocation at a Watershed Level
Wen et al., 2004	MapObjects	FAO Modified Blaney-Criddle, Thornthwaite, Penman-Monteith	Regional Irrigation Water Demand Assessment
Xie et al., 2005	ArcIMS	-	Spatial–Temporal Analysis of Monsoon Rainfall Patterns
Zhan and Huang 2004	ArcMap	NRCS CN	Generating Curve Number and Runoff Maps

2.6 Summary and Research Needs

The literature review has been done on the issues related to watershed management specifically on water resource management and water harvesting. Integrated planning of water resources is found to be emerging area of development in arid and semi-arid ecosystems. Application of remote sensing and GIS techniques applied to the various studies related to watershed hydrology has been demonstrated, specially for Indian conditions.

These techniques are found to be useful to tackle the problem of data availability. Integration of hydrological models and GIS has been discussed in details, as it is crucial for the design and development of DSS. Over the years, the development in the field of information technology has lead many modellers and hydrologists to develop various sophisticated models. The object oriented approach along with the embedded coupling of hydrological models, make it easy to implement the decision methods. The out come of which usually leads to the development of unified systems such as information systems.

From the wide literature and other resources available on the DSS, it is observed that the most of the DSS developed or available are either area specific or problem specific. Many DSS have been reported on river basin and reservoir planning & management. Some of the DSSs available for the watershed concentrate on environmental problems, such as pollutant load and water quality. The Indian approach of watershed management is generally based on natural resources management. However, the objectives may vary according to interest groups and implementing agencies (water users, agriculturists, foresters and land use planners). Hence, these DSS can not be directly used for Indian conditions. The watershed based water resources planning approach can be implemented by developing the software based DSS with user friendly Graphical User Interface (GUI) if it is to be readily adopted by the decision makers.

CHAPTER 3

CONCEPTUAL FRAMEWORK OF DECISION SUPPORT SYSTEM

3.1 Prelude

Conceptual framework provides a foundation and basis for the development of any Decision Support Systems (DSS) or Spatial Decision Support Systems (SDSS). With the recent advances in the information technology, there are many alternatives to develop the software-based DSS. The object oriented programming languages and their compatibility with certain Geographical Information System (GIS) software or workstations have given developers an added advantage to go for stand-alone software-based DSS.

This chapter discusses the various approaches which are available to develop DSS. Different alternatives of coupling of models to the Graphical User Interface (GUI) and subsequently to the GIS data have been covered in details. This chapter closes with the system architecture of proposed DSS, considering the enormous need of software platform to be developed.

3.2 System Design of DSS

The DSS and SDSS design given by Walsh (1993) can be considered as one of the pioneering frameworks, the components of which are shown in Fig. 3.1. The elemental difference in the DSS and SDSS is integration of GIS to GUI. This has been illustrated in Fig. 1a and Fig.1b. Essential components of DSS and SDSS are;

(i) Database capabilities with access to internal and external data and information

(ii) Modelling functions accessed by a GIS (in case of DSS) and model base and

(iii) User interface.

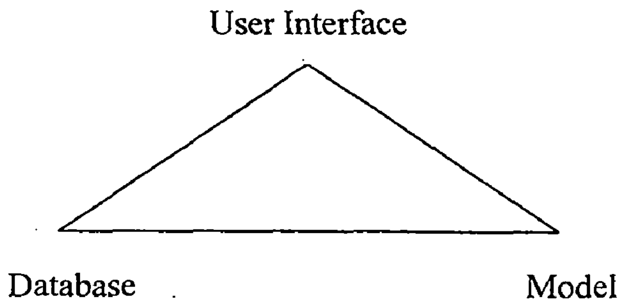


Fig 3.1a.Componenets of a DSS

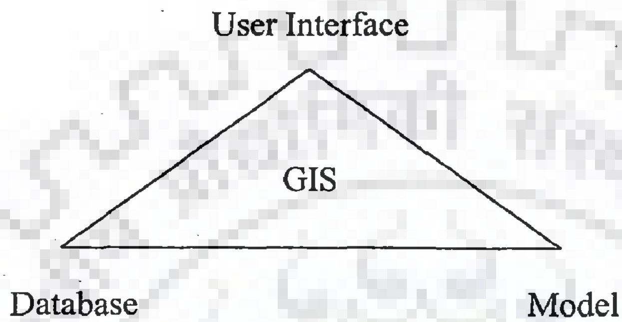


Fig 3.1b.Components of a SDSS

The DSSs incorporate the spatial and general database, simulation and optimization models and user interface to aid the interactive decision making (Walsh, 1993). The numerical or simulation modelling related to spatial problems is carried out in an integrated platform of GIS, user interface and database. The GIS and DSS are closely related, as the existence of DSS needs inclusion of GIS elements or components. The GIS has capabilities of data storage, queries and visualization of spatial data. In spite of having low capabilities of mathematical modelling of spatial systems, it supports external modelling routine and interfacing. Thus, the user interface, database and model base, and GIS are the core constituents of any DSS.

The spatial analysis tools, such as GIS or Computer-Aided Design (CAD) do not include the analytical capabilities. Therefore, they may not provide a complete solution to the problems of modern decision-making. Integration of automated tools to form a DSS is desirable, if not essential. There are many challenges related to data management and data inter-operability between the modules. Data exchange and transfer, sharing of results between models, a smooth data flow and efficient processing of information, are some of the critical issues in the development stages of DSS.

3.2.1 Database

Database is important in any decision-making activity. In DSS, it forms a core component which manages the data for models and methodologies to be used. Watershed management DSS requires substantial amount of data. Spatial data related to watershed can be held in any GIS, whereas non-spatial data can be stored in the Relational Data Base Management System (RDBMS). For watershed management problem, four sets of data provide fundamental information to each of the models used in the system, viz; spatial data (such as Digital Elevation Model-DEM), remote sensing data (e.g. land cover, soil data) and hydrological & meteorological data.

Using the DEM, users can derive the number of important functions, such as delineation of watershed, topography and watershed slopes, which are important inputs to many hydrological models. Remote sensing data can be used for the description of spatial pattern of land cover, which can provide the land use change information to models. The soil data is important for the derivation of land capability classification maps. This can also be helpful in defining the subsurface behaviour of hydrological models, and in planning and allocation of new land use after watershed restoration. Lastly, meteorological data are critical input to the hydrological and any crop-based agricultural models.

3.2.2 Model Base

Models form the important component of any DSS. They are used to define the relationship among the important variables that are crucial in decision-making. The models in a DSS can be both procedural (i.e. algorithmic) and non-procedural (e.g. heuristics). The procedural models are typically built around the mathematical algorithm, which are efficient but opaque to users (Walsh, 1993).

In a broad sense, there are two modelling approaches; either to build a new model for each application or to utilize existing models wherever possible. The first approach has the benefit of controlling the model design and linkage, but requires longer development time. The second approach saves development time, but requires additional work to link up the existing models (Lam, et al., 2004). Examples of both modelling approaches for reservoir management and water resources planning can be found in the literature (e.g. Loucks and da Costa, 1991).

3.2.3 User Interface

Since DSSs are intended to work closely with the decision makers in carrying out their operations, they can only be as effective as their interface with human being (Mallach, 2003). The user interface forms a linking media between the input parameters, database and model base. This provides a gateway to the system. It is not only used for displaying data and information held within the system but also for generating new watershed management scenarios. Recent development of information technology, interfaces can be designed and operated on GIS platform using Visual Basic for applications. There can be many utilities in the user interface, such as physical data, socio-economic data, and hydrological models, including groundwater, optimization models for management of resources, based on the availabile constraints.

3.3 Evolution of DSS Architecture

Until the development of object oriented paradigm and executable modelling languages (EML) and architecture of decision support the Structure, Mechanism and Policies (SMP) approach has been used in the decision-making (Segera, et al., 2003). These types of problems are solved by mainly multi-criteria decision making methods, such as optimization. The programming languages, such as PROLOG have been used for the development of the systems. Use of GIS is hardly found in these types of systems. Various GIS platforms developed their own programming languages, such as Avenue of Arc View, Arc Macro Language (AML) of Arc Info, and Grass Modelling Language (GML) of GRASS. Various researchers and developers have used these languages for the development of DSS and enhancing the applicability of GIS. The object oriented programming (OOP) approach and its use in DSS development for integrating numerical models is quite convenient with the use of fourth generation programming languages, such as MS Visual Basic, Java, HTML and now XML.

Various researchers have tried to meet these challenges by developing the DSS architecture or system design. Development in the information and geo-processing technologies has lead to the evolution of DSS design architecture. Various possibilities of development of DSS were explored before finalizing the tight coupling method of integration of models to GIS and user interface. The various ways of integration have been discussed in the following sub-sections.

3.3.1 Loose Coupling

This type of approach does not directly integrate the GIS with models. Rather the output generated by the GIS is accessed by the simulation packages or platforms, then the modelling or simulation activities are carried out. The advantage with this type of system is possibility of use of higher algorithm, such as artificial neural networks and genetic algorithm in the decision-making. Graphic output generation and embedding can be a limitation to this type of system. Fig. 3.2 shows the use of simulation package MATLAB in the DSS coupled with GIS optimization of water resources (Markopoulos, et al., 2003).

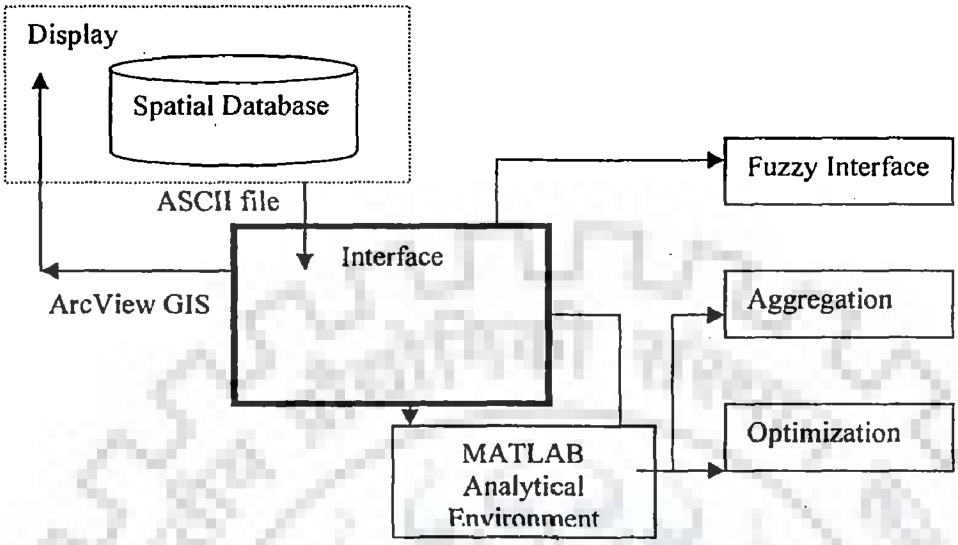


Fig 3.2. System architecture by loose coupling (Markopoulos et al.,2003)

3.3.2 Tight Coupling

GIS and numerical models are linked through a common user interface. More often, the models are developed outside the GIS. It has its own data format of exchange between GIS and model.

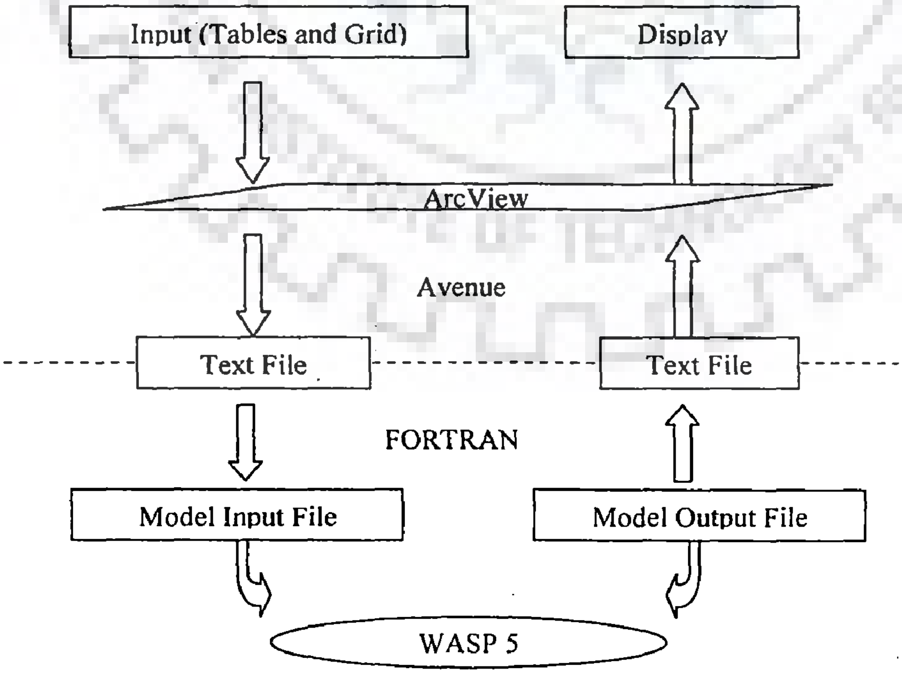


Fig. 3.3. DSS architecture as used by tight coupling (Baneman et al., 1996)

The exchange of data is completely behind the GUI. The advantage with this type of coupling is that the replacement or improvement in the input data or model is possible. These types of systems may have pre-processors and post-processors. The system architecture for this type of integration using Arc View is shown in Fig. 3.3. It explains the DSS architecture of model WASP5 programmed in FORTRAN linked to Arc View by the interface developed in Avenue (Baneman, et al., 1996).

3.3.3 Embedded Coupling

The use of EML in GIS and compatibility of different programming languages with GIS have made it possible for the development of DSS using embedded coupling approach. Model is developed and run within a GIS using the programming and development tools of a given GIS (Application Programming Interface (API), scripting tools). Inputs and outputs are in a GIS database and computation is efficient; however the processing speed of the application can be slower (Mitasova, 2004).

The various technologies available can be used in the development of DSS. The system architecture for various such possible technologies is presented in the following sections:

3.3. 3.1 MS Visual Basic and ESRI MapObjects

ESRI MapObjects is an ActiveX (combined collection of program) control with nearly 50 programmable ActiveX automation objects that can be plugged into many standard Windows development environments, such as VB, Visual Basic for Applications (VBA), Visual C^{++}, Visual Studio.NET (VB.NET), C#, Delphi, and Borland C^{++} Builder (Ralston, 2002). Those have many capabilities of analysis and data format support. Fig. 3.4 explains the schematic architecture of DSS of development using Map Objects and Visual Basic (Dhore, et al., 2005). The application can be deployed as an executable file or set up file to launch the application.

3. 3. 3.2 ArcObjects and VBA

ESRI's ArcGIS 8X environment has come up with the incorporated macros using Microsoft's Component Object Model (COM) technology, which supports the extended application development inside the platform. The development platform for ArcGIS applications is called as ArcObjects. These macros can be used as tool for DSS development using COM compliant language, such as Visual basic and VC^{++} (Zeller, 2001).

The VBA, which is embedded in the ArcMap, uses the functionality and framework of ArcMap (Razavi, 2002). This can be used to develop the DSS by creating the graphical user interface (GUI) and integrating models. The context diagram for such type of system is given in Fig 3.5.

All the system design architecture discussed above, are based on the stand-alone application and deployment. Web based deployment is becoming more popular amongst the DSS users.

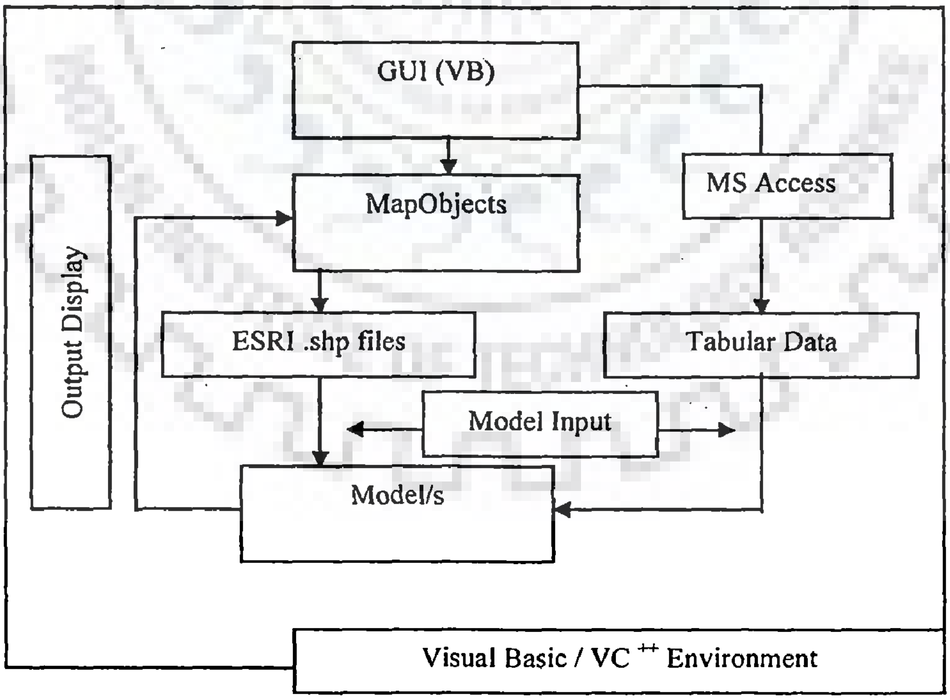


Fig. 3.4. DSS architecture using MapObjects and Visual Basic

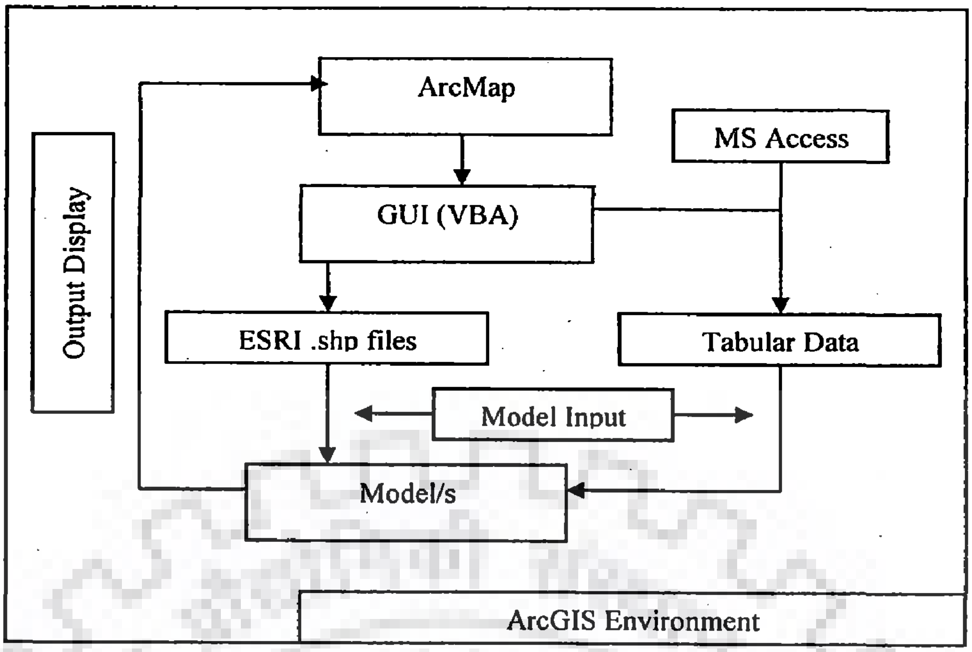


Fig. 3.5. DSS architecture using Arc Objects and Visual Basic for application

3.3.4 Web based DSS Design

The ESRI MapObjects technology can be used for development of web-based DSS using Map-server, Hyper Text Markup Language (HTML) and VB scripts. The system design architecture can be divided in two parts; client side and server side. The client side interface can be programmed in HTML, while server side can be deployed with MapServer (Choi and Engel, 2003). The schematic of such a DSS is presented in Fig 3.6.

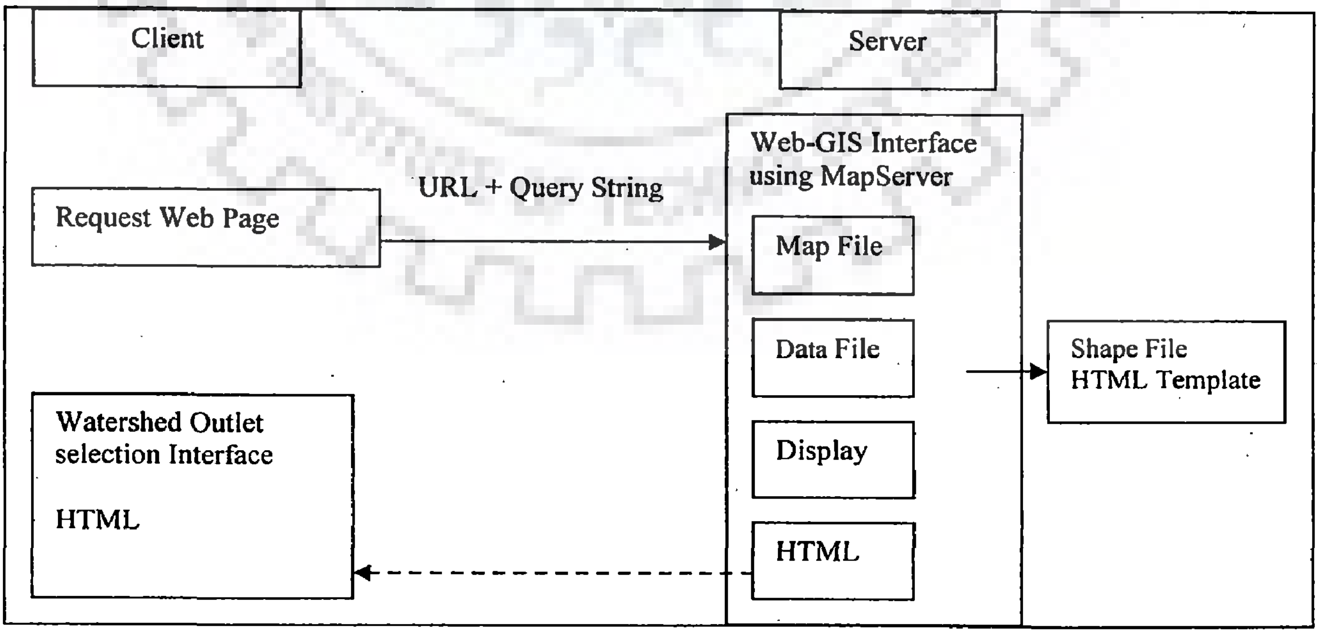


Fig. 3.6. Schematic of Web-GIS map user interface (Choi and Engel, 2003)

3.4 System Architecture for Proposed DSS

Water resource planning in a watershed can be divided into three major components viz; (i) assessment of available water, (ii) assessment of demands, and (iii) formulation of policy for allocation of water use among different user sectors. The available water can be either surface water or groundwater or both as result of seasonal rainfall. The water demands can be domestic needs of human population as well as of animals. The agricultural water requirement is also a major part of water demand in the watershed. The water allocation at particular time interval would comprise of judicial allocation from different sources in the various demand sectors. To yield the desired benefits of watershed management approach, certain conservation measures need to be adopted in the watershed. The land use allocation among the different crops can be optimized depending on the population, their needs and water availability. Considering this, the proposed DSS is planned to be developed with various interfaces or modules. These modules are Basic data, Rainfall, Evapotranspiration, Geomorphology, Surface runoff, Groundwater recharge, Water conservation structures, Water use plan, Land allocation, and Forecasting. Various sub-modules have also been developed in the respective module, wherever required. In most cases, the sub-modules have provided an alternative to each other depending upon the data needs of model. The various modules and their sub-modules have been illustrated in Fig. 3.8

Implementation of these modules and their sub modules was done in the form of DSS that could handle GIS data. The basic structure or conceptual framework of the DSS has been illustrated as follows.

Using the tight coupling concept of model integration to GIS and user interface, the DSS is planned to be developed by using the system architecture, as shown in Fig. 3.7. This architecture uses an ActiveX control of ESRI MapObjects with MS VB 6.0.

A conceptual system framework for proposed DSS is shown in Figure 3.7 In this framework, information flows from raw sources (A) through filters (B) into a user interface (C). Specific object data (D) is extracted from user interface to input files for models or for use in data analyses (E). The results of modelling and data analyses are used in output display module (F), which defines the relationships between variables. Finally, output data are accessed to the scenario generation (G) to produce the decision support (H), as needed for different watershed management problems. Each of the nodes shown in the flowchart (Fig 3.7) is one of three types: database, user interface and program modules. These are described, followed by a description of the key blocks of nodes in the diagram:

(1) Database nodes represent any data that is passed through the DSS, either into or out of software modules. This database includes raw and filtered data, data summaries and other information to be used in the decision making process.

(2) Program modules represent either a block of code within a software program or an independent software program, which analyses and produces information. These modules include functions for filtering raw data sets, producing data, performing data analyses, modelling and taking user input for further use.

(3) Requests made to the system by the users are represented in user interface nodes.

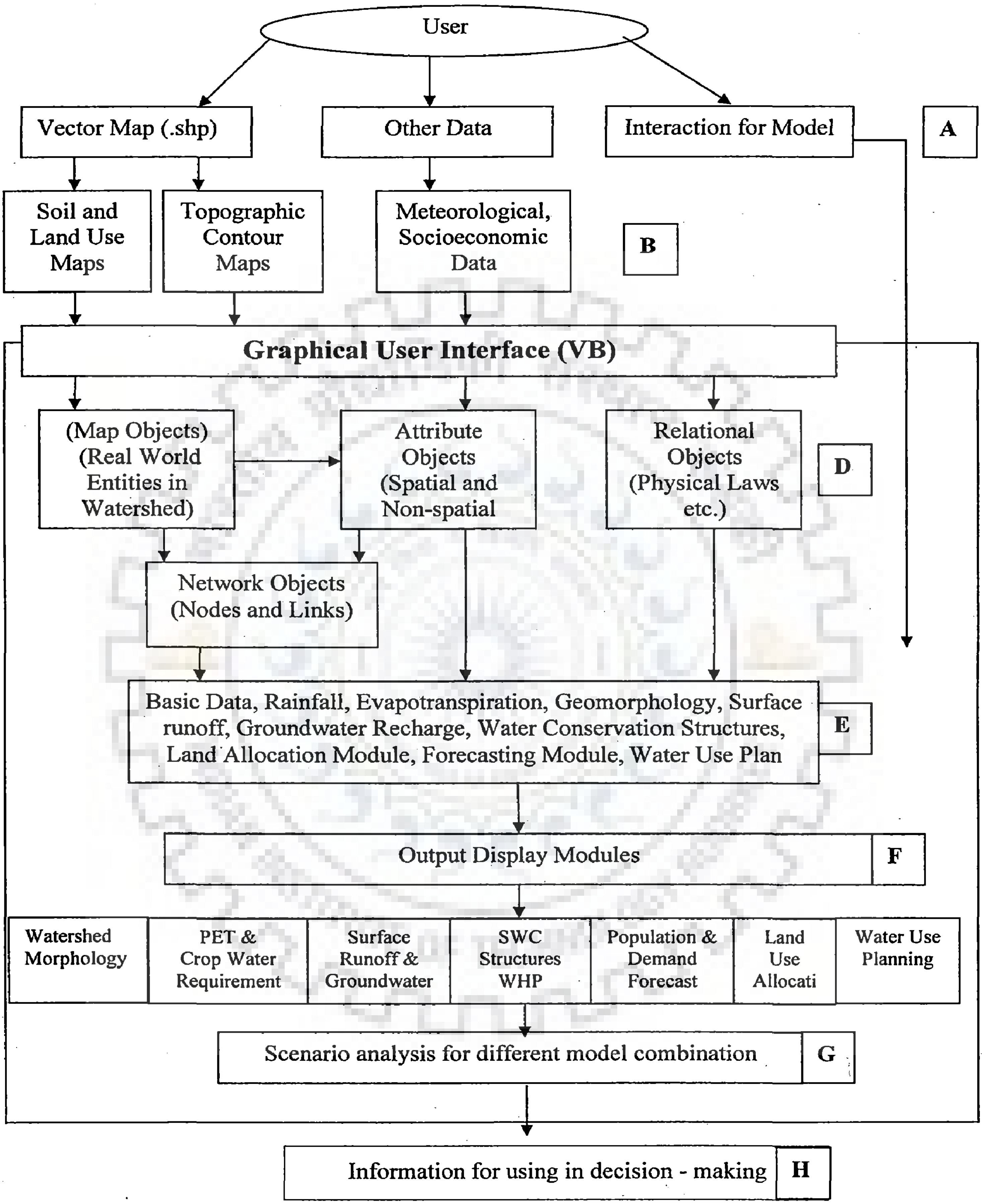


Fig.3.7 Conceptual Framework of Proposed DSS

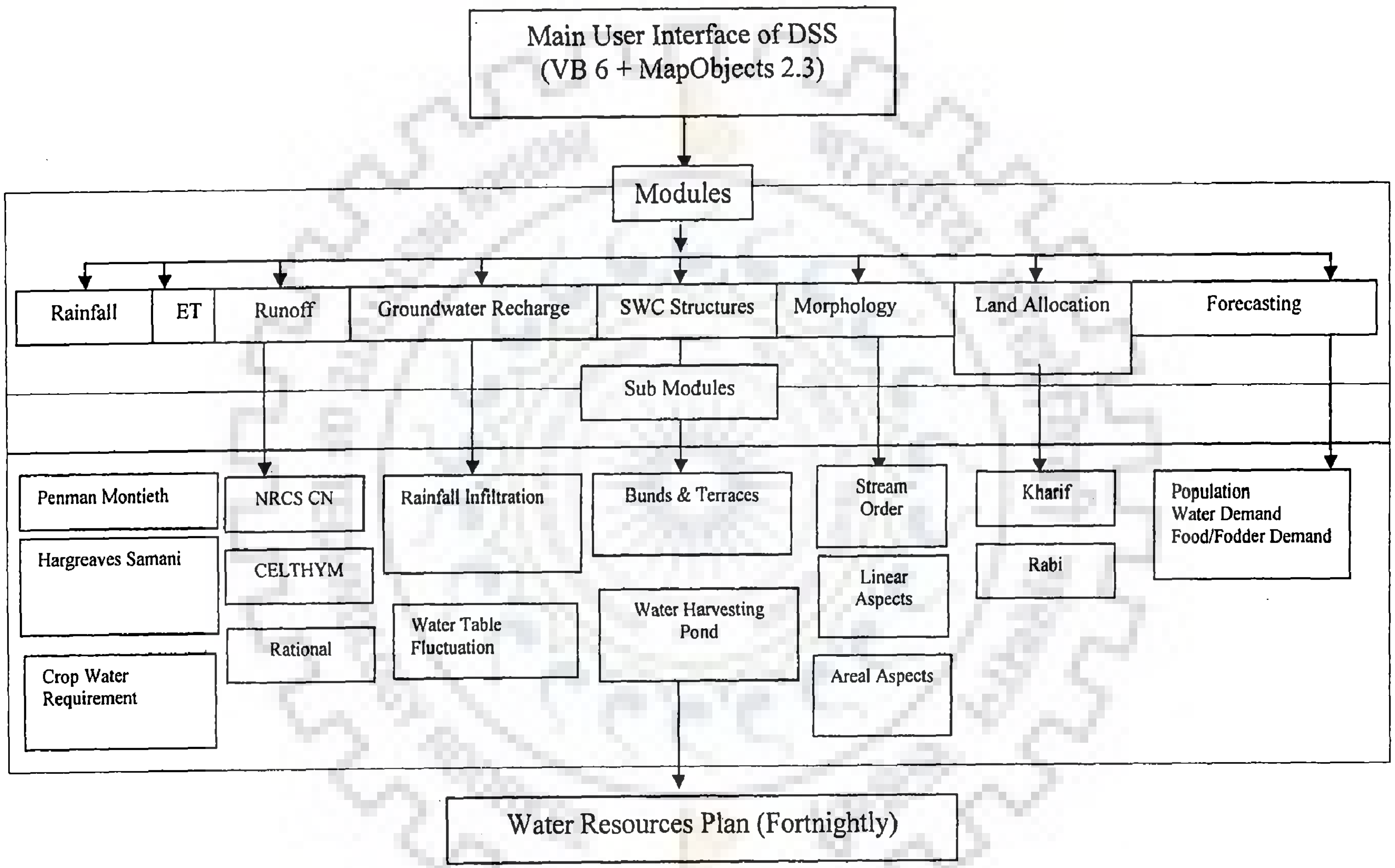


Fig. 3.8 of Modules and their sub modules in DSS

CHAPTER 4

STUDY AREA PROFILE

4.1 Prelude

This chapter gives the general information of the selected rural watershed of Khadak Ohal village in Nashik district of Maharashtra state in the western India. It furthermore gives the information regarding the general nature of soils in area, geology and overall climatic or meteorological picture.

4.2 Topography

The Khadak Ohal watershed comprises of 1726 ha (Anon, 1998) area in Khadak Ohal, Goldari, Deodongra and Deodongri villages having a total population of a 5844 (Census of India, 2001). The watershed lies in the Survey of India topographic sheet number 48N/6 with longitude from $73^0$16.5' to $73^0$19' E and 20^0 2.7' to 20^0 6' N latitude (Anon, 1998). The watershed has an elevation difference of around 360 m from outlet to the ridge of the watershed with a maximum distance of 6.436 km along the main drain. The maximum extent of watershed is 4.215 km across the main drain. Nearly 16 % of total area of the watershed has more than 25% slopes. Around 400 ha out of the total area have slopes less than 10 %.

4.3 Physiography

Khadak Ohal watershed lies in much dissected region situated to the west of the *Sahyadri* edge of *Deccan* plateau in district Partakes of the nature of costal area called *Konkan* and, may be described as *Downghat Konkan* tract. It lies in newly carved Trimbakeshwar Tahsil out of Peint and Surgana in the extreme northwestern part of Nashik District in the state of Maharashtra, India. Figure 4.1 gives the location map of the watershed.

The area has a series of valleys and interfluves resulting from dissection by streams running in very deep beds. The hills are in many cases higher than those of the plateau edge of the *Sahyadri*, which itself is an evidence of the easterly retreat of the watershed, but the general elevation is about 200 m below the levels of the plateau edge. The continuous succession of billowy ranges and green patches of villages in the valleys give this region an air of picturesqueness.

The villages in the area are generally located on the lowest ends of spurs, which offer relatively high sites surrounded on all sides by depressions where cultivation takes place, or on low interfluves between adjacent valleys, which offer high sites above inundation levels. The consequence of such a high site is that the people will have to go down some distance to obtain their domestic water supplies from the wells located in the valleys down below. The extreme isolation and backwardness with the unproductive nature of the terrain accounts for the general poverty of the area.

The climate of this part is different from rest of the district. The winter is fairly severe but generally of short duration. Summer months are very sultry and unbearable. The rainfall of this tract is heaviest in the district but is wholly confined to the monsoon months from June to September. Outside this season water is a serious problem for people and crops. Forest occupies most of the area and the land suited for agriculture is limited owing to the extreme ruggedness of terrain.

Agriculture consists of mainly Paddy growing in the valleys and millets on hill slopes (Mehrotra, 1999). The smaller valleys are converted into a beautiful series of rice terraces one below the other in the trough. The higher terraces in these troughs are sown early with rice in the monsoon season, as the heavy rains do not damage them because of good drainage conditions. Fig. 4.3 shows the typical agricultural areas in the lower reaches.

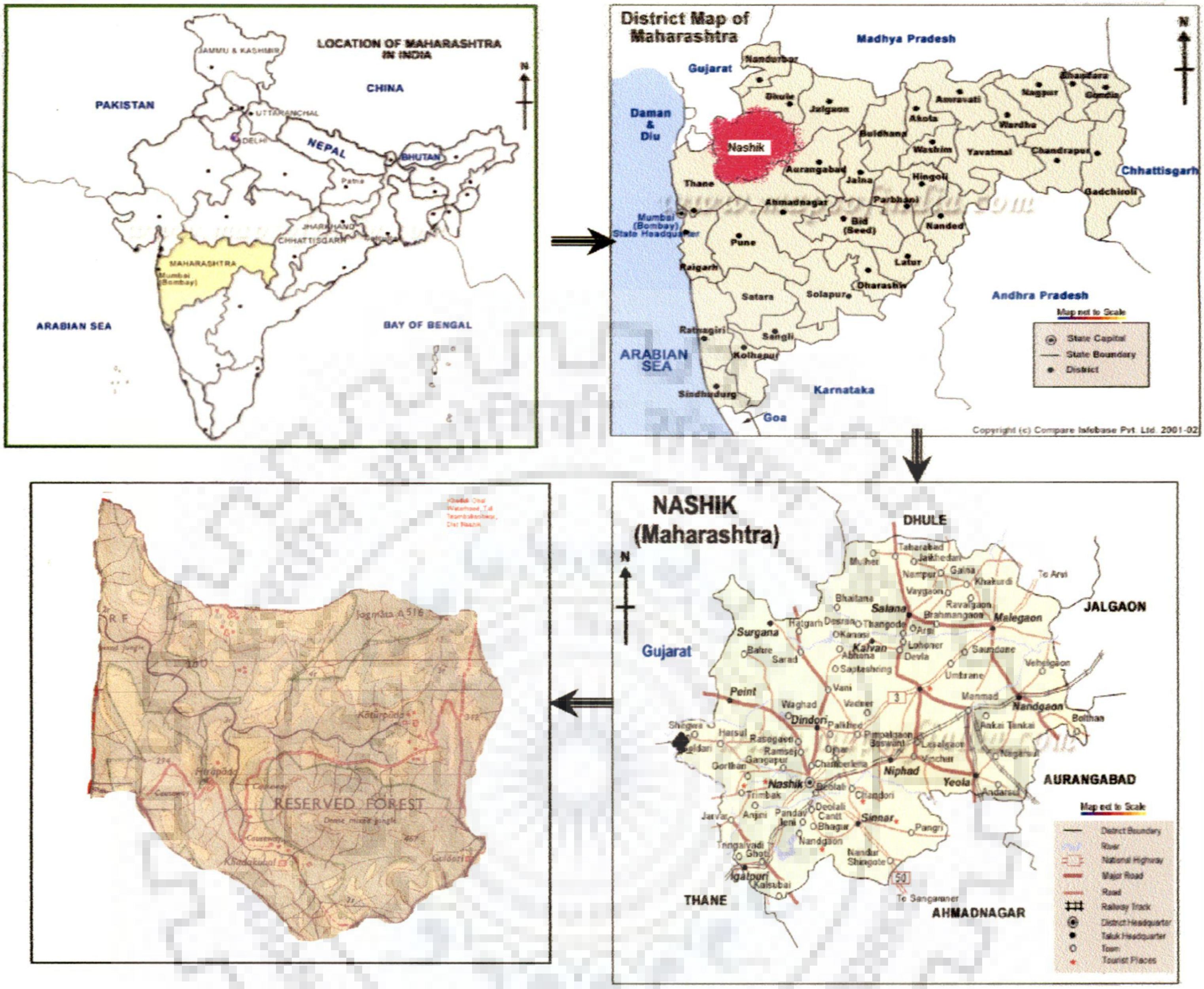


Fig. 4.1 Study area location map

There is a progressive delaying of the time of sowing down in the lower terraces, so as to escape the adverse effects of flooding during the heavy rains and also to take advantage of the longer period of accumulation and retention of moisture in such low areas. So in the month of October, one can notice the gradual variation from the harvested stubbles of crop in higher fields up the valley through mature crops waiting to be harvested to the growing crops in green lower down the valley. River Damanganga drains complete area in to Arabian sea near Vapi in Gujarat state.

4.4 Damanganga Valley

The Dawan River, known as the Damanganga in its upper course, rises near Mangone (Mangunpada) and flows southwards and turns westwards. From here, it has a long winding, a deeply entrenched course to the west, where its tributary, the Gordi River, joins it. The latter rises west of Peint and after flowing a short distance westward, it turns southwards forming the state boundary to join the Dawan or the Damanganga. The principal river makes a slight bend into the district so as to include Khamshet village on the right bank within the district and turns and runs westwards forming the Gujarat state boundary for the rest of course in the district leaving it to the north-west of Deodongri village.

The Damanganga basin is situated at longitude of $72^0$40'-$73^0$40' E and latitude $19^0$45'-$20^0$20' N falling in two states of Maharshtra and Gujarat and union territory of Div, Daman and Dadra Nagar Haveli. The elevation difference in the basin is 950m. The average forest area is about 47% of the total geographical area of the basin (Mehrotra, 1999) Figure 4.2 shows the index map of the Damanganga basin. Figure 4.4 shows the photograph of the Damanganga valley.

River Valley Project, Ministry of Agriculture, Government of India has subdivided entire upstream area of Madhuban Dam on Damanganga River into number of watersheds having high priority. The Khadak Ohal watershed has been numbered as DC1b. The silt monitoring station (SMS) has been installed in 1999 for watershed, which gauges 805.78 ha for Khadak Ohal watershed.

4.5 Water Resources

Groundwater is the main source of water in the watershed. There are 3 dug wells in the watershed, which forms the lone source of drinking water. Some of the springs were seen in the watershed generally used for fulfilling other domestic needs of habitants. Considerable amount of runoff is generated from the watershed due to assured rainfall of around annual average of 2200 mm (Mehrotra and Singh, 1998). In absence of any storage or detention structure, it simply goes down stream in Gujarat state to join the Madhuban reservoir. The agricultural water requirement is met through growing only *Kharif* crops. There is no facility for irrigation during the *Rabi* and summer. The average rate of evapotranspiration is about 0.3 mm/hr in summer.

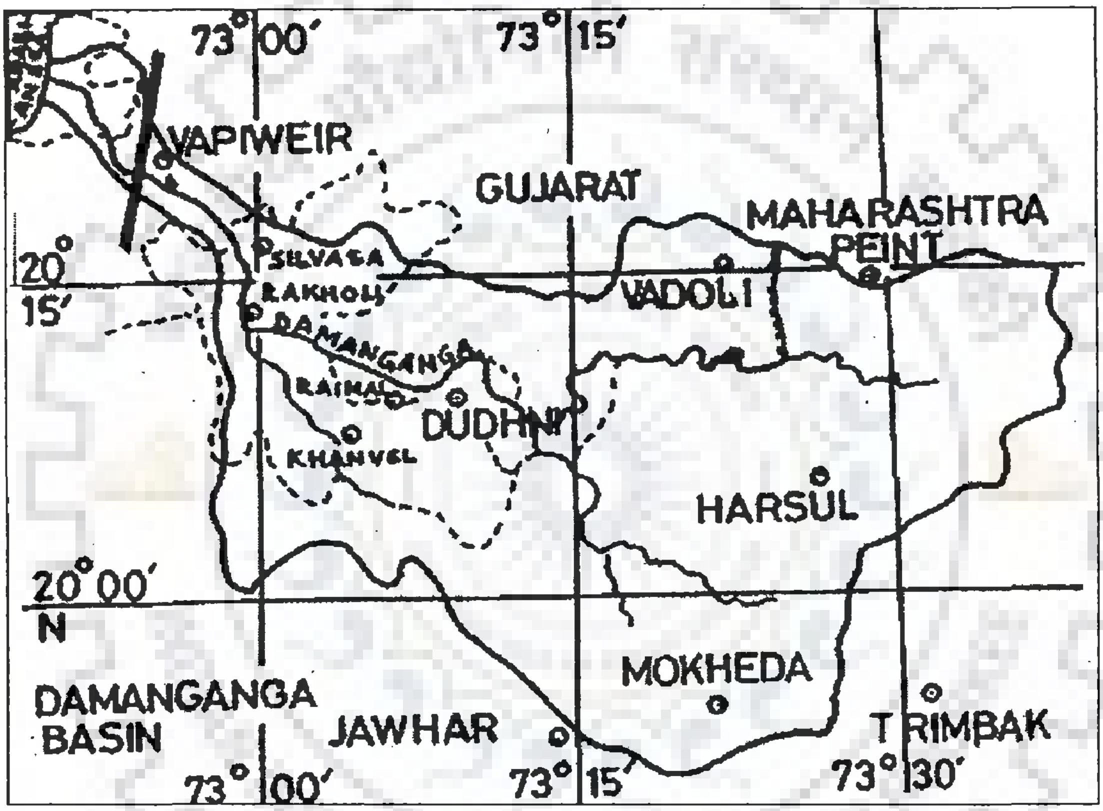


Fig. 4.2. Index map of the Damanganga basin.

Fig. 4.3 Agricultural area in the lower reaches of the Khadak Ohal watershed

Fig. 4.4 Damanganga valley as seen from the ridge of the watershed

4.6 Geology

The Great Trap region of the *Deccan* covers the whole district. It is entirely of volcanic formation. The volcanic portion consists of compact, stratified basalts, and an earthy trap. The basalts are the most conspicuous geological feature. To the west, they lie in flat-topped ranges, separated by valleys, trending from west to east. In some flows, the basalt is columnar and then it weathers into the fantastic shapes. The formation at the base of the traps is chiefly amygdaloidal, containing quartz in vertical veins, crystals and zeolitic minerals, especially apophyllite weathering into a gray soil. The absence of laterite, which caps the summits of the hills to the south, is a curious feature in the geology of the area. The basalt is either fine textured or coarse and nodular.

4.7 Soils

The parent material all over the district is Deccan trap. The soil formation is mainly affected by the climatic conditions and topography of the district. In the western part of Igatpuri, Surgana and Peint, soils are developed under humid conditions, with some laterite soils being observed at higher altitudes of the hills. Light shallow soils are noticed on hill-slopes and very coarse textured soils on still higher relief.

The soils in this zone are neutral in reaction, containing higher amounts of organic matter and low in their base status. They are slightly alkaline in reaction and contain moderate amount of organic matter. The exchangeable bases are observed to be high as compared to the soils of transition and heavy rainfall tract. The typical soil profiles in the study area are given in the Table 4.1.

Table 4.1. Description of typical soil profiles in the hilly tract of Nashik district (District Gazetteer, 1975)

Phase	Medium deep
Depth (cm)	Soil Characteristics
0-15	Yellowish brown silt clay loam; single grained; friable; slightly moist; black concretions present
15-30	Dark yellowish- brown clayey; slightly moist, blacker concretions; yellowish murum; pebbles present.
< 30	Reddish murum
Phase ⟶	Very deep
0-17.5	Yellowish brown; clay loam; compact; black and white concretions present.
17.5-50	Grayish brown; clay loam; slightly moist and massive; white and black concretions in increased quantity present.
50-120	Dark grayish yellow; clay loam; more moist and massive; compact; profuse black and white concretions present

4.8 Climate

Climate of the area is characterized by dryness except in the south-west monsoon season. The year may be divided into four seasons; the cold season from December to February, followed by the hot season from March to May and the south-west monsoon season from June to September, followed by the post-monsoon season during October and November.

4.8.1 Rainfall

There is an uneven distribution of rainfall. In the narrow strip of the district in the close proximity of the *Western Ghats,* the rainfall is more than the rest of the district. On an average, the rainfall in this narrow strip increases from 2,351.6 mm at Peint in the north to 3,341.6 mm at Igatpuri in the south; it decreases to 600.00 mm in the central and eastern sectors of the district. The western track of the district is covered by high hills, and has a rugged terrain. The monsoon wind carrying moisture first meets these hilltops where it deposits much of its water. Surgana, Peint and Igatpuri come under this track. About 88 percent of the annual rainfall is received during the southwest monsoon season from June to September; July being the rainiest month. During May and the post-monsoon months of October and November some rainfall, mainly in the form of thundershowers occurs.

The number of rainy days are high on the narrow strip of the district in close proximity to the *Western Ghat*, and varies from 89 days at Peint in the north to 102 days at Igatpuri in the south. The heaviest rainfall in 24 hours recorded at any station in the district is 473.7 mm at Peint on July 2, 1941. Table 4.2 gives the average monthly rainfall and number of rainy days in the three *tahsils* of hill tract.

4.8.2 Temperature

There are two meteorological observatories in the district, one at Malegaon in the eastern part and the other at Nashik. In the region of the *Western Ghats*, the temperatures may be much lower than at Nashik depending on the elevation. Temperatures begin to increase rapidly from about the latter half of February. May is the hottest month with the mean daily maximum temperature at 37.4 °C (99.3 ° F) at Nashik. Mean minimum and maximum temperature are given in Table 4.3.

4.8.3 Humidity

The air is very humid during the southwest monsoon season. In the post-monsoon during cold and summer seasons the air is dry. The summer season is the driest part of the year. It is reported in literature (District Gazetteer, 1975) that RH may become as low as 20% to 25% in afternoon on some days during summer season. Monthly variation of relative humidity is given in Table 4.3.

Table 4.2. Average rainfall with average rainy days in western part of Nashik district (District Gazetteer, 1975)

		Months					
Stations		Jan	Feb	Mar	April	May	June
Peint	R.D.	1.4	1.0	1.0	2.0	3.0	11.9
	R.F.	6.7	7.3	6.0	18.5	51.2	264. 9
Trimbakeshwar	R.D.	2.2	1.0	1.5	1.6	3.0	13.2
	R.F.	16.1	7.2	5.4	20.2	12.1	273.8
		July	Aug	Sept	Oct	Nov	Dec
Peint	R.D.	26.7	26.9	15. 6	5.2	2.4	1.4
	R.F.	948.2	649.2	313.5	91.5	40.9	15.3
Trimbakeshwar	R.D.	27.0	26.7	19.6	5.47	2.5	1.5
	R.F.	985. 5	709.7	315.8	108.8	34.8	13.5

RD = Rainy Days, RF = Rainfall, mm

Table 4.3 - Normal temperature and relative humidity (District Gazetteer, 1975)

Month	Mean Daily Maximum Temperature °C	Mean Daily Minimum Temperature °C	Relative Humidity (Mean) %
January	28.4	10.1	73
February	29.9	11.3	66
March	34.7	15.0	51
April	36.2	18.9	53
May	37.4	21.5	63
June	32.7	22.8	77
July	27.7	21.8	85
August	27.6	20.9	85
September	28.3	19.8	85
October	31.6	17.7	75
November	30.4	13.2	66
December	28.3	10.2	69

4.9 Concluding Remarks

The Khadak Ohal watershed described in this chapter has been used as a prototype watershed to test and demonstrate the application of developed DSS. This watershed was considered appropriate for the water resources planning as it experiences the scarcity of water during the non-monsoon months. The extreme living conditions of people in the area motivated to select this watershed for demonstration. The GIS database has been generated for this watershed, which would be discussed in Chapter 6. This GIS has been used as input to the models wherever required in the modules and sub-modules of DSS.

CHAPTER 5

MODEL BASE

5.1 Prelude

This chapter gives the details of models and methods used in development of the interfaces of DSS. Each model used in present study has been described with their formulae, associated data and the assumptions. The models have been selected keeping the various needs of DSS and their input data requirement. The following points are taken into consideration while opting for a particular model form a variety of available models.

1. Popularity of model in global and Indian context
2. Simplicity of the model in terms of implementation and algorithm
3. Minimal data requirement (as in India, there are very few watersheds having detailed data, i.e. gauging, sediment monitoring)
4. Ability to integrate with the spatial or GIS data
5. Availability of programing codes

Most of the models have been used in their present available form and are described from the source, but in order to reach at the decision in the DSS certain models (i.e. optimization) have been developed. The entire algorithms have been discussed in the following fourteen sub-sections, according to the module structure of DSS.

5.2 Methods for Surface Water Resources Assessment and Storm Runoff

There are two aspects of hydrologic design which are required in water resources planning on watershed basis. Hydrologic design for water use is concerned with the development of water resources to meet human and animal needs and with conservation of natural life in a watershed.

The other aspect of hydrologic design is concerned with mitigating the adverse effects of high flows or floods.

Several methods and computer based models are available in the text books on hydrology (Chow, et al., 1988) for surface water resources assessment. Some of the popular methods are NRCS Curve Number, SWAT, SWMM, KINORES, and CELTHYM.

In the present study following methods have been included in the development of module of DSS.

- NRCS Curve Number
- CELTHYM

These methods are commonly used by the water resources planners being relatively simple and requiring a few input parameters which can be applied to the daily time scale. These are most suitable to Indian conditions in light of the data availability. Extensive data normally are not available for micro watersheds. Further, main emphasis in the present study is on the development and demonstration of DSS.

For estimation of storm runoff are most commonly used methods Rational and SCS method.

In the present study Rational method has been used because of its popularity, simplicity and minimal data requirement. Input parameters for various stations across India have been standardized by Central Soil and Water Conservation Research and Training Institute, Dehradoon, India. Inclusion of this method in the DSS will help users to design the specific structures such as spillways.

5.2.1 Storm Runoff Estimation

The peak runoff resulting from a rainfall of uniform intensity can be determined by rational method or rational formula. The rational formula follows certain assumptions, which are given below:

i. The predicted peak discharge has the same probability of occurrence (return period) as that of rainfall intensity (I),

ii. The runoff coefficient (C) is constant during the rainstorm, and

iii. The recession time is equal to the time of rise.

The rainfall intensity is given by rainfall-frequency-duration relationship:

$$I = \frac{KT^{a}}{(t+b)^{n}} \quad (5.1)$$

Where, I = intensity of rain in mm/hr for design recurrence interval and duration equal to the time of concentration (t_c) of the watershed

T = return period in years

t = storm duration in hours

K, a, b, n are the constants.

The time of concentration is given by the Kirpich formula (Singh et al., 1990)

$$t_C = 0.01947K^{0.77} \quad (5.2)$$

In above equation, K can be estimated as:

$$K = \sqrt{\frac{L^3}{H}} \quad (5.3)$$

where, L = Length of flow path, m

H = difference in elevation (m) between most remote point (divide) and outlet

By the rational formula the peak rate of runoff (m^3/sec) can be estimated as:

$$Q = \frac{CIA}{360} \quad (5.4)$$

where, A = watershed area in ha

C = runoff coefficient

The values for the runoff coefficients (C) can be obtained from Table 5.1, and the values of a, b and n can be taken from Table 5.2, which describes the intensity –duration- return period relationship of storms in India. These constants for many places in India have been derived from the studies by Central Soil and Water Conservation Research and Training Institute, Dehradun, India (Subramanya, 2000).

Table 5.1. Values of C in Rational Formula (Singh, et al., 1990)

Vegetative Cover and Slope	Soil Texture		
	Sandy Loam	Clay and Silt Loam	Stiff Clay
I Cultivated Land			
0-5%	0.30	0.50	0.60
5-10%	0.40	0.60	0.70
10-30%	0.52	0.72	0.82
II Pasture Land			
0-5%	0.10	0.30	0.40
5-10%	0.16	0.36	0.55
10-30%	0.22	0.42	0.60
III Forest Land			
0-5%	0.10	0.30	0.40
5-10%	0.25	0.35	0.50
10-30%	0.30	0.50	0.60

5.2.2 Runoff Depth Estimation

There are two models used in this module to develope the interface of each module. The curve number method and cell based long term hydrological model (CELTHYM). These two models have been described in subsequent sections.

5.2.2.1 NRCS Curve Number Method

After considering various available methods of runoff estimation, the United States Department of Agriculture, Soil Conservation Service (SCS, now known as the Natural Resources Conservation Service, or NRCS) Runoff Curve Number (CN) method was chosen. The SCS curve number method is an empirical description of infiltration. It combines the infiltration with initial losses (interception and detention storage) to estimate the rainfall excess, which would appear as runoff. This model is relatively simple requiring a few input parameters. It can be applied to the daily time scale, which is most suitable to Indian conditions as most generally available data in India are the amounts measured by non-recording rain gauges.

Table 5.2. Intensity –duration- return period relationship in India

Zone	Station	K	a	b	n
Northern Zone	Agra	4.911	0.1667	1.25	0.6293
	Allahabad	8.57	0.1692	0.5	1.019
	Amritsar	14.41	0.1304	1.4	1.296
	Dehradun	6	0.22	0.5	0.8
	Jaipur	6.219	0.1026	0.5	1.1173
	Jodhpur	4.098	0.1677	0.5	1.0369
	Lucknow	6.074	0.1813	0.5	1.0331
	New Delhi	5.208	0.1574	0.5	1.1072
	Srinagar	1.503	0.273	0.25	1.0636
	Northern Zone	5.914	0.1623	0.5	1.0127
Central Zone	Bagra-Tawa	8.5704	0.2214	1.25	0.9331
	Bhopal	6.9296	0.1892	0.5	0.8767
	Indore	6.928	0.1394	0.5	1.0651
	Jabalpur	11.379	0.1746	1.25	1.1206
	Jagdalpur	4.7065	0.1084	0.25	0.9902
	Nagpur	11.45	0.156	1.25	1.0324
	Punasa	4.7011	0.2608	0.5	0.8653
	Raipur	4.683	0.1389	0.15	0.9284
	Thikri	6.088	0.1747	1	0.8587
	Central zone	7.4645	0.1772	0.75	0.9599
Western Zone	Aurangabad	6.081	0.1459	0.5	1.0923
	Bhuj	3.823	0.1919	0.25	0.9902
	Mahabaleshw	3.483	0.1267	0	0.4853
	Nandurbar	4.254	0.207	0.25	0.7704
	Vengurla	6.863	0.167	0.75	0.8683
	Veraval	7.787	0.2087	0.5	0.8908
	Western Zone	3.974	0.1647	0.15	0.7327
Eastern Zone	Agartala	8.097	0.1177	0.5	0.8191
	Dumdum	0.594	0.115	0.15	0.9241
	Gauhati	7.206	0.1557	0.75	0.9401
	Gaya	7.176	0.1483	0.5	0.9459
	Imphal	4.939	0.134	0.5	0.9719
	Jamshedpur	6.93	0.1307	0.5	9.8737
	Jharsuguda	8.596	0.1392	0.75	0.874
	North	14.07	0.1256	1.25	1.073
	Sagar Island	16.524	0.1402	1.5	0.9635
	Shillong	6.728	0.1502	0.75	0.9575
	Eastern Zone	6.933	0.1353	0.5	0.8801
Southern Zone	Banglore	9.275	0.1262	0.5	1.1280
	Hyderabad	5.250	0.1354	0.5	1.0295
	Kodaikanal	5.914	0.1711	0.5	1.0086
	Madras	6.126	0.1664	0.5	0.8027
	Manglore	6.744	0.1395	0.5	0.9374
	Tiruchirapalli	7.135	0.1638	0.5	0.9624
	Trivendrum	6.762	0.1536	0.5	0.8158
	Vaizag	6.646	0.1632	0.5	0.9963
	Southern zone	6.311	0.1523	0.5	0.9465

Ponce and Hawkins (1995) indicated that the method is widely used in USA and other countries, because of the perceived advantages of its (i) simplicity (ii) predictability (iii) stability (iv) reliance on only one parameter and (v) responsiveness to major runoff-producing watershed properties, including soil type, land use/treatment, surface condition and antecedent condition.

The curve number is estimated for a drainage basin using a combination of land use, soil, and antecedent soil moisture condition (AMC). The information needed to determine a curve number is the hydrologic soil group, which indicates amount of infiltration the soil will allow. Significant infiltration occurs in sandy soils while no infiltration occurs on heavy clay or rock formations. There are four hydrologic soil groups; A, B, C and D. The characteristics of each are given in Table 5.3.

Table 5.3. Definition of hydrologic soil groups

Hydrologic Soil Group	Soil Group Characteristics
A	Soils having high infiltration rates, even when thoroughly wetted and consisting chiefly of deep, well to excessively-drained sands or gravels. These soils have a high rate of water transmission.
B	Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.
C	Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.
D	Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

The USDA NRCS curve method predicts direct surface runoff using the following runoff equation:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \tag{5.5}$$

where, Q = actual runoff in mm

P = rainfall in mm

S = potential maximum retention and

I_a = initial abstraction during the period between the beginning of rainfall and runoff in equivalent depth over the catchment.

Antecedent moisture conditions are the soil moisture conditions of the watershed at the beginning of a storm. These conditions affect the volume of runoff generated by a particular storm event.

The AMC is defined as the initial moisture condition of the soil prior to the storm event of interest. SCS methodology expresses this parameter as an index, based on seasonal limits for the total 5-day antecedent rainfall (McCuen, 1982), as follows:

1. AMC I conditions represent dry soil with a dormant season rainfall (5-day) of less than 1.25 cm and a growing season rainfall (5-day) of less than 3.5 cm,
2. AMC II conditions represent average soil moisture conditions with dormant season rainfall averaging from 1.25 to 2.75 cm and growing season rainfall from 3.5 to 5.25 cm, and
3. AMC III conditions represent saturated soil with dormant season rainfall of over 2.75 cm and growing season rainfall over 5.25 cm. In general, curve numbers are calculated for AMC II, then adjusted up to simulate AMC III or down to simulate AMC I.

Depending on the AMC of the regions, the I_a values can be estimated as follows (Singh, et al., 1990)

For black soil region AMC II and III

$$I_a = 0.1S \tag{5.6}$$

For black soil region AMC I

$$I_a = 0.3S \tag{5.7}$$

For all other regions

$$I_a = 0.3S \tag{5.8}$$

The value required for S can be computed by using the following relationship between S and CN

$$CN = \frac{25400}{254 + S} \tag{5.9}$$

These AMC II values may be converted to AMC I or AMC III. The expressions for which are given as follows (Chow et al., 1988):

$$CN(I) = \frac{4.2CN(II)}{10 - 0.058CN(II)} \tag{5.10}$$

$$CN(III) = \frac{23CN(II)}{10 + 0.13CN(II)} \tag{5.11}$$

The AMC of a particular watershed can be decided depending on the 5-day antecedent rainfall. Table 5.4 gives the rainfall limits for estimating the antecedent moisture conditions. The curve numbers shown in Table 5.5 correspond to AMC II.

Table 5.4. Rainfall limits for estimating the antecedent moisture conditions

Antecedent Moisture Condition	5 day total antecedent rainfall, cm	
	Dormant Season	Growing Season
I	< 1.25	< 3.5
II	1.25 to 2.75	3.5 to 5.25
III	> 2.75	> 5.25

Table 5.5 Runoff curve numbers for hydrologic cover complex (for watershed condition II and $I_a = 2.0$ S)

Land Use/Cover	Treatment/Practice	Hydrologic Condition	Hydrologic Soil Group			
			A	B	C	D
Fallow	Straight Row	-	77	86	91	94
Row Crops	Straight Row	Poor	72	81	88	91
	Straight Row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Contoured and terraced	Poor	66	74	80	82
	Contoured and terraced	Good	62	71	78	81
Small Grains	Straight Row	Poor	65	76	84	88
	Straight Row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Contoured and terraced	Poor	61	72	79	82
	Contoured and terraced	Good	59	70	78	81
Close Seeded legume	Straight Row	Poor	66	77	85	89
	Straight Row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
	Contoured and terraced	Poor	63	73	80	83
	Contoured and terraced	Good	51	67	76	80
Pasture or Range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
Meadow(Permanent)		Good	30	58	71	78
Woodlands(Farm Wood)		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads			59	74	82	86
Road(Dirt)			72	82	87	89
Road (Hard Surface)			77	84	90	92

(Source: Singh, et al., 1990)

5.2.2.2 CELTHYM Model

The cell-based long-term hydrological model (CELTHYM) was developed to simulate the stream flow from small rural watersheds. The CELTHYM is a simplified, operational and conceptual model that uses grid data and a daily time-step.

A watershed is described in the model as a set of cells or grids. The watershed is comprised of several sub-watersheds, which are connected to the stream network grid, and each sub-watershed is composed of grids. The runoff is estimated by the sum of direct runoff and base flow. The direct runoff is calculated by the curve number method, and the base flow is estimated by the release from groundwater. The difference between precipitation and direct runoff is treated as infiltration. By comparing infiltration and soil moisture depletion, soil moisture and deep percolation is estimated (Choi, et al., 2002).

The CN is chosen from the CN table for a specific AMC based on land use and hydrological soil group. In CELTHYM model, an equation was proposed to estimate CN continuously to allow representation of varying soil moisture conditions. Using the definition of the AMC, AMC II was assumed at 50% of maximum available soil moisture (0.5 X ASMmax), AMC I was considered the soil moisture wilting point (*WP*), and AMC III was soil moisture field capacity (*FC*), because the soil moisture varies from *WP* to *FC* for natural situations after drainage of excess soil water by deep percolation processes. The *ASM*max value can be estimated as the difference between *WP* and *FC*. Estimation of *FC* values can be difficult owing to conditions that are site specific in terms of soil characteristics, combinations of different soil profiles and even presence of hardpans. However, reasonable *FC* values for CELTHYM operation can be obtained from tables, given soil texture and soil characteristics (Beasley et al., 1980). Although Arnold et al., (1995) suggested that the CN can be varied non-linearly, using soil characteristics and moisture condition, such an approach would be difficult to use with readily available soil data owing to the complexity of data items. Therefore, the CN was estimated to vary linearly from the CN I at AMC I to the CN II at AMC II, and the CN III at AMC III with equations given below. When the available soil moisture is less than 50% of ASM_{max} then:

$$a=\frac{(SM-WP)}{0.5\times ASM_{max}} \tag{5.12}$$

$$CN_{adj}=a\times CN_{II}+(1-a)\times CN_{I} \tag{5.13}$$

When the available soil moisture is greater than or equal to 50% of ASM_{max} then:

$$a=\frac{(ASM_{max}-(SM-WP))}{0.5\times ASM_{max}} \tag{5.14}$$

$$CN_{adj}=a\times CN_{II}+(1-a)\times CN_{III} \tag{5.15}$$

where, a - ratio between soil moisture of above/below 50% of ASM_{max} and 50% of ASM_{max},

CN_{adj} - adjusted CN for the current soil moisture condition and

SM - available soil moisture, which is estimated daily using soil moisture routing.

After CN estimation for each watershed grid, the potential retention parameter, S, is calculated for each grid by following equation

$$S=\frac{25400}{CN_{adj}-254} \tag{5.16}$$

The direct runoff of a grid, *qdr* (mm), is computed with precipitation, P (mm) and S

$$qdr=\frac{(P-0.2S)^2}{(P+0.8S)} \quad \text{for} \quad P>=0.2S \tag{5.17}$$

$$qdr=0 \qquad \text{for } P<0.2S \tag{5.18}$$

The sub-watershed direct runoff, Q_{sub} (mm), is computed as the mean depth of direct runoff from the grids:

$$Q_{sub}=\frac{\sum_{i=1}^{N} qdr_i}{N} \tag{5.19}$$

where, N is number of grids in a subwatershed.

The total direct runoff of the main watershed, Q_{dr} (mm), can be obtained by the area weighted average of the subwatershed direct runoff using following equation:

$$Q_{dr}=\sum_{j=1}^{N} Q_{subj}\times AF_j \tag{5.20}$$

where, N is number of subwatersheds and AF_j is the area ratio of the jth subwatershed to the main watershed.

Daily soil moisture is used for the estimation of infiltration rate and direct runoff calculation. Furthermore, the soil moisture affects evapotranspiration and deep percolation. The soil water balance equation can be written as:

$$DSM=SM_t-SM_{t-1}=(RAIN+UP_t+HI_t)-(qdr_t+ET_t+DP_t+HO_t)$$

or (5.21)

$$DSM=SM_t-SM_{t-1}+SR_t-ET_t-DP_t \tag{5.22}$$

$$SR_t=RAIN-qdr_t \tag{5.23}$$

where DSM is soil moisture change (mm), RAIN is precipitation (mm), UP is capillary rise of water (mm), HI is horizontal inflow (mm), qdr is direct runoff (mm), ET is evapotranspiration (mm), DP is deep percolation from effective soil depth (mm) and HO is horizontal outflow (mm), SR is soil moisture retention (mm).

The maximum soil moisture depletion of effective soil depth, DF_{max}, is equal to the maximum available soil moisture (ASM_{max}). The DF_{max} value is also the same as the maximum quantity of retained water and can be calculated by equation (5.24)

$$DF_{max} = ASM_{max} = FC - WP \quad (5.24)$$

where, FC is the field capacity (mm) and

WP is the wilting point (mm)

The DF_{maxadj} value is the adjusted value of DF_{max} by the soil storage coefficient (STC), and the relationship of STC and DF_{max} is presented by following equation

$$DF_{maxadj} = STC \times DF_{max} = STC \times (FC - WP) \quad (5.25)$$

The soil moisture deficit (DF, mm) is modified daily by the soil moisture change and estimated by

$$DF_t = FC - (SM_t - WP) \quad (5.26)$$

Deep percolation (DP) is estimated by the relationship of SR and DF. Depending on the situation, DP is estimated by equation (5.27) or (5.28); If $SR_t > DF_t$

$$DP_t = SR_t - DF_t \quad (5.27)$$

If $SR_t < DF_t$

$$DP_t = 0 \quad (5.28)$$

The values of field capacity and wilting point have been adopted from Rao (1998), and water retention properties are given in Table 5.6.

Table 5.6. Water retention properties classified by soil texture (Rao, 1998)

Texture Class	Residual Water Content, cm^3/cm^3	Field Capacity cm^3/cm^3	Wilting Point cm^3/cm^3
Sand	0.02	0.091	0.033
Loamy Sand	0.035	0.125	0.055
Sandy Loam	0.041	0.207	0.095
Loam	0.027	0.27	0.117
Silt Loam	0.015	0.33	0.133
Sandy Clay Loam	0.068	0.255	0.148
Clay Loam	0.075	0.318	0.197
Silty Clay Loam	0.04	0.366	0.208
Sandy Clay	0.109	0.339	0.239
Silty Clay	0.056	0.387	0.25
Clay Loam	0.09	0.396	0.272

5.3 Watershed Geomorphology

Horton (1945) introduced the foundation of quantitative geomorphology, which was earlier operated almost on descriptive basis. The quantification of watershed's morphology may also be termed as morphometry. These characteristics of watershed provide a means for describing its hydrological behaviour (Bardossy and Schmidt, 2002).

The concept of stream order has been widely used, since Horton (1945) formulated the rules for assigning the order to streams of a network. Subsequently, numerous revisions and additions to this concept were made by Strahler (1957) and other researchers. Mathematical concepts involved in the Strahler system were further derived by Melton (1958). Assuming stream network map, including all-intermittent and permanent flow lines located in clearly defined valleys, the smallest fingertip tributaries are designated as order 1. Where two first order streams join, a stream segment of order 2 is formed: where two streams of order two join segment of order 3 is formed, and so on. After the stream network elements have been assigned their order numbers, the segments of each order are counted to yield the number N_u of a segment of given order u. The ratio of number of segments of given order N_u to the number of segments of a higher order N_{u+1} is termed as bifurcation ratio (R_B).

$$R_B = \frac{N_u}{N_{u+1}} \tag{5.29}$$

The ratio of mean length of segments of order u to mean length of segments of next lower order u-1 is termed as stream length ratio (R_L).

$$R_L = \frac{L_u}{L_{u-1}} \tag{5.30}$$

The ratio of mean area of segments of order u to mean area of segments of next lower order u-1 is termed as basin area ratio (R_A).

$$R_A = \frac{A_u}{A_{u-1}} \tag{5.31}$$

5.3.1 Stream Ordering

The GIS based shape files by default contains the information about the FID (field ID number) of particular stream and its length after building its topology. It can have two more attributes of fnode (from node) and tnode (to node), when converted from coverage to shape file. Well-versed GIS user with the concepts of stream numbering can do so with adding new attributes to its database file and giving numbers manually. This is quite simple for stream network of lower orders or small extent.

These coordinates are written with reference to the coordinates of map display in the module. The written coordinates of the original stream file are exported to the new shape file. The new fields Fxi, Fyi and Txi, Tyi are added to the database of new shape file: where Fxi, Fyi are the two-dimensional coordinates of starting end of stream (from end), and Txi, Tyi are coordinates of the end points of the stream (to end).

Program initializes from stream FID = 0, it gets the Fxi, Fyi and Txi, Tyi coordinates of the stream. Then it checks, if Fxi, Fyi coordinates are equal to the coordinates of the other streams. If these coordinate equals to the Txi, Tyi coordinate of other streams, it takes that point as node and gets the FID of other streams: on the contrary, it is the first stream. From the node point, other stream is identified: same loop is run as for the first stream. If there is no equivalence, then both of the streams are ordered as 1. From the node point the FID of downstream of the stream is taken and the respective stream is ordered as two. Thus, program runs through the entire stream network till the last stream is reached by condition Txi, Tyi are not equal to Fxi, Fyi of any other stream. This is illustrated in Fig. 5.1 through a flowchart. Streams, whose orders are defined, displayed in the *MSFlexGrid* with FID, length and order of the stream for further computation of morphometrical parameters.

Based on theses three rules of geomorphologic analysis, various parameters related to areal and linear aspects were calculated, the details of which are given in Table 5.7.

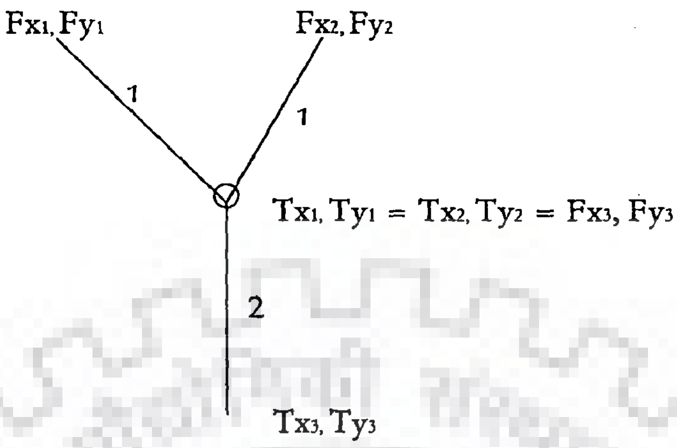


Fig. 5.1 Representation of Stream Numbering with Shape File

Table 5.7. Different formulae used for the computation of linear and areal parameters (Pakhmode et al., 2003)

Sr.No.	Parameter	Formula
1	Bifurcation Ratio (R_B)	N_{u+1}/ N_u
2	Stream Length Ratio (R_L)	L_{u+1}/ L_u
3	Drainage Density (D_d)	$\sum L_u/A$
4	Compactness(C)	$P/2\sqrt{\pi A}$
5	Stream Frequency (S_F)	$\sum N_u/A$
6	Length of Overland Flow (L_g)	$1/2\ D_d$
7	Constant of Channel Maintenance (C_C)	$1/ D_d$
8	Basin Circularity (B_C)	$1/C^2$
9	Infiltration Number (I_N)	$D_d * S_f$
10	Basin Length (L_B)	$1.312*A^{0.568}$
11	Form Factor (F_F)	A/ L_B^2
12	Shape Factor (F_S)	L_B^2/A
13	Elongation Ratio (R_E)	$1.128*P/A^{0.5}$
14	Texture Ratio (R_T)	N_1/P

Where

N_u – Number of streams of particular order

N_1 – Number of streams of first order

L_u – Length of streams of particular order in m

P – Perimeter of the watershed in km

A – Area of the watershed in km^2

5.4 Estimation of Evapotranspiration

Reference crop evapotranspiration (ET_0) is a key component in hydrological studies. ET_0 is used for agricultural and urban planning, irrigation scheduling, regional water balance studies, and agroclimatological zoning. Various equations are available for estimating ET_0. These equations range from the most complex energy balance equations requiring detailed climatological data (Allen, 1989) to simpler equations requiring limited data (Blaney and Criddle, 1950: Hargreaves and Samani, 1982, 1985). The Penman-Monteith method is widely recommended because of its detailed theoretical base and its accommodation of small time periods. However, the detailed climatological data required by the Penman-Monteith method are not often available, especially in developing nations.

Simplified equation that requires only temperature and latitude given by Hargreaves and Samani (1982, 1985) has been used in this study as an alternative to Penman-Monteith method. Both of these methods have been discussed in following sections.

5.4.1 FAO Penman – Monteith Method

FAO Penman–Monteith Method (Allen, et al., 1998) of estimating the reference evapotranspiration is maintained as the sole standard method for the computation of ET_0 from meteorological data. Therefore this method is included as an alternative option to Hergrives Samani method.

From the original Penman-Monteith equation and the equations of the aerodynamics and canopy resistance, the FAO Penman-Monteith equation for estimation of daily ET_0, mm/day is derived as:

$$ET_O = \frac{0.408\Delta.40 \;-G) + \gamma \frac{900}{T+273} U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \qquad (5.32)$$

Where, ET_0 - Reference evapotranspiration (mm day^{-1})

R_n - Net radiation at the crop surface (MJ m^{-2} day^{-1})

G - Soil heat flux density (MJ m^{-2} day^{-1})

T- Air temperature at 2 m height (°C)

U_2- Wind speed at 2 m height (m s^{-1})

e_s - Saturation vapour pressure (kPa)

e_a - Actual vapour pressure (kPa)

(e_s - e_a) - Saturation vapour pressure deficit (kPa)

Δ - Slope vapour pressure curve (kPa °C^{-1})

g- Psychometric constant (kPa °C^{-1})

Slope of the saturation vapor pressure-temperature curve, Δ, in equation 5.32 is computed as:

$$\Delta = \frac{4098 * 0.6108 EXP((17.27 * T_{mean})/(T_{mean} + 273.3))}{(T_{mean} + 273.3)^2} \quad (5.33)$$

Where, T_{mean} is the mean daily air temperature in °C, which is computed as:

$$T_{mean} = \frac{T_{max} + T_{min}}{2} \quad (5.34)$$

Where, T_{min} – minimum temperature in ^{0}C and

T_{max} – maximum temperature in ^{0}C

The psychometric constant, γ is defined as:

$$\gamma = \frac{0.00163 * \rho}{2.45} \quad (5.35)$$

Where, ρ is density of air (Kg/m^3), which in equation 5.34 is a function of latitude

$$\rho = 101.3 * \left[\frac{293.0 - 0.0065 * lat}{293}\right]^{5.26} \quad (5.36)$$

Where, *lat* - latitude in degrees.

The vapour pressure at minimum temperature $e(T_{min})$ is computed as:

$$e(T_{min}) = 0.6108 * Exp\left[\frac{17.27 * T_{min}}{T_{min} + 237.3}\right] \quad (5.37)$$

The vapour pressure at maximum temperature $e(T_{max})$ is computed as:

$$e(T_{max}) = 0.6108 * Exp\left[\frac{17.27 * T_{max}}{T_{max} + 237.3}\right] \quad (5.38)$$

The saturation vapour pressure (e_s) is computed as given in equation (5.39)

$$e_s = \frac{e(T_{max}) + e(T_{min})}{2} \quad (5.39)$$

The actual vapour pressure (e_a) can be computed as:

$$e_a = \left[\frac{e(T_{min}) * RH_{max}}{100} + \frac{e(T_{max}) * RH_{min}}{100}\right]/2 \quad (5.40)$$

Where, RH_{max} and RH_{min} are the maximum relative humidity and minimum relative humidity, %, respectively.

Most of the observatories record the wind speed at a height of 10 m, but in order to use it in this model a wind speed is required at 2m height, which may be computed as follows if data is not available:

$$U_2 = \frac{U_{10} * 1000}{3600} * \frac{4.87}{\ln(67.8 * 10^{-5.42})} \quad (5.41)$$

The inverse relative distance Earth-Sun, d_r,

$$d_r = 1 + 0.0033\cos\left[\frac{2\Pi}{365} - J\right] \quad (5.42)$$

Solar declination (δ) is given by:

$$\delta = 0.409\mathrm{Sin}\left[\frac{2\Pi}{365}J - 1.39\right] \quad (5.43)$$

Where, J is the number of the day in the year between 1 (1 January) and 365 or 366 (31 December).

The sunset hour angle (ω_s,) is given by:

$$\omega_S = \arccos[-\tan(lat).\tan(\delta n]$$ (5.44)

Where, $$lat = \frac{lat^0 * \Pi}{180}$$ (5.45)

Where, lat^0- is the latitude in degrees.

If a mathematical function arccos is not available then an alternative equation (5.46) may be used to determine the sunset hour angle (ω_s):

$$\omega_S = \frac{\Pi}{2} - \arctan\left[\frac{-\tan(lat).\tan(\delta n}{X^{0.5}}\right]$$ (5.46)

Where, $X = 1 - ([\tan(lat)]^2[\tan(lat)]^2)$

and if X<=1, then X = 0.00001 (5.47)

For hourly or shorter periods the solar time angle at the beginning and end of the period should be considered when calculating R_a:

$$R_a = \frac{24(60)}{\Pi} Gsc.d_r[\omega_S.\sin(lat).\sin(\delta i + \cos(lat).\cos(\delta s(\delta).s\omega_S)]$$ (5.48)

Where, R_a -extraterrestrial radiation in the hour (or shorter) period (MJ m^{-2} $hour^{-1}$)

G_{sc} - solar constant = 0.0820 MJ m^{-2} min^{-1}

d_r - inverse relative distance Earth-Sun (Equation 5.42)

δ- solar declination (rad) (Equation 5.43)

lat - latitude (rad) (Equation 5.45)

ω_1 - solar time angle at beginning of period (rad) (Equation 5.49)

ω_2 - solar time angle at end of period (rad) (Equation 5.50)

The solar time angles at the beginning and end of the period are given by:

$$\omega_1 = \omega - \frac{\Pi t_1}{24}$$ (5.49)

$$\omega_2 = \omega + \frac{\Pi t_1}{24}$$ (5.50)

Where, ω -solar time angle at midpoint of hourly or shorter period (rad),

t_1 -duration of the calculation period (hour): i.e., 1 for hourly period or 0.5 for a 30-minute period

The solar time angle at midpoint of the period is give as

$$\omega = \frac{\Pi}{12}\left((t + 0.06667(L_Z - L_m) + S_C) - 12\right) \qquad (5.51)$$

Where, t - Standard clock time at the midpoint of the period (hour). For example for a period between 14.00 and 15.00 hours, t = 14.5

L_z - longitude of the centre of the local time zone (degrees west of Greenwich)

L_m - longitude of the measurement site (degrees west of Greenwich)

S_c - seasonal correction for solar time (hour)

The daylight hours, N, are given by:

$$N = \frac{24}{\Pi}\omega_S \qquad (5.52)$$

Where, ω_s - sunset hour angle in radians and given by Equation 5.44 or 5.46.

If the solar radiation, R_s is not measured, it can be calculated using the Angstrom formula which relates solar radiation to extraterrestrial radiation and relative sunshine duration:

$$R_S = \left(a_S + b_S \frac{n}{N}\right)R_a \qquad (5.53)$$

Where, R_s - solar or shortwave radiation (MJ m^{-2} day^{-1})

n - actual duration of sunshine (hour)

N - maximum possible duration of sunshine or daylight hours (hour)

n/N - relative sunshine duration

R_a - extraterrestrial radiation (MJ m^{-2} day^{-1})

a_s - regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days (n = 0)

a_s+b_s - fraction of extraterrestrial radiation reaching the earth on clear days (n = N)

R_s is expressed in the above equation in MJ m^{-2} day^{-1}. The corresponding equivalent evaporation in mm day^{-1} is obtained by multiplying R_s by 0.408. Depending on atmospheric conditions (humidity, dust) and solar declination (latitude and month), the Angstrom values a_s and b_s will vary. Where no actual solar radiation data are available and no calibration has been carried out for improved a_s and b_s parameters, the values a_s = 0.25 and b_s = 0.50 are recommended. The actual duration of sunshine, n, is recorded with a Campbell Stokes sunshine recorder.

The calculation of the clear-sky radiation, R_{so}, when n = N, is required for computing net long wave radiation.

For near sea level or when calibrated values for a_s and b_s are available:

$$R_{SO} = (a_S + b_S)R_a \tag{5.54}$$

Where, R_{so} - clear-sky solar radiation (MJ m^{-2} day^{-1})

a_s+b_s - fraction of extraterrestrial radiation reaching the earth on clear-sky days (n = N).

When calibrated values for a_s and b_s are not available:

$$R_{SO} = (0.75 + 2*10^{-5}.Z)R_a \tag{5.55}$$

Where, Z- station elevation above sea level (m)

The net shortwave radiation resulting from the balance between incoming and reflected solar radiation is given by:

$$R_{ns} = (1-\alpha)R_s \tag{5.55}$$

Where, R_{ns} - net solar or shortwave radiation (MJ m^{-2} day^{-1})

α - albedo or canopy reflection coefficient, which is 0.23 for the hypothetical grass reference crop (dimensionless)

R_s - The incoming solar radiation (MJ m^{-2} day^{-1})

R_{ns} - is expressed in the above equation in MJ m^{-2} day^{-1}

The rate of longwave energy emission is proportional to the absolute temperature of the surface raised to the fourth power. This relation is expressed quantitatively by the Stefan-Boltzmann law.

$$R_{nl} = \sigma\left[\frac{T_{max.K^4} + T_{min.K^4}}{2}\right]\left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35\frac{R_S}{R_{SO}} - 0.35\right) \tag{5.56}$$

Where, R_{nl} - net outgoing longwave radiation (MJ m^{-2} day^{-1}),

σ - Stefan-Boltzmann constant (4.903 10^{-9} MJ K^{-4} m^{-2} day^{-1}),

$T_{max, K}$ - maximum absolute temperature during the 24-hour period

(K = °C + 273.16),

$T_{min, K}$ - minimum absolute temperature during the 24-hour period

(K = °C + 273.16),

e_a - actual vapour pressure (kPa),

R_s/R_{so} - relative shortwave radiation (limited to 1.0),

R_s - Measured or calculated. Solar radiation (MJ m^{-2} day^{-1}),

R_{so} - calculated clear-sky radiation (MJ m^{-2} day^{-1}).

The net radiation (R_n) is the difference between the incoming net shortwave radiation (R_{ns}) and the outgoing net longwave radiation (R_{nl}):

$$R_n = R_{ns} - R_{nl} \tag{5.57}$$

Complex models are available to describe soil heat flux. Because soil heat flux is small compared to R_n, particularly when the surface is covered by vegetation and calculation time steps are 24 hours or longer, a simple calculation procedure is presented here for long time steps, based on assumption that the soil temperature follows air temperature:

$$G = C_S \frac{T_i - T_{i-1}}{\Delta t} \Delta Z \qquad (5.58)$$

Where, G - soil heat flux (MJ m^{-2} day^{-1})

c_s - soil heat capacity (MJ m^{-3} °C^{-1})

T_i - air temperature at time i (°C)

T_{i-1} - air temperature at time i-1 (°C)

Δt - length of time interval (day)

Δz - effective soil depth (m)

For day and ten-day periods:

As the magnitude of the day or ten-day soil heat flux beneath the grass reference surface is relatively small, it may be ignored and thus:

$$G_{day} \approx 0 \qquad (5.59)$$

5.4.2 Hargreaves – Samani Method (Samani, 2000)

The most important parameters in estimating ET_0 are temperature and solar radiation. Simplified equation that requires only temperature and latitude (Hargreaves and Samani 1982, 1985) can be used to estimate the ET_0 is described as follows

$$ET_O = 0.0135(KT)(R_a)(TD^{1/2})(TC + 17.8) \qquad (5.60)$$

Where ET_0 = reference crop evapotranspiration: TD = Tmax - Tmin (^{0}C): and TC = average daily temperature (^{0}C), Tmax = Maximum temperature (^{0}C), Tmin = Minimum temperature (^{0}C). Equation (5.60) explicitly accounts for solar radiation and temperature. *Ra* =

extraterrestrial radiation (mm/day): and *KT* = empirical coefficient which can be determined by equation (5.61)

$$KT = 0.00185(TD)^2 - 0.0433TD + 0.4023 \qquad (5.61)$$

5.5 Soil and Water Conservation Structure

Wide range of soil and water conservation techniques have been reported in literature such as bunds, terraces, gabions, check dams, ponds (Samra, et al., 2002). These techniques help in conserving the surface runoff and in reducing soil erosion and thereby increasing the groundwater availability.

In the present study bunds and terraces have been considered as representative structures which are depending on the slopes and rainfall in the watershed. However other structures are often reported as site specific (Singh, et al., 1990). The dugout type water harvesting ponds have been considered for storage of surface runoff which is simple in the design. The advantage of dugout ponds is that watershed managers have freedom of its location in the watershed. The slope ranges (Table 5.8) for different kinds of bunds/terraces are adopted based on the general recommendations for Indian conditions (Samra et al., 2002)

Table 5.8. Limits of slopes to decide the type of soil and water conservation structures.

Slope (%)	Type of Structure
0-6	Contour Bund
6 – 10	Graded Bund
10 – 30	Bench Terrace

5.5.1 Design of Bunds

The main criterion for spacing of bunds is to intercept the water before it attains the erosive velocity. This depends on many factors, the most important being slope rainfall, cropping programme and conservation practices.

5.5.2 Vertical Interval (Ramser's Formula)

C.E. Ramser (Singh et al., 1990) has established a general equation for vertical interval (VI) based on the field observation and experiments for sub-humid areas and soils with good infiltration characteristics as given below:

$$VI = 0.3\left[\frac{S}{3} + 2\right] \quad (5.62)$$

Where, S – slope of the land parcel (%)

5.5.3 Horizontal Interval

The horizontal interval (HI) can be computed by using the following equation:

$$HI = \frac{VI}{S} x100 \quad (5.63)$$

$$\text{Length of contour bund/ha} = \frac{10000}{HI} \quad (5.64)$$

5.5.4 Design for Terraces

5.5.4.1 Width of Terrace

The width of the terrace (W) depends on the depth of productive soil (m):

$$W = \frac{200.d}{S} \quad (5.65)$$

Where, d- Effective depth of soil (m)

5.5.4.2 Vertical Interval

Vertical interval (VI) between two consecutive terraces (in m) can be obtained by:

$$VI = \frac{W.S}{100 - S} \quad (5.66)$$

5.5.4.3 Horizontal Interval

Horizontal interval (HI) between two consecutive terraces (in m) can be computed by equation given below:

$$HI = W + VI \quad (5.67)$$

$$\text{Length of terrace/ha} = \frac{10000}{HI} \quad (5.68)$$

5.6 Design of Water Harvesting Ponds

An inverted truncated pyramid shape pond (Fig. 5.2) has been considered for the design. This is selected in the present study because of its minimum wetted perimeter per unit stored volume of water. It is also most practical shape to be constructed with ease. The side slope is taken as 1:1. Depth of pond beyond 3.5 to 4 m becomes uneconomical since the cost increases out of proportion to the volume of excavation. A depth of 3 to 4 m may be considered suitable in general for ponds (Samra et al., 2002). Considering these, a depth of 4 m is assumed for this DSS. The bottom of pond is assumed to be square in shape. Sharma (2002) gave the bottom dimension of ponds for different regions. For western region it can be considered as 90 m, while for east and north region of India 120 m and 103 m can be considered respectively. For the southern region bottom dimension has been taken as 75 m (Samra et al., 2002). The estimated runoff is used as storage capacity of the ponds. However the actual site of construction of ponds can be decided by watershed managers as per site conditions. The following equations have been used for calculating the various design parameters:

$$V = 2D^2 + 2BD^2 + 2B^2D \tag{5.69}$$

$$BA = B^2 \tag{5.70}$$

$$TA = (B + 2D)^2 \tag{5.71}$$

$$TSA = 5.657(B + D)D \tag{5.72}$$

Where, V– volume of pond (m^3)

D- depth of pond (m)

B- bottom width/length (m)

BA- bottom area of pond (m^2)

TA- top surface area (m^2)

TSA- total side area (m^2)

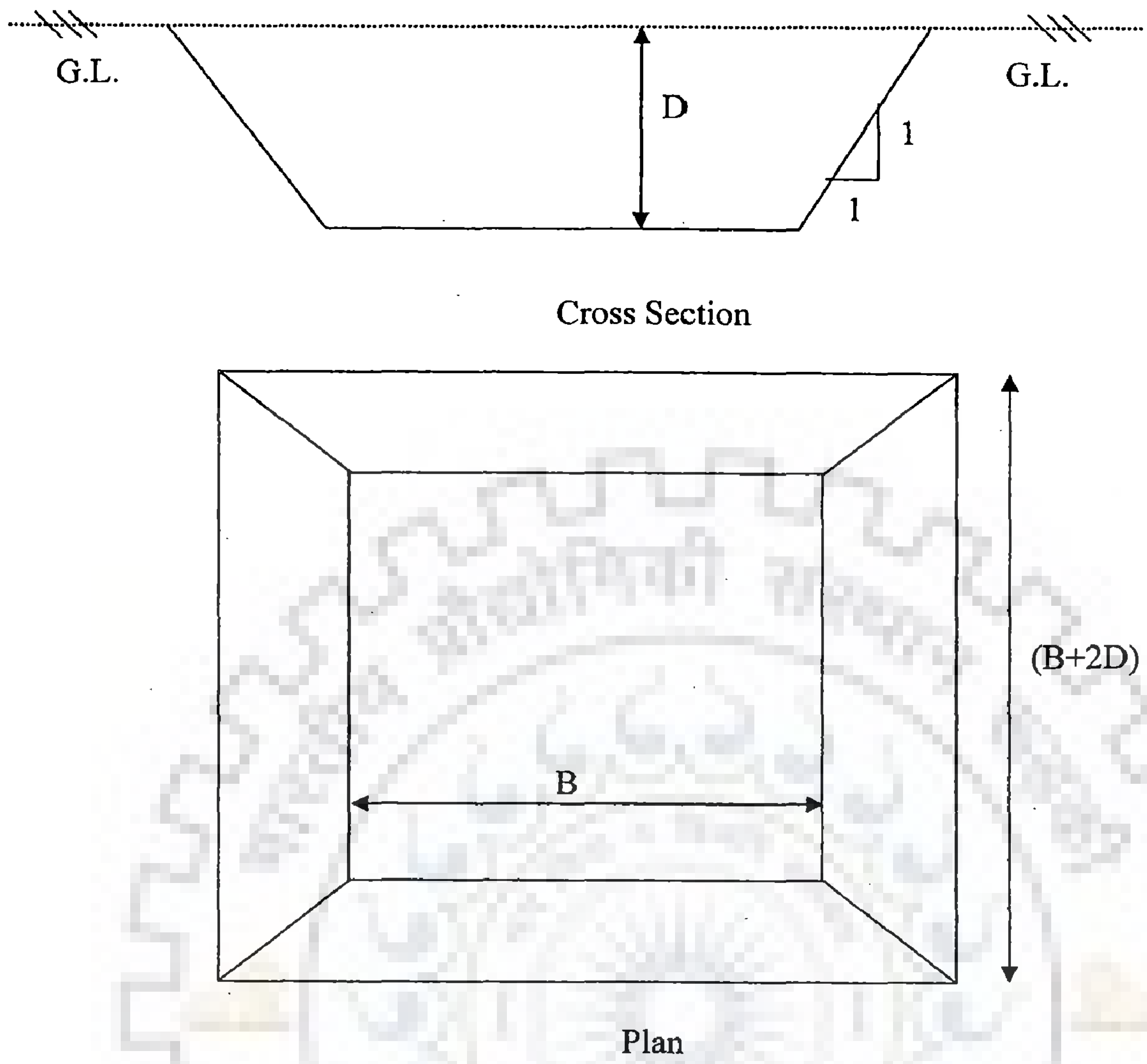


Fig. 5.2.Geometry of inverted truncated pyramid shape pond

5.6.1 Losses from Ponds

Evaporation and seepage from the ponds are major losses. The seepage can however be reduced to certain extent by introducing the clay compaction in bottom and sides of the pond. This practice makes the pond convenient for storage purpose. Availability of actual data on seepage from ponds is one of the major constraints in planning of water harvesting systems. Hence data on the seepage loss are taken from the literature, as the infiltration data do not give real values of seepage from ponds.

Reddy (1993) reported that, seepage loss in sandy loam soil varied from 20 mm/day to 45 mm/day for reservoir depth of 2m and 3.5m respectively. In clay loamy soil, it was found to be

4.75 mm/ day in pond having depth up to 3.5 m (Sahu, 2000). For various lining materials and soil types the seepage rates have been adopted from Samara et al., (2002).

In absence of pan evaporation data, the evaporation losses from the ponds can be worked out using the computed evapotranspiration data. Experiments have shown that the appropriate correction factor can vary from 0.5 to 0.85. From literature, this factor is typically found to be about two-third (FAO, 1997).

$$PET_{fullcover} = 0.66.E_{pan} \tag{5.73}$$

Where, $PET_{fullcover}$ – Potential evapotranspiration (mm)

E_{Pan} – Pan evaporation (mm)

5.7 Groundwater Recharge

Sophisticated models such as MODFLOW, DRASTIC, SPRING are available for groundwater recharge assessment. But these are too complicated in terms of processes involved and extensive data requirement. Implementation of these models in DSS becomes difficult with limited information available for micro watersheds.

Two methods have been recommended by the Groundwater Resource Estimation Committee of Government of India (GEC, 1997) i.e. method based on rainfall infiltration and method based on water table fluctuation, have been used in present study. Information required for both these methods is normally available. Simplicity, popularity and acceptability make it convenient to implement these methods in the DSS. As per the guide areas having higher slopes should not be considered in the recharge estimation. In this case, areas having slopes more than 25 % have not been considered.

5.7.1 Rainfall Infiltration Method

With a view to review the 'Ground Water Resources Estimation Methodology' and to look into all the related issues, a Committee on Ground Water Estimation was again constituted in

November 1995 by the Ministry of Water Resources, Government of India. The report of the Committee was released in June 1997. The Committee has also revised the norms of recharge assessment based on rainfall infiltration factor. It has been reported that the ground water resource estimation methodology recommended by Committee is being used by most of the organisations in India. As a guideline, following norms (Table 5.9) for recharge from rainfall may be adopted:

Table 5.9. Portion of rainfall going to the recharge

Sr. No	Geological Formation	Portion of Rainfall, %
1	In sandy areas	20 to 25
2	In areas with higher clay content	10 to 20
3	Friable and highly porous (Semi-consolidated sandstones)	10 to 15
4	Weathered and fractured Granite	10 to 15
5	Unweathered Granite	5 to 10
6	Vesicular and jointed basalt	10 to 15
7	Weathered basalt	4 to 10
8	Phyllites, limestones, sandstones, quartzites, shales etc	3 to 10

The values indicated above are given as a guideline, and it does not automatically imply that upper limit can invariably be applied. Based upon the status of knowledge available, a value in between can be chosen.

5.7.2 Water Table Fluctuation Method

The change in ground water storage is an indicator of the long term availability of ground water. The change in ground water storage between the beginning and end of non-monsoon season indicates the total quantity of water withdrawn from ground water storage, while the change between the beginning and end of monsoon season indicates the volume of water that has gone into the reservoir. During the monsoon season, the recharge is more than the extraction, and hence the ground water storage increases, which can be utilized in the subsequent non-monsoon season. To assess the changes in ground water storage, the water levels are observed through a network of observation wells spread over the area. The water levels are highest immediately after monsoon in the month of October or November and lowest just before rainfall in the month of May or June. The change in storage can be computed from the following equation :

$$\Delta S = \sum h.A.S_y \qquad (5.74)$$

Where, ΔS - Change in storage (ha-m)

h - Change in water level (m)

A - Area influenced by the well (ha) and

Sy - Specific yield

The specific yield may be computed from pumping tests. As a guide, the following specific yield values (Table 5.10) for different types of geological formations in the zone of water level fluctuation have been adopted (GEC, 1997):

Table 5.10. Specific yield values for different types of geological formations

Sr.No	Geological formation	Specific Yield, %
1	Sandy alluvial area	12 to 18
2	Valley fills	10 to 14
3	Silty/Clayey alluvial area	5 to 12
4	Granites	2 to 4
5	Basalts	1 to 3
6	Laterite	2 to 4
7	Weathered phyllites, shales, schist and associated rocks	1 to 3
8	Sandstone	1 to 8
9	Limestone	3
10	Highly karstified limestone	7

5.8 Population Forecasting Module

Population forecasting is an important step in any planning process. The following equations have been used in forecasting population:

$$P = P_o(1+r)^n \qquad (5.75)$$

Where, P = population in desired year, P_o= population in base year, r = population growth rate and n = difference in years of desired and base year.

The population growth rate and population at the base year can be obtained from census data. In case of unavailability of growth rate data, it can be computed from two years of population data for particular duration as follows:

$$r = \left(\frac{P}{P_0}\right)^{\frac{1}{n}} - 1 \qquad (5.76)$$

Using this computed growth rate, desired population for any year may be computed. This module further computes the water demand and food and fodder requirement, as discussed in sub-sequent sections. Indirect methods for estimating the demand are relatively straight forward to use, and are the most practical methods for the estimation of water demand on a sub-catchment and catchment basis. The following information is required:

- Population data and
- Per capita demand

5.9 Water Demand

Water demand is defined as the volume of water required by users to satisfy their needs. In a simplified way, it is often considered equal to water consumption, although conceptually the two terms do not have the same meaning. This is because in some cases, especially in rural areas, the theoretical water demand considerably exceeds the actual consumptive water use. Typical water consumption for all habitants is given in Table 5.11.

Table 5.11 Typical water consumption for different categories (BIS, 1993).

Type of habitant	**Water consumption** (litres per head per day)
Human	40
Cattle	40
Buffalo	50
Sheep and goats	5

5.10 Food and Fodder Requirements

5.10.1 Food Requirement

Indian Council of Medical Research (ICMR, 1990) released a report giving the details of combined dietary allowances for human being in Indian conditions considering all nutritional needs. This has been shown in Table 5.12.

Table 5.12. Food requirement per capita for different food types

Food Type	**Requirement** (gm/capita/day)
Cereals	480
Pulses	50
Oilseeds	35
Vegetables	70

5.10.2 Fodder Requirement

Sharma and Bhadra (1986) gave the fodder requirement of 2800 kg/yr/cattle. Thapa and Poudel (2002) have given the concept of livestock unit (LSU) in which they considered buffalo as 1 LSU, cattle as 0.69, improved cattle as 0.95 and sheep/goat as 0.22 LSU. Combining these two units the fodder requirement can be summarised as given in Table 5.13.

Table 5.13. Fodder requirement for different livestock types according to LSU.

Livestock Type	LSU	Fodder Requirement kg/Year
Buffalo	1.00	2800
Cattle	0.69	1932
Cattle Improved	0.95	2660
Sheep/Goat	0.22	616

5.11 Water Allocation Module

There are various ways in which water can be allocated. The challenge is to find an optimal allocation that firstly, adheres to laid down regulations, and secondly, satisfies the water demand of all users as much as possible. Water allocation is not generally an issue when water availability is more than that of water demand. In such situations, all demands can be satisfied, and there may be no need for a regulated allocation of water. However, this is not the case for the peninsular India. In most of the catchments, water availability is frequently less than the demand. It is therefore necessary to find a suitable allocation of the scarce water resource. In this module, water allocation uses the balancing approach between the demand side and supply side on fortnightly basis.

5.11.1 Water Demand Side

The domestic water demand for human being and livestock has been considered in this part. The irrigation water requirement for all crops is another major component in the demand side. The various losses from storage system may also be considered as atmospheric demand.

5.11.2 Water Supply Side

The supply side has two major components, stored runoff and groundwater available from particular season's rainfall. The effective rainfall during monsoon or *kharif* season has been considered as the supply side.

5.11.3 Water Allocation Policy

Certain policy considerations have been made in allocation of water resources amongst the various demand sectors. These may be enumerated as follows:

1. The domestic water requirement for human being has to be met from groundwater throughout the year (A figure of 100 ha-m has been added to the supply source as an groundwater balance).

2. The livestock water requirement has to be met from stored surface water till its availability, and beyond that it may be supplied from groundwater throughout the year.

3. The irrigation water requirement of crops during monsoon season may be balanced from effective rainfall available during the particular fortnight. In case of crops in non-monsoon season, the first priority for allocation is given to stored surface water, and second priority to groundwater with no mining criteria.

4. The losses from the storage system have been deducted to compute water available during a particular fortnight.

This policy can be expressed mathematically as follows:

Priority 1

$$TGWA_{i+1} = GWR_{i+1} + TGWA_i - HWD_{i+1} \tag{5.77}$$

Priority 2

If $IWR < RF$, then

$$IWR_i = RF_i \tag{5.78}$$

Priority 3

If $SWA_i >= LWD_{i+1} + IWR_{i+1} + SL_{i+1} + EVL_{i+1}$, then

$$SWA_{i+1} = SWA_i - LWD_{i+1} - IWR_{i+1} - SL_{i+1} - EVL_{i+1} \tag{5.79}$$

Else

Priority 4

$$SWA_{i+1} = SWA_i - LWD_{i+1} - SL_{i+1} - EVL_{i+1} \tag{5.80}$$

and $$TGWA_{i+1} = GWR_{i+1} + TGWA_i - HWD_{i+1} - IWR_{i+1} \tag{5.81}$$

If $SWA_i = 0$, then

Priority 5

$$TGWA_{i+1} = GWR_{i+1} - LWD_{i+1} - TGWA_i - HWD_{i+1} - IWR_{i+1} \tag{5.82}$$

For $\sum_{i=1}^{24} TGWA = \sum_{i=1}^{24} GWR$ (No Mining Criteria)

Where,

TGWA = Total ground water available

SWA = Surface water available

GWR = Groundwater recharge

IWR = Irrigation water requirement

HWD = Human water demand

LWD = Livestock water demand

SL = Seepage losses

EVL = Evaporation losses

RF = Rainfall

5.12 Land Allocation Module

This module directs a planner to allocate the land amongst different crops, considering the availability of water and food requirement of habitants in the watershed. The separate problems have been formulated for the *rabi* and *kharif* seasons. The formulation given below is for *rabi* crops, in case of *kharif* crops the total availability constraint has not been considered. This is with the assumption that the crop water requirement can be meet from effective rainfall. For this purpose, a linear programing approach has been used considering the constraints of total area available, food requirement and water availability. The problem formulation for this purpose is given as below:

Objective function $$\text{Max}Z = \sum_{i=1}^{n} X_i \quad (5.83)$$

Area constraint $$\sum_{i=1}^{n} X_i <= A \quad (5.84)$$

Food requirement constraint $$P_1.X_1 >= FR_1,\ P_2.X_2 >= FR_2 -----,\ P_n.X_n >= FR_n \quad (5.84)$$

Total water availability constraint $$\sum_{i=1}^{n} X_i.WR_i <= TWA \quad (5.85)$$

Where, X_i - area of individual crop (ha)

n - Number of crops

P_i - Productivity of individual crop (kg/ha)

A - Total area available for cultivation for a particular season (ha)

FR_i- Food requirement of individual crop (kg)

WR_i - Water requirement of particular crop (m)

TWA- Total water available (ha –m).

5.13 Estimation of Crop Water Requirement

Crop water requirement, ETc can be estimated as

$$ETc = Kc_{ini}.ET_0 \quad (5.86)$$

$$ETc = Kc_{mid}.ET_0 \quad (5.87)$$

$$ETc = Kc_{end}.ET_0 \quad (5.88)$$

Where,

ETc - crop evapotranspiration (mm/day)

Kc - crop coefficient (dimensionless)

ET_0- reference crop evapotranspiration (mm/day)

Net irrigation water requirements (NIWR) in a specific scheme for a given year are thus the sum of individual crop water requirements (CWR_i) calculated for each irrigated crop. Multiple cropping (several cropping periods per year) is thus automatically taken into account by separately computing the crop water requirements for each cropping period. An irrigation water requirement is obtained in terms of depth by dividing the water requirement with the area, and can be expressed in mm or in m^3/ha (1 mm = 10 m^3/ha).

$$NIWR = \frac{\sum_{i=1}^{n} CWR_i . S_i}{S} \qquad (5.89)$$

Where, S_i is the area cultivated with the i^{th} crop (ha).

Gross irrigation water requirement (GIWR) is the amount of water to be extracted (by diversion, pumping) and applied to the irrigation. It includes NIWR plus water losses:

$$GWIR = \frac{1}{E} . NIWR \qquad (5.90)$$

Where, E is the efficiency of the irrigation system.

The crop coefficient values for initial, mid and end condition are given in Table 5.14.

Table 5.14 Typical values for $K_{c\ ini}$, Kc_{mid} and $K_{c\ end}$ for various agricultural crops

Crop	$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$
Legumes (Leguminosae)	0.4	1.15	0.55
Beans, green	0.5	1.05	0.90
Beans, dry and Pulses	0.4	1.15	0.35
Chick pea		1.00	0.35
Green Gram and Cowpeas		1.05	0.60-0.35
Groundnut (Peanut)		1.15	0.60
Lentil		1.10	0.30
Peas			
- Fresh	0.5	1.15	1.10
- Dry/Seed		1.15	0.30
Soybeans		1.15	0.50
Fibre Crops	0.35		
Cotton		1.15-1.20	0.70-0.50
Oil Crops	0.35	1.15	0.35
Castorbean (Ricinus)		1.15	0.55
Rapeseed, Canola		1.0-1.15	0.35
Safflower		1.0-1.15	0.25
Sesame		1.10	0.25
Sunflower		1.0-1.15	0.35
Cereals	0.3	1.15	0.4
Barley		1.15	0.25
Oats		1.15	0.25
Spring Wheat		1.15	0.25-0.4
Maize, Field (grain) (field corn)		1.20	0.60-0.35
Millet		1.00	0.30
Sorghum - grain		1.00-1.10	0.55
Rice	1.05	1.20	0.90-0.60

5.14 Concluding Remarks

As mentioned earlier, model base component is one of the core elements in any decision support system. The model base used in the study has been described in detail in this chapter. All the models and methods used in the study have been programmed using VB. The GUIs has been developed by using the algorithm of the particular model and method. Each set of GUIs of a particular model is called as module, which is named after the name of model or method used. All these modules have been described in the chapter 7 i.e. development of GUI.

CHAPTER 6

GIS DATABASE GENERATION

6.1 Prelude

The pre-requisite of any DSS or SDSS is to have data in proper format to perform the model simulation and analysis. The spatial data are essential in case of SDSS. It is very important that the data are well structured. It should be ensured that functional geographic database containing the number associated layers is available, where each layer contains clean topology.

The study required various thematic layers viz. land use/land cover, geology, and drainage, Digital Elevation Model (DEM), slope, contour and soil. These layers needed as input to various models and methods. The methodology of generation of these layers is discussed in following sections with their source and software used.

6.2 Data and Software Used

A database is core component of any DSS/SDSS. Data can be spatial or non-spatial, such as numeric or qualitative. To generate the required database format and develop the DSS various softwares are used. Following two sections describe the source of data and details of various softwares used.

6.2.1 Spatial and Non-Spatial Data Used

A large amount of data sets are needed to describe the spatial variability of many watershed characteristics. The increasing availability of spatial data in electronic format and GIS software to manage and prepare spatial data has led to a renewed interest in the use of distributed watershed models (Garbrecht et al., 2001).

A number of parameters are required for water resources planning. Apart from these, demographic data are used for planning of resources in the area. Thus, large quanta of spatial as well as non-spatial data are required in decision-making process. The collection and proper organization of updated and reliable data, both thematic and attribute is necessary for any study.

The thematic information used in this study has been mainly derived from Survey of India (SOI) topographic maps, unpublished maps in project reports at Department of Soil Conservation and Watershed Management, Government of Maharashtra, prepared using survey and field data, and published literature. The demographic data have been derived from census reports and project reports supplied by the concerned authorities. The details of the used data have been compiled in Table 6.1

Table 6.1: Details of the data used in the study

S.No	Data	Scale	Year	Source
1.	Topographic maps -	1: 50,000	1964-65	Survey of India, Dehradun
2.	Geological Data		2004-2005	Field visit
3.	Soil Data		1999	NBSSLUP, Nagpur
4.	Population/Demographic data at village level	-	1991	DoSC &WSM, GoM, Anon1998
5.	Population/Demographic data at village level	-	2001	Census of India, CD
6.	Land Use Map	1:1000	2001	DoSC &WSM, GoM, 1998
7.	Ground data collection	-	2005	Field visits
8.	Water table fluctuation	-	2001-2004	Central Ground Water Board, Nagpur
9.	Drainage Network Map	1:1000	2001	DoSC &WSM, GoM, Anon1998
10.	Runoff and Sediment Discharge	Watershed	2001-2003	Taluka Agril. Officer, Trimbak, Dist, Nashik, Maharashtra
11	Rainfall and Meteorological	Daily	1998-2003	Indian Meteorological Department, Pune and Government of Maharashtra

The topographic map number 48N/6 is used as a principal source to generate the base layers and other layers such as DEM. The topographic map was electronically converted to the *.bmp file. This data was registered to Polyconic projection in metric units, which was geo-referenced. Area of the study was a sub-set from the full topographic map.

6.2.2 Software Used

The integration and analysis of multi-thematic information were the key for generating digital databases for the study area, which was further used as input for the developed DSS. The spatial and non-spatial data, collected from various sources, were required to be organized in GIS. Image processing software ERDAS 8.5 was used for registering the topographic map and spatial data. Since vector data in the form of shape file was planned and required for the input to the DSS, to generate the various layers spatial information converted to the digital format by digitizing it in ESRI Arc GIS 8.3.

Many algorithms and models other than spatial information were required to run in the unified system (refer to the DSS in this study). The software programming was done in graphic programming language Microsoft's Visual Basic 6.0. The visual basic in its core format does not support the reading and loading of spatial data in vector format, therefore an incorporable ActiveX GIS component, MapObjects 2.3, developed by ESRI was used. The details of software used to create various thematic layers are given in Table 6.2.

Table 6.2: Details of the software used in the study

S.No.	Software	Version	Developed by
1.	ERDAS Imagine	8.5	Earth Resources Data Analysis System (ERDAS), Atlanta, Georgia, US
2.	Arc GIS	8.3	Environmental Systems Research Institute (ESRI), Redlands, California, US
3.	Visual Studio Professional Edition	6.0	Microsoft Inc., US
4.	MapObjects	2.3	Environmental Systems Research Institute (ESRI), Redlands, California, US

Arc Map is the interactive windows-based version of popular ARC INFO software. ARC INFO workstation version is mostly command-driven and its module ArcTools has limited windows-interface. In ARC INFO workstation version, ARC is designed to store coordinate data and perform all operations on that data, whereas INFO is a Relational Database Management System (RDBMS), and is used to store and perform operations on descriptive/attribute data (ESRI, 1994).

Arc Map is very simple to use. Function for switching on the required module e.g. Spatial Analyst etc., at the time of need, made it computationally very efficient. Density analysis and buffering are performed in Arc Map. Also operations for recoding of data and overlaying of raster layers are used in Arc Map. Arc Map's layout composer is used to prepare cartographic-quality maps for presentation. The ArcGIS suite contains the various extensions used for spatial and 3D analyst. These extensions are handy to produce Triangulated Irregular Network (TIN) map, generating contours and DEM. The 3D analyst extension was used to generate the various vector and raster layers.

ERDAS Imagine software consisted of several geographic imaging modules, ranging from simple mapping of an image to advanced features for remote sensing applications (ERDAS, 2000). It allows accessing several raster and vector formats. The software was used to register and project the spatial data. ERDAS also provided several easy-to-use functions for spatial, radiometric and spectral enhancements, as well as for topographic and GIS analysis. Various operations like preparation of DEM, slope map and aspect map were performed in ERDAS.

Visual Basic (VB) is a part of Microsoft Inc.'s Visual Studio. VB is one of most powerful programming languages available these days with very good graphic capability. Since, almost every GIS and remote sensing application to hydrologic problems requires visualization of GIS and satellite data, therefore VB was used for development of the proposed DSS. One of the limitations of VB was to access the spatial data in the vector format. This limitation was overcome by adding an ActiveX component, MapObjects, to the VB programming environment. The MapObjects provides the linkage between any object oriented programming language, such as VB, C++, Borland and Java and GIS database. This makes it quite easy to access the GIS component from within the software. It is a suite integrated with nearly 50 automation objects (ESRI, 2005), each containing the analysis and display capability information of GIS data. This approach of developing the software that includes both spatial data and analytical or simulation models is very effective in developing any stand alone SDSS with GIS data component. Both of these software and programs, i.e. VB, MapObjects and its combine working for code running in VB is discussed in detail in the next chapter.

Various themes, as mentioned in this chapter, have been developed specifically for this study, but in the coming years with the establishment of National Spatial Data Infrastructure (NSDI) and digital data-sharing platforms, it will be easier to take up this type of study by taking the database layers from the national database pool and just applying the developed SDSS and methodology for watershed problems.

6.3 Database Generation

Khadak Ohal watershed as discussed in the Chapter 4 was marked on SOI topographic map. The boundaries of watershed were delineated from the topographic map. This boundary of watershed was then digitized as a polygon and converted to the coverage to clean and build the topology. The new shape file was created from this coverage and area & perimeter of watershed were obtained. The map created as above is shown in Fig. 6. 1.

6.3.1 Land use/land cover map preparation

Land use refers to man's activities and the various uses, which are carried on land. Land cover refers to natural vegetation, water bodies, rock/soil, artificial cover and others resulting due to land transformations (Clawson, 1965). The terms land use and land cover is closely related and interchangeable. Information on land use/land cover in the form of maps and statistical data is vital for spatial planning and management and utilization of land for route planning. Today, with the growing population pressure, there is a need for optimum utilization of land resources (Gautam et al., 1989). Land use plays a very vital role for the future development of any area. The area under forest, cultivation etc. can be found out from the land use map.

Land use map prepared by the Authorities of Department of Soil Conservation and Watershed Management, Government of Maharashtra, on the basis of field survey in the year 2000 was used for the preparation for land use/land cover map. Use of this data gave the capability to prepare updated map as compared to map prepared from SOI toposheet, which were surveyed in 1964-65. The land use map was prepared at a scale of 1: 1000.

Accurate registration/geo-referencing of maps is preliminary requisite of any GIS database. The land use map was geo-referenced with the SOI toposheet. RMS error of ± 0.14 was obtained, which was in the acceptable limits. The SOI toposheet is available in Polyconic projection with Mount Everest as a ellipsoid. In the present study the maps were used with the same projection system. Coordinates of new map were then matched with the identical points in the toposheet, co-registering it with the base toposheet. These co-ordinates values were available in easting and northing as metric units. There are three major land use classes available in the watershed viz. agriculture, forest and wasteland. The details of these land use classes have extracted are given below:

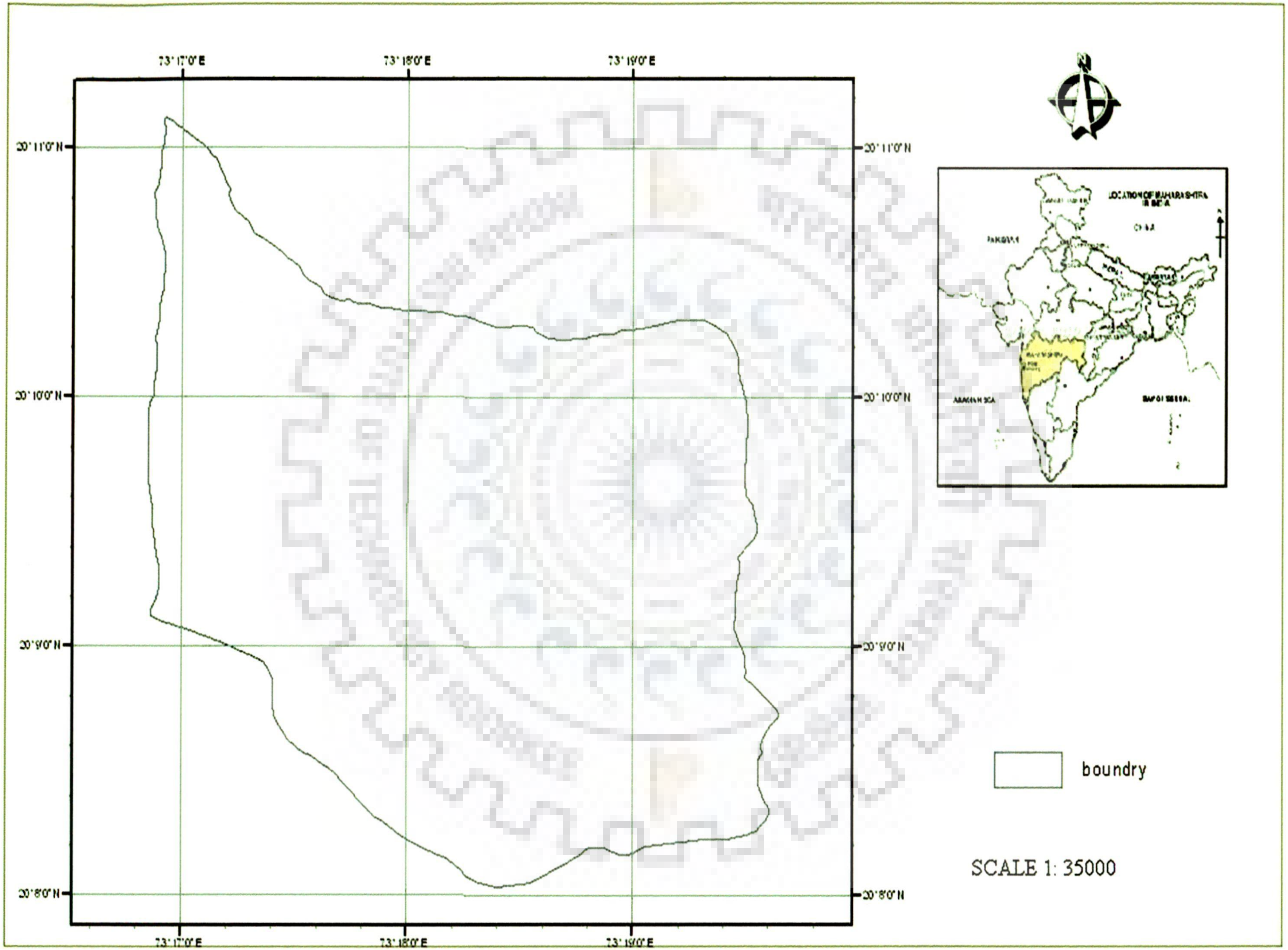


Fig. 6.1 Boundry Map

6.3.1.1 Agriculture

Areas used for farming, production of food, fibre and other commercial or horticultural crops were classified as agriculture. All polygons mapped as agriculture area were digitized and given the additional attribute of agriculture in new attribute column of land use. These are predominantly straight row crop areas with most of the cropping activity restricted to monsoon season only. However the spatial distribution of individual cropping areas was not available from the surveyed map. The distribution of this in terms of the numerical data was available in the report, and used in the estimation of crop water requirement.

6.3.1.2 Forest

Areas with canopy density more than the 10% were marked as the forest. There can be dense forest and open forest. The digitization and assigning the attribute text to the land use attribute was given only a forest. This was a dominating land use class in the present study.

6.3.1.3 Wasteland

This land use has been kept unused for certain purpose in the watershed. This comprised of very little proportion of land as compared to other two classes. Areas pertaining to this land use were found in and around to the habitant settlement.

The digitized shape file was exported to the coverage file to clean and build the topology. This coverage was again exported to the shape file to get final input to the runoff module of DSS. This gave the area of individual land use class. Land use map prepared is shown in Fig 6.2. This land use map was then rasterised by exporting to raster data of grid size 100m X 100m. Each grid carried the attribute of the land use field available in the original polygon of shape file. The new map was created again by converting each grid to the polygon, thus forming a new virtual grid in the vector format. The shape file was made error free by checking individual grid. The merged grids in case were made to single by split polygon method in the editing tool of ArcMap. The grid based land use map prepared as above is displayed in Fig. 6.3. This map was required for input to the CELTHYM model.

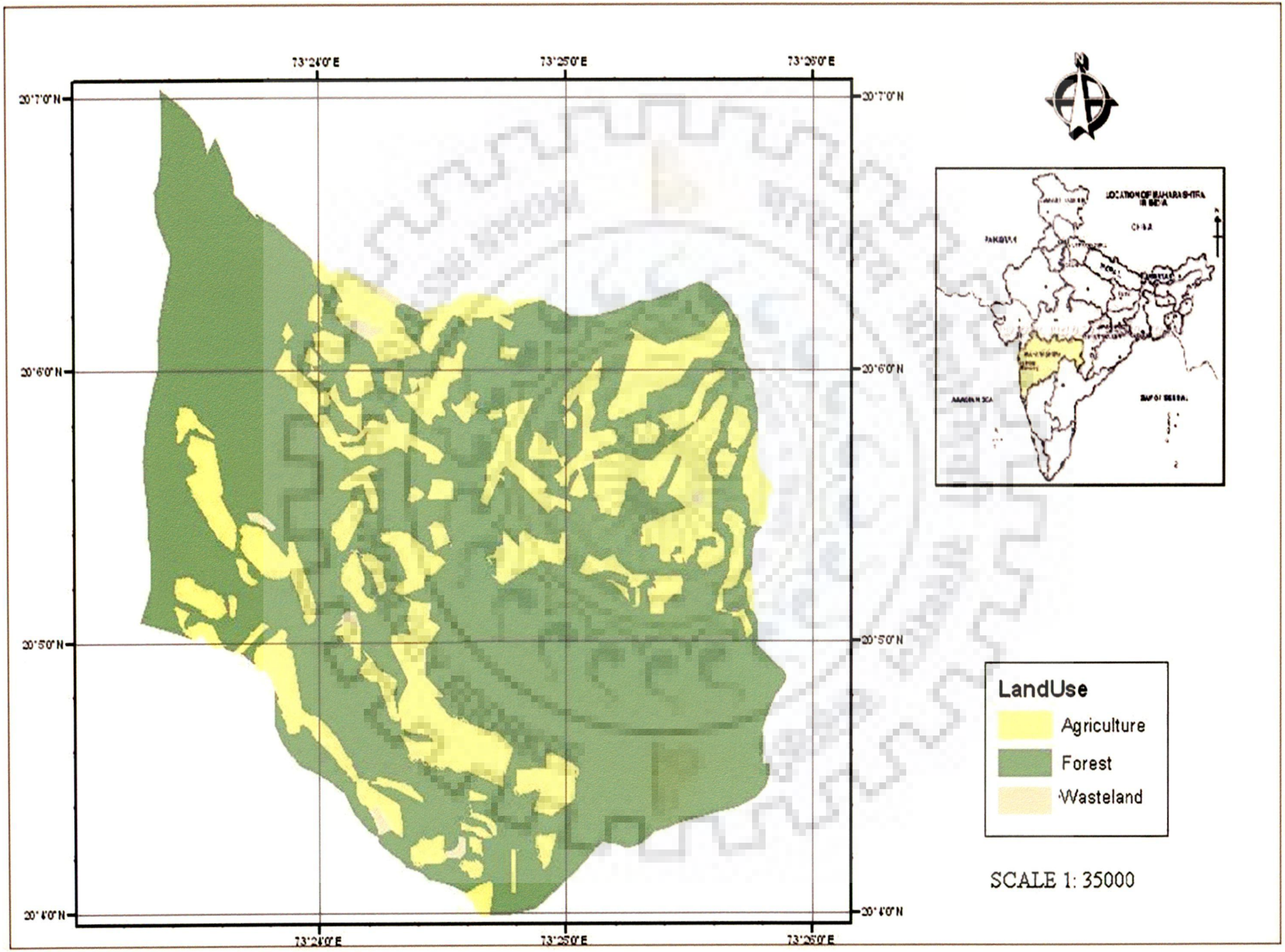


Fig. 6.2 Land use\ land cover map

Alternative way of generating these maps, in absence of field data, is by using of remote sensing data. Inspite of high cost of images, the role of remote sensing in surveying and monitoring has increased dramatically (Roy and Joshi, 2001). Satellite remote sensing has played a pivotal role in generating latest information about forest cover, vegetation type and land use changes (Roy et al., 1991). The increase in processing speed and the digital storage has increased the application of digital satellite images. Digital image can easily be enhanced to bring out details of interest, e.g. vegetation stress, settlements etc.

6.3.2 Drainage Map Preparation

Drainage map is very important, as it decides the most hydrological and geo-morphological characteristics of the watershed. The morphometric characteristics of any watershed should have the typical parameters of stream length and its order. These characteristics are more useful in prioritizing the watershed for implementing a management plan.

The drainage map was prepared by digitizing the drainage network map supplied by the Department of Soil Conservation and Watershed Management, Government of Maharashtra. The drainage order was decided according to the Strahler's configuration of stream ordering and later marked as attribute on individual drainage arc ID in GIS database. The smallest streams in a drainage network have no tributary streams. However a separate methodology has been developed in the programming of DSS for ordering of drainage network, as discussed in section 5.3.1.

This shape file was assigned the geo-reference of the registered toposheet. This shape file was exported to the line coverage to clean and build the topology. The coverage was later converted to the shape file to input this file to geomorphology module. The developed drainage map as described above, having streams as line vector is shown in Fig. 6.4

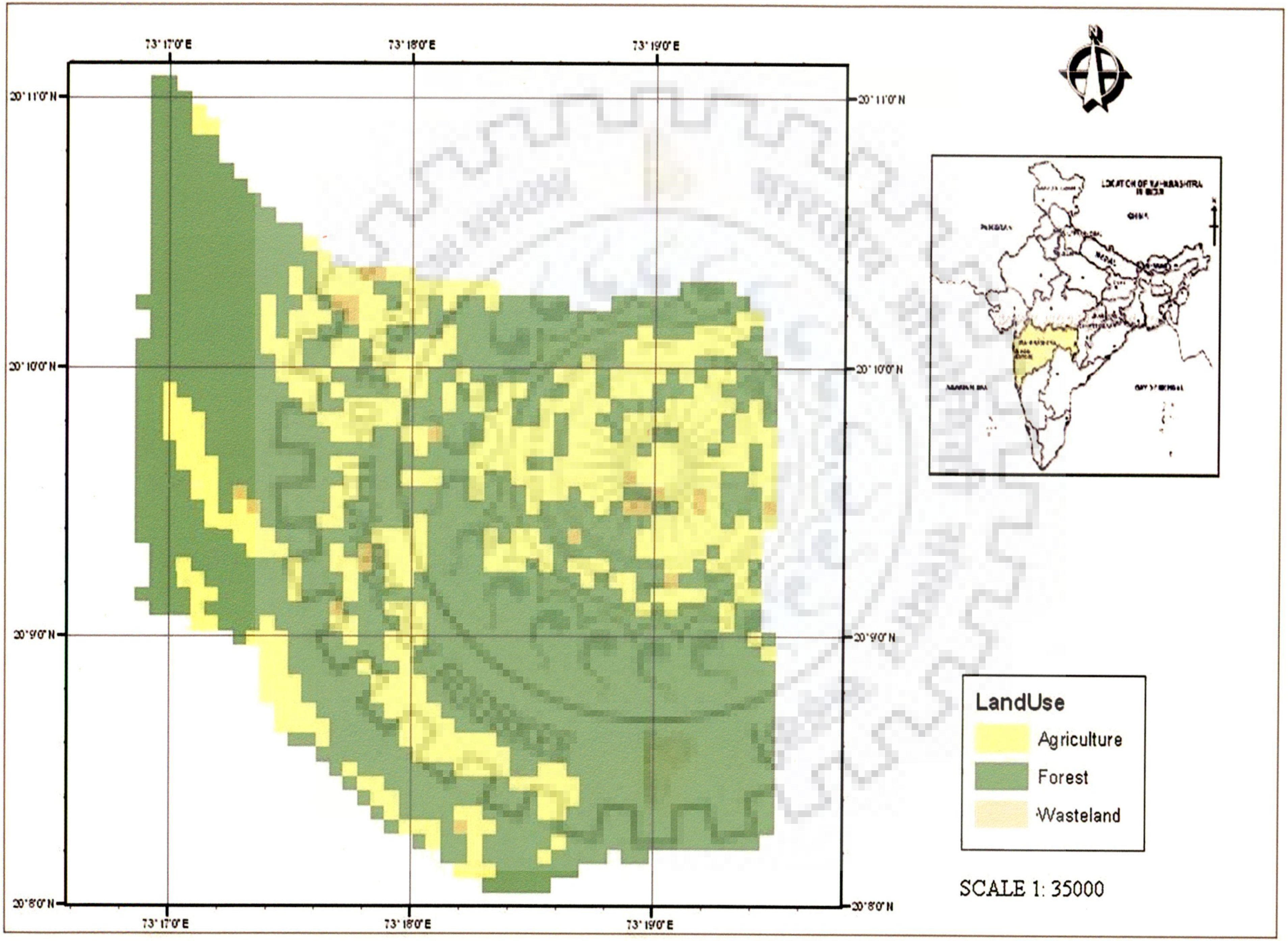


Fig 6.3 Grid based land use/land cover map

6.3.3 Soil Map Preparation

Soil is a product of geological, chemical, biological and cultural interaction. Soil characteristics should be studied with respect to suitability for planning purpose. Physiographic analysis was carried out to study the soil types in the region. The analysis was based upon a thorough knowledge of relation between physiography and soils.

Physiography refers to the comprehensive study of surface form, geology, climate, soils, water and vegetation and their relationships.

The soil map was prepared using the land use map as reference or base map. Same polygon was used in the land use map for individual land use unit. To assign the soil type in the respective land use unit, reconnaissance soil survey was carried out in the study area. Soil texture of different units was determined. The clayey skeletal soils were found to be major type in the area.

The photograph of the side cut at one of the places in watershed is shown in Fig. 6.5. By this methodology soil map was prepared by digitizing the soil class as polygon. This map was used as input to the other models. To avoid the multiple generations of data base layers, a new attribute of soil type was added to the exiting polygon coverage of land use. This made it quite convenient to use a single shape file containing information about both the land use and soil type. The map displayed with the soil type attribute in the land use shape file is shown in Fig. 6.6.

The soil type polygon map was converted to the grid-based map on similar lines to that of land use map. The map, thus generated, is as shown in Fig. 6.7.

Fig. 6.5 Soil seen at *Kathavpada* approach road in hill cut.

6.3.4 Geological Map Preparation

Geology plays an important role in ground water resources evaluation of any area. Fraction of rainfall that is going to the aquifer basically depends on type of underlying geology of the area. A reconnaissance survey was carried out in the study area to map the geology. A type of geological strata was decided by observing the lithology of dug out wells (nearly fifteen) in the study area. The profile of an under construction dug out well is shown in Fig. 6.8. It was observed that area is underlined by fractured *Deccan* trap (a typical type of Basalt). This information was supported by District Gazetteers web site. There was no variation in the type of geology as study watershed comprised of very less area (about 1700 ha). However in other areas, there can be much variation in the strata. The above said map was generated by digitizing the polygon. The new attribute of geology was added to the new shape file. The type of geology was strictly decided on the basis of norms given by the Central Ground Water Board (CGWB).

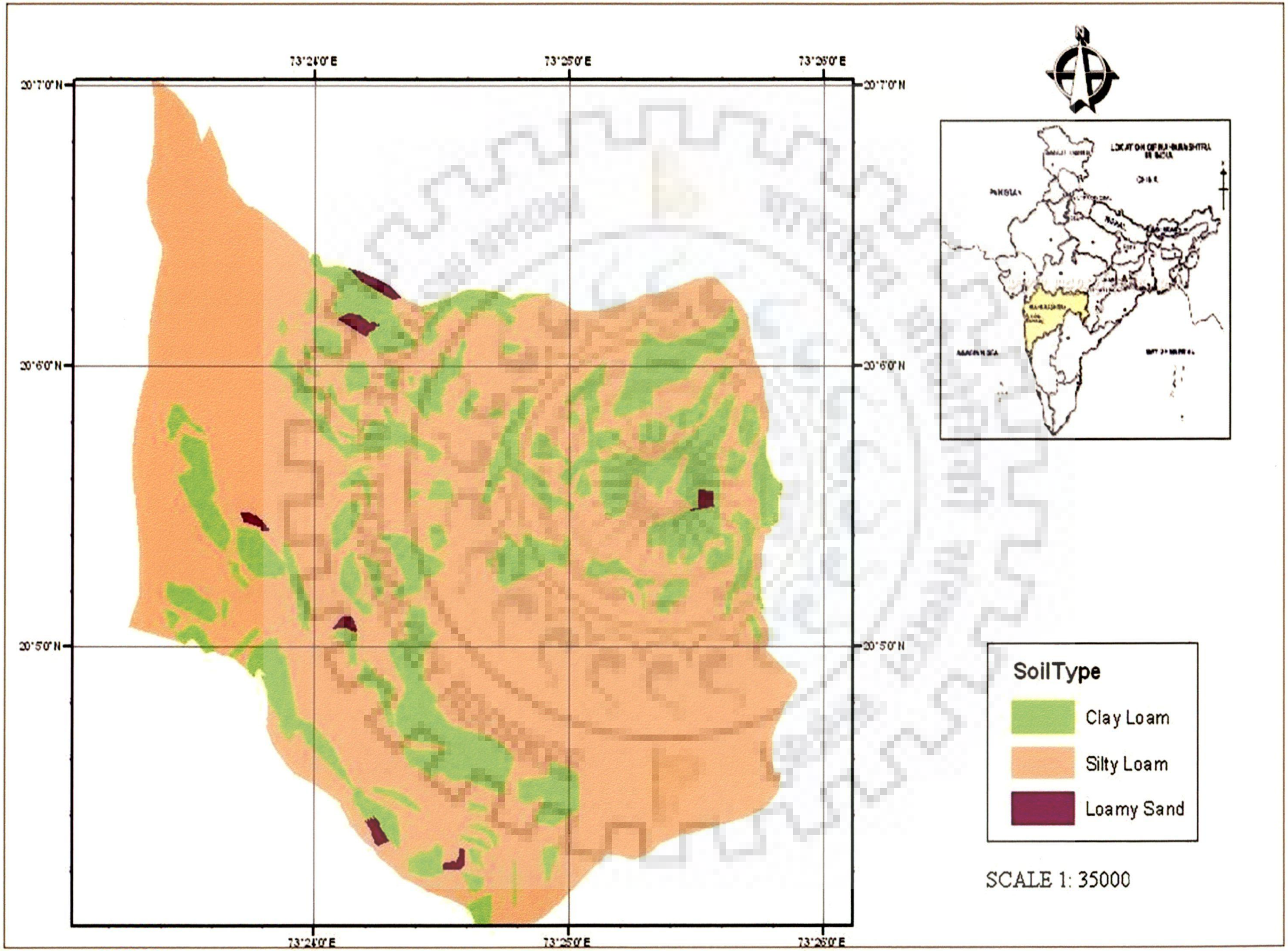


Fig 6.6 Soil Map

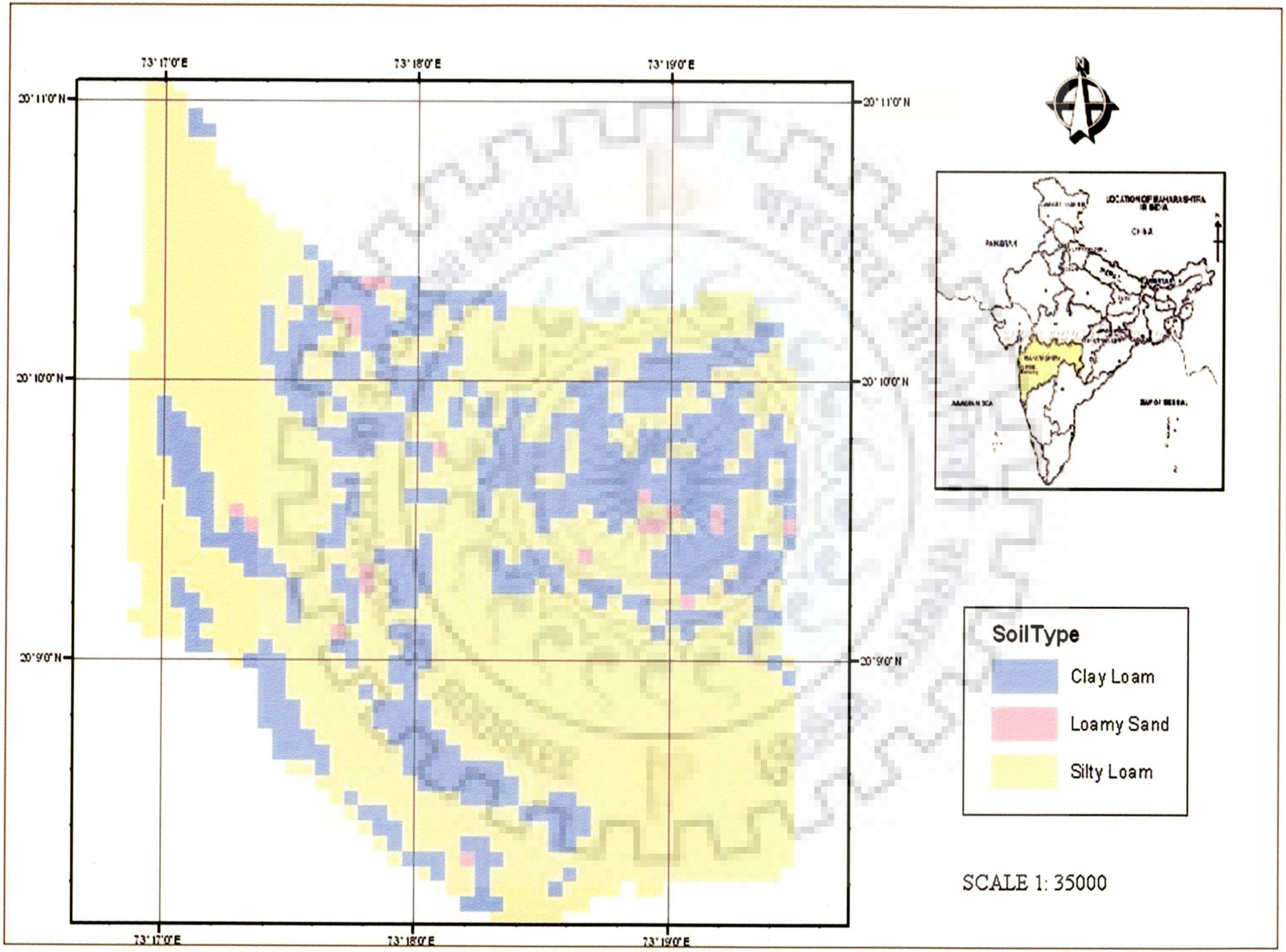


Fig 6.7 Grid based soil map

Fig. 6.8 Basalt as seen in the under construction dug out well

6.3.5 Contour Map Preparation

The contour is a line joining the equal elevation. Generation of contour map is very important aspect of any spatial study. The contour map forms a base map for generating number of GIS layers, such as TIN, DEM, slope and aspect maps. The SOI toposheet number 48N/6 at 1:50,000 scale with contour interval of 20m was used to generate this map. The contours within a boundary of a watershed were digitized in a newly created shape file having polyline spatial object. This shape was assigned the same geo-referencing and co-ordinates as the registered SOI topographic map. The minimum elevation of contour was found to be 140m, while maximum elevation of contour is 500m. The digitized shape file was then exported to coverage to clean and build the topology. The coverage then converted to another shape file, which was ready to use for further analysis and input to the DSS (Rational sub-module in the runoff module). The contour map as developed above is displayed in Fig. 6.9.

6.3.6 TIN Generation

TIN is a popular short form for triangulated irregular network. A vector based data structure for storing terrain information in digital terrain modelling is termed as TIN. In a TIN data model, each sample point has an x, y coordinate and height, or z value. All the points are connected by edges to form a network of nonoverlapping triangle that collectively represent the terrain surface. TIN is also referred to as irregular triangular mesh. A TIN (Fig. 6.10) was build from the contour map, which carried a z value i.e. the value of the elevation of contours. The Arc GIS /Arc Map extension 3D analyst was used to generate the TIN.

6.3.7 Slope Map Generation

TIN was used to generate the raster-based elevation at 100m X 100m grid size. This raster was then converted to the polygon on similar lines as used in land use grid generation. The generated shape file was geo-referenced with the registered SOI toposheet. The map is displayed in Fig. 6.11.

This elevation file was then used to generate the slope range, as given in Fig. 6.12. The co-registered and geo-referenced file was then added with the land use and soil type in the slope range with polygon as spatial object. This was used as the input to the rational sub-module of the DSS.

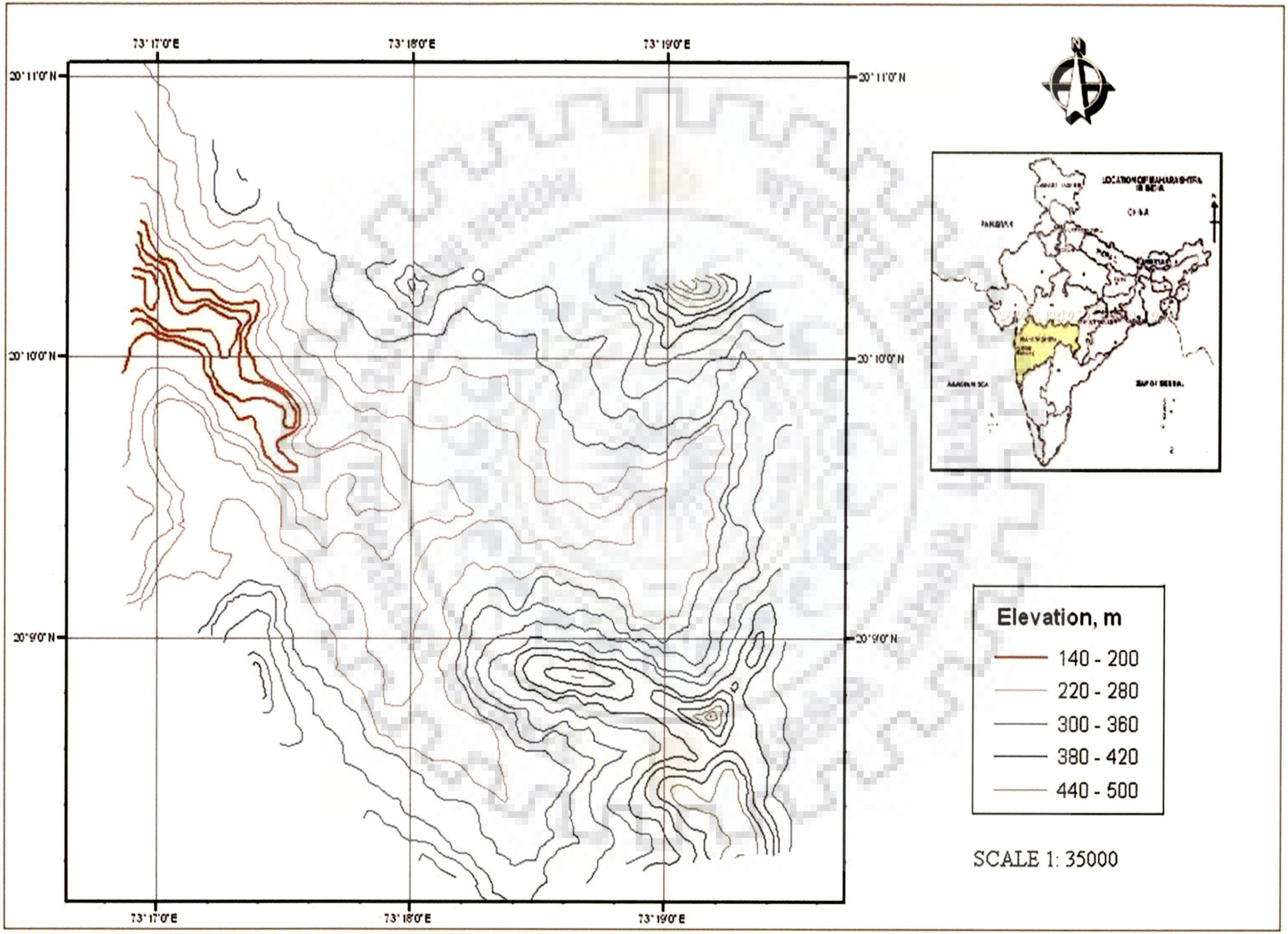


Fig 6.9 Contour map

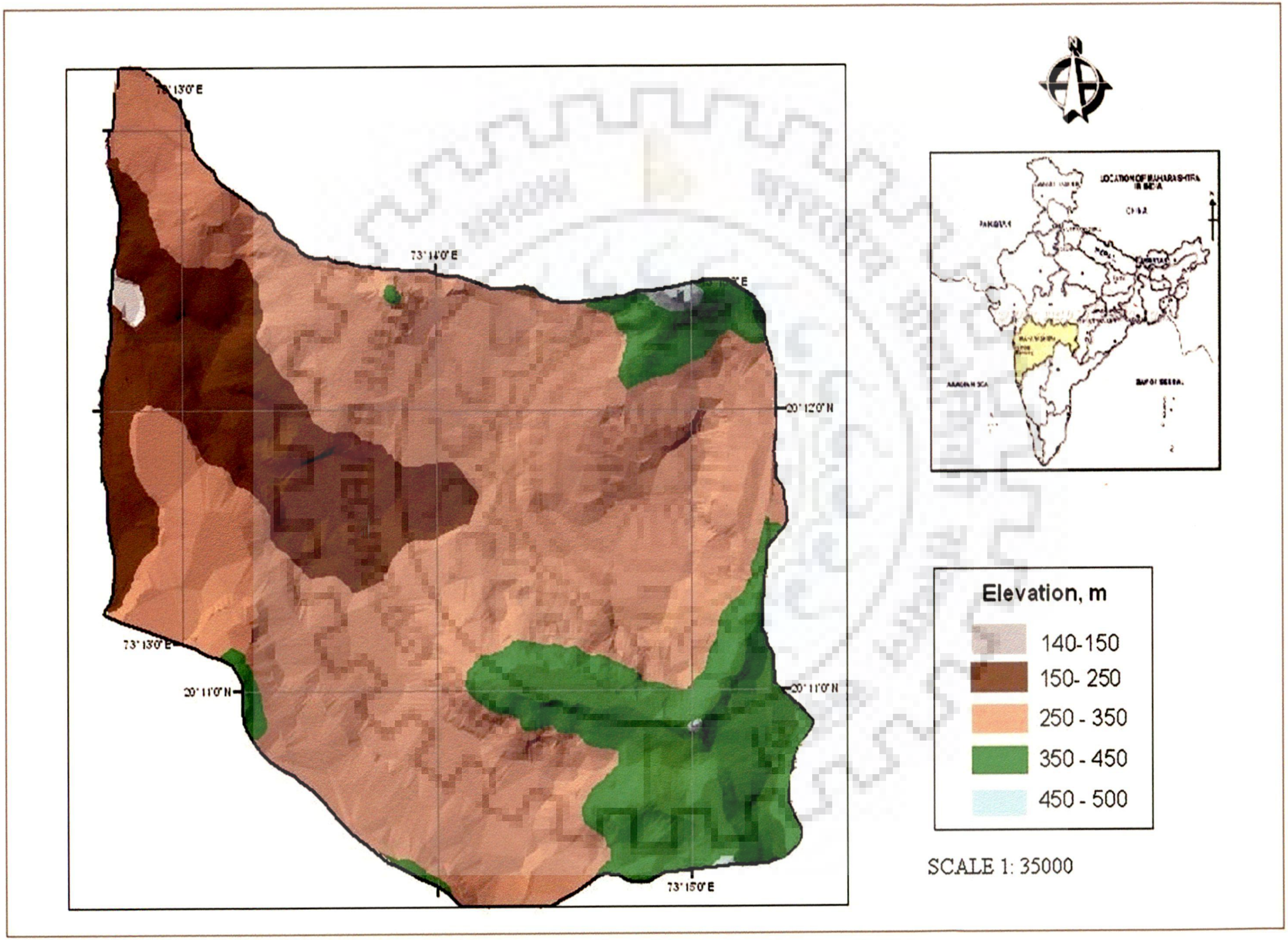


Fig 6.10 TIN map generated by ArcGIS 3D analyst

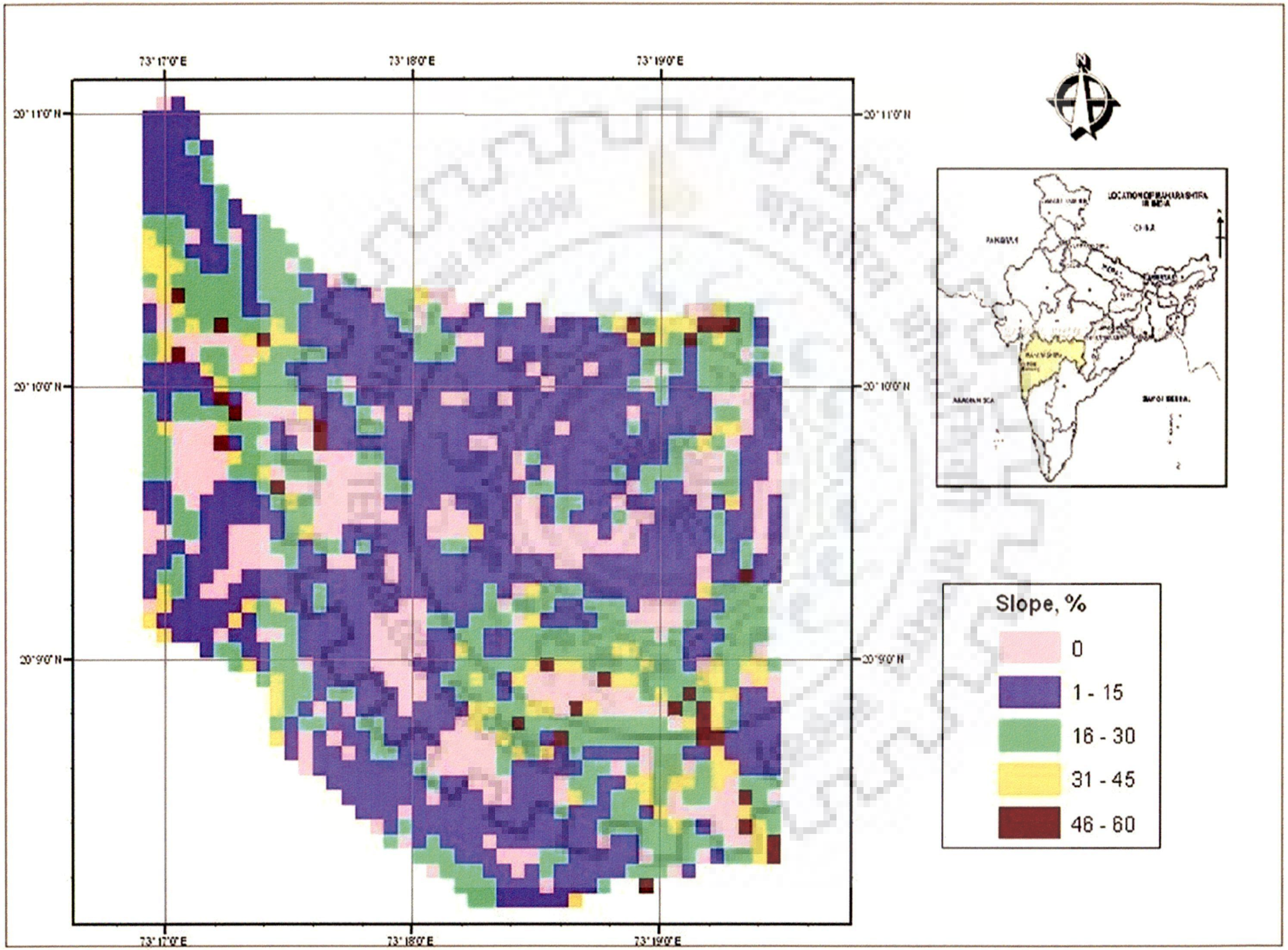


Fig 6.11 Slope map

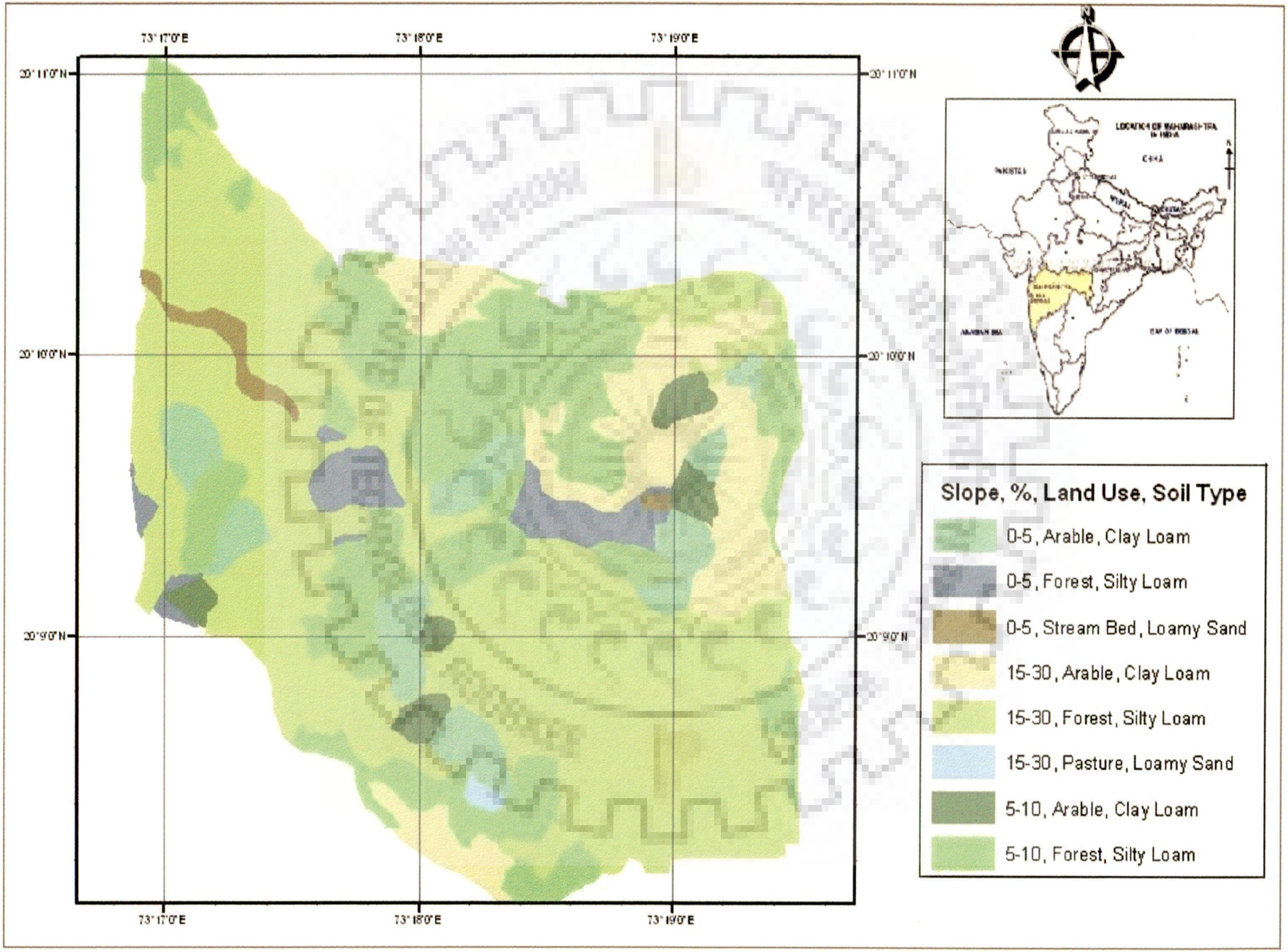


Fig 6.12 Slope range map

6.4 Concluding Remarks

The database forms an essential component of the any DSS. The spatial and non-spatial data both are required for planning of watershed or water supply schemes. The spatial database given in this Chapter is generated for input to DSS. The methodology for creation of database is described in the chapter. The similar database can be created for any other area, where prototype DSS has to applied and demonstrated.

CHAPTER 7

DEVELOPMENT OF GRAPHICAL USER INTERFACE

7.1 Prelude

The GUI is an important and core component in any DSS. A GUI is graphical method of controlling interaction of a user with a computer to perform various tasks. To make user friendly, an object-oriented approach of programming with Microsoft's Visual Basic is used. To make spatial data accessible, the ActiveX Control of ESRI's MapObjects is incorporated in the program. This chapter gives the methodology for GUI development for all models used in the study.

7.2 Microsoft Visual Basic

Visual Basic is an object oriented programming development system for creating applications that run under any of Microsoft windows environment. It makes developing and debugging objects relatively easy. In large part, this is because Visual Basic is an interpreted language. As such, the user has very tight focus to step through the lines of code as the application runs and to see where errors occur. It uses an integrated development environment (IDE) as shown in Fig. 7.1. The IDE has two major components.

1. An extensive collection of prewritten tools, called controls. These controls are accessible as icons within a graphical programming environment for creating customized windows component (e.g., menus, dialog boxes, text boxes, flexible grids, etc.)

2. A complete set of program commands, derived by from Microsoft's implementation of classical basic programming language. The command set includes features that embrace contemporary programming practices.

Creation of a user interface and adding basic instructions to carry out the actions associated with each of the control are two basic steps in Visual Basic programming.

7.2.1 Object Related Concept

7.1.1.1 Forms

In Visual Basic, a window is called a form. Each form includes a title bar at the top. It may include a menu bar or status bar. All controls can be dragged and dropped in the form.

7.2.1.2 Controls

The icons with which the user interacts are called controls. Commonly used controls are command buttons, check boxes, labels, lost boxes and menus.

7.2.1.3 Objects

The forms and controls are collectively referred as objects. Most of the objects are associated with the events. They are also associated with their own properties and methods.

7.2.1.4 Properties

Objects include properties that generally define the appearance of behaviour. The choice of properties depends on the type of object.

7.2.1.5 Methods

Some objects also include special program statement called methods. A method brings about some predefined action affecting the associated object.

The IDE ready to write program with the displayed form as shown in Fig. 7.2

7.3 MapObjects

MapObjects is an ActiveX control, developed by ESRI, with nearly 50 programmable ActiveX automation objects that can be plugged into many standard Windows development environments, such as Visual Basic, Visual Basic for Applications (VBA), Visual C++, Visual Studio.NET (VB.NET and C#), Delphi, Borland C++ Builder, Visual FoxPro, and PowerBuilder. ActiveX is not a programming language, but a set of rules to share the information in application. Programmers can develop ActiveX controls in a variety of languages, including C, C++, Visual Basic, and Java. MapObjects functionality and programming have been used with the VB 6 development environment throughout the Chapter.

MapObjects consists of OLE (Object Linking and Embedding) automation objects which assist in map-making and spatial analysis. In other words, MapObjects consists of embeddable GIS components. Fig 7.3 shows how to include the MapObjects component to Visual Basic environment. Fig 7.4 presents the included MapObjects component. These components allow developing applications that display maps with multiple layers and images.

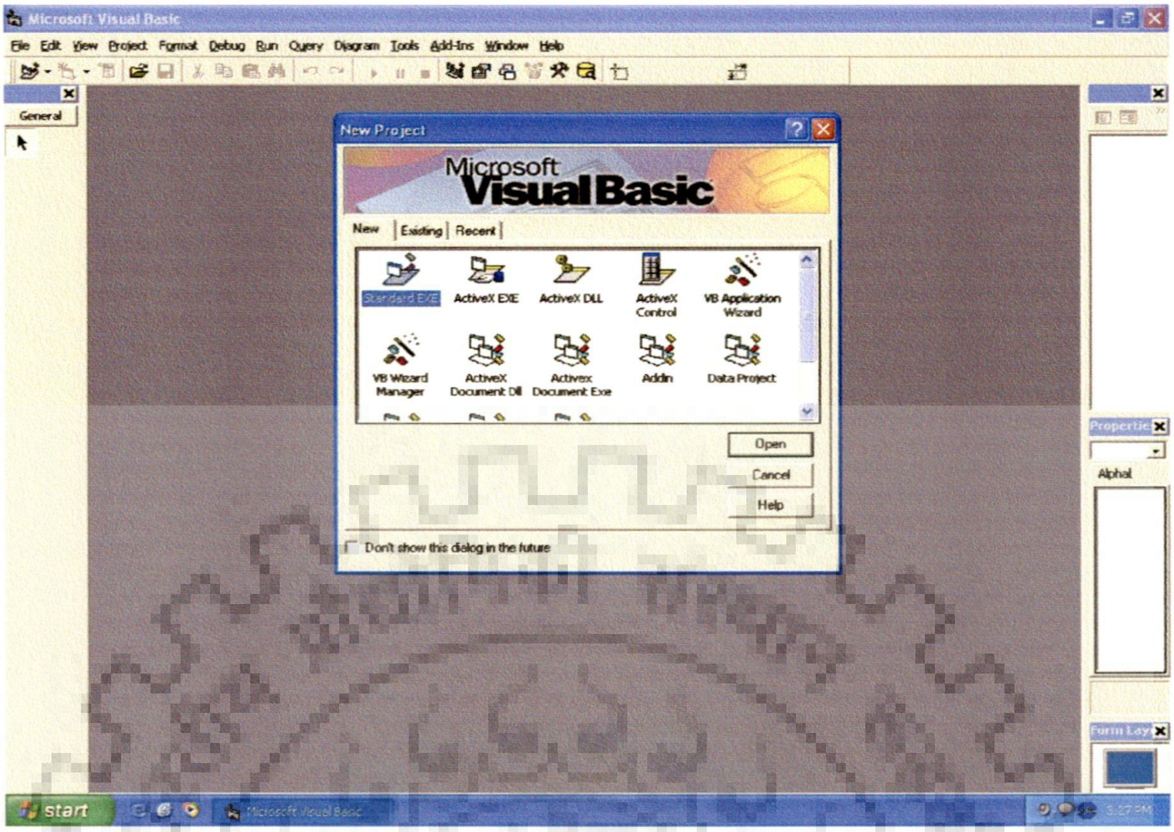


Fig. 7.1 Integrated development environment of Visual Basic

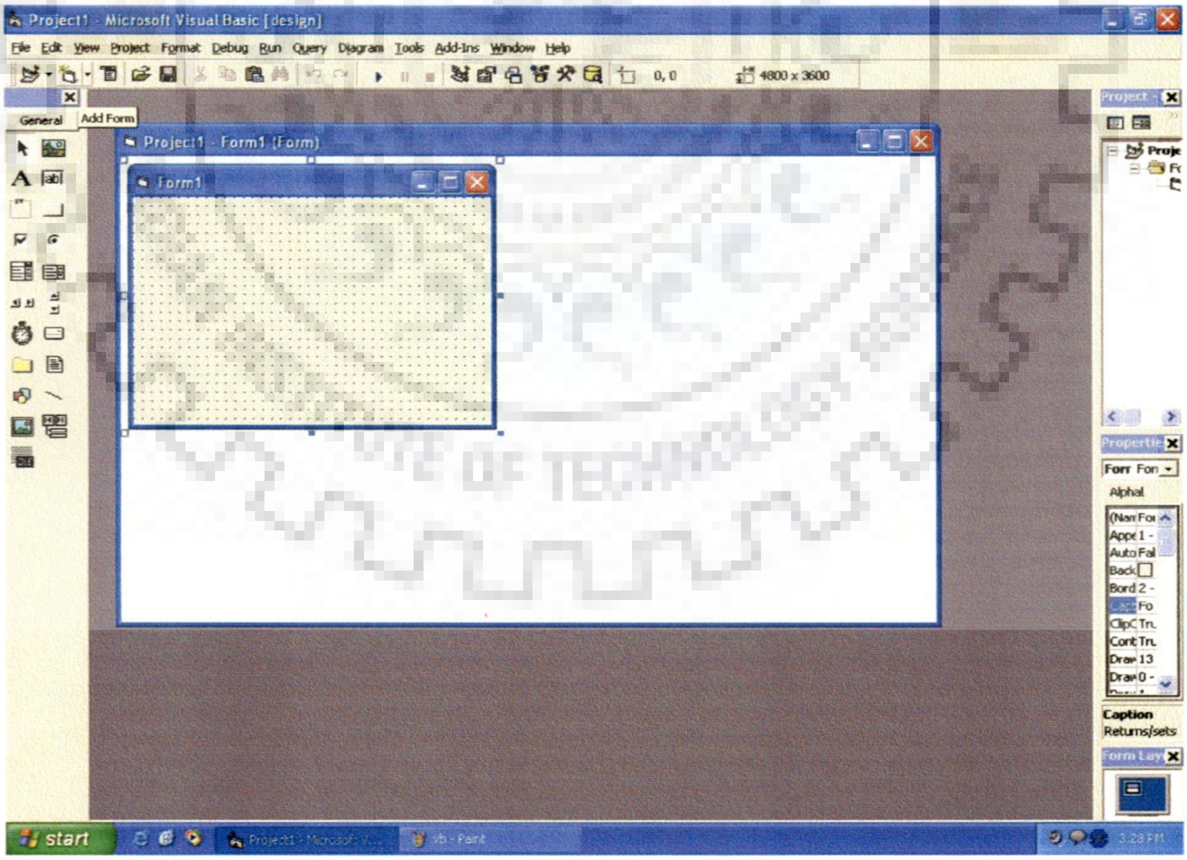


Fig. 7.2 IDE ready to write program with the displayed form

The analysis capabilities of MapObjects have been listed below.

1. Pan, Zoom, Reshape
2. Custom symbols
3. Map display using vector and raster data
4. Classifications
5. Dot density
6. Pie/Bar charts
7. Z-Rendering
8. Spatial queries and analysis
9. SQL query
10. Connectivity to external DBMS
11. Geometric operations
12. Union, Intersect, Buffer, XOR, Difference
13. Draw graphics and text
14. Calculate statistics
15. Compatible with ArcIMS
16. Export & Print maps

The MapObjects support nearly all-spatial data formats. The data that can be accessed by using MapObjects based on any application are given below:

1. ArcSDE 8.x
2. Coverages
3. Shapefiles
4. Images
5. GRID
6. CAD drawings
7. VPF
8. Tabular data via ODBC, DAO & ADO

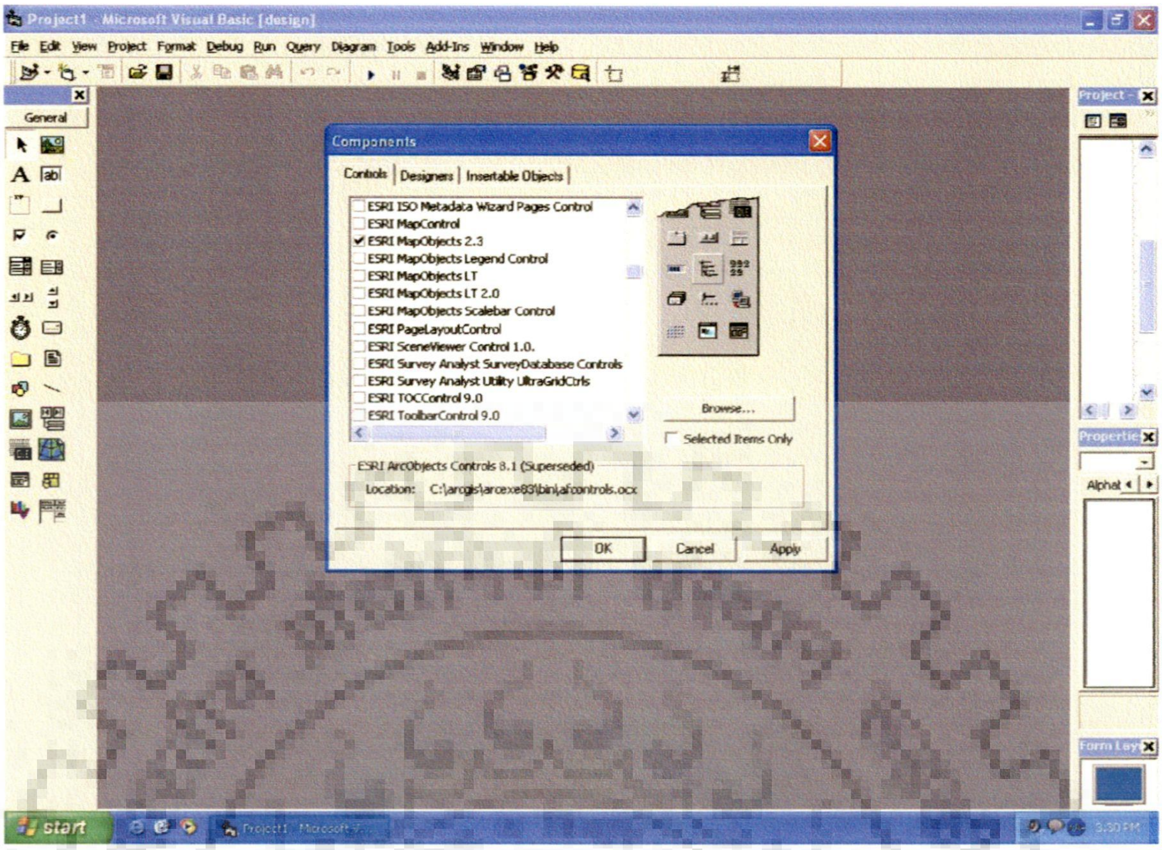


Fig 7.3 Procedure to include the Mapobjects component

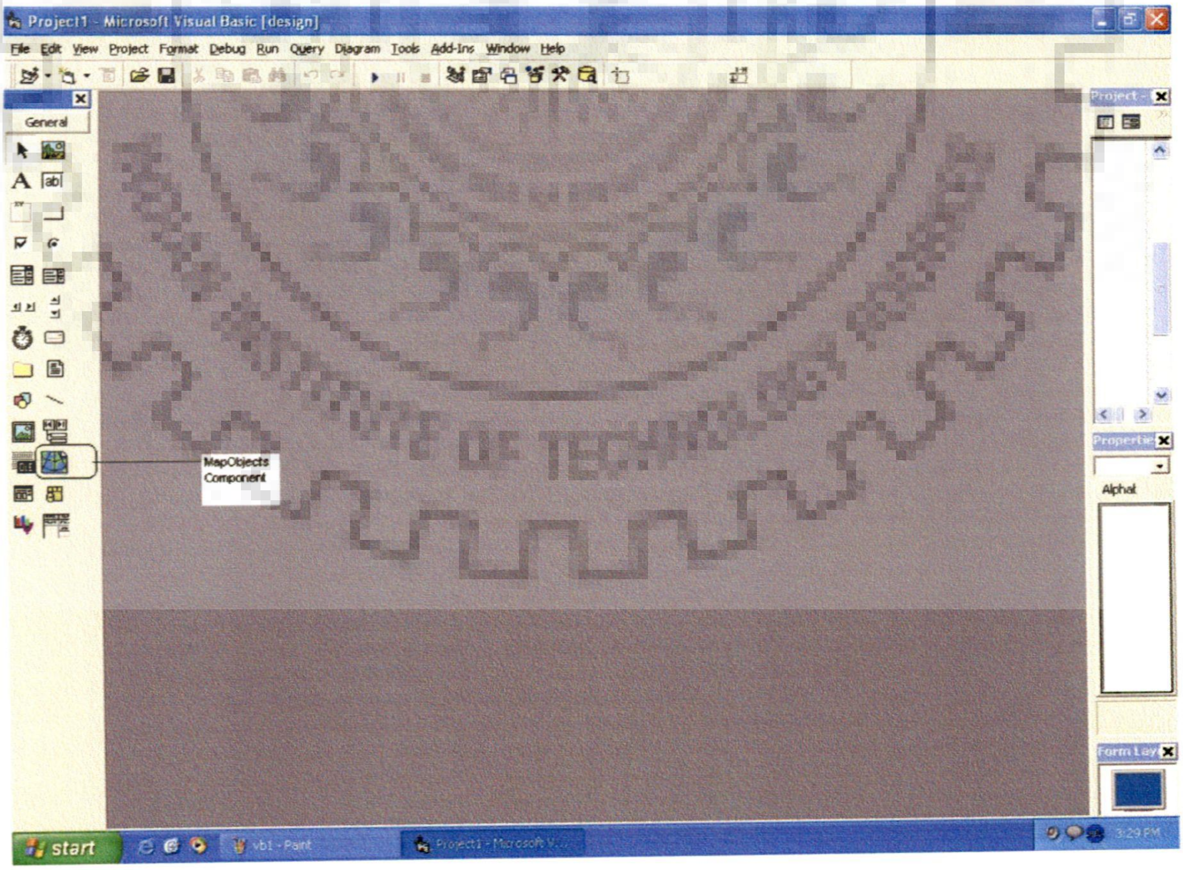


Fig 7.4 Included MapObjects component to VB environment

MapObjects has five major types of objects; data access objects, map display objects, address matching objects, projection objects and geometric objects. Each of these types of objects consists of several objects, and each of which has properties and methods. Data access objects are used to open and add layers and work with database tables. Map display objects are used to control the display of map layers. Address matching objects are used for geocoding. Maps can be projected and map layers with differing projections can be displayed with projection objects of MapObjects functionality.

Geometric objects consist of different types of entities, such as lines, polygons, rectangles and points. These objects can be combined to add functionality to the maps. To display layer information on map, map control, layers collection and at least one of the MapLayer object (Vector data), ImageLayer object (raster data) and/or Tracking Layer object (dynamic even data) are must be included in any program. Fig. 7.5 displays all the objects relationships in MapObjects.

7.4 Working with MapObjects and Visual Basic

Visual Basic has two sides of programming; (i) Inserting forms and putting controls over it so as to make graphical and (ii) Writing codes to activate the control and perform the desired operation. To make spatial data accessible, one needs to handle both Visual Basic and MapObjects codes simultaneously. Having MapObjects components in the programming environment, the object library of MapObjects is activated for Visual Basic. With this activation, one can use any object and its associated procedure and event. Fig 7.6 shows the MapControl mode added to *form1* of the Visual Basic project. The codes for this activation are displayed in Fig. 7.7

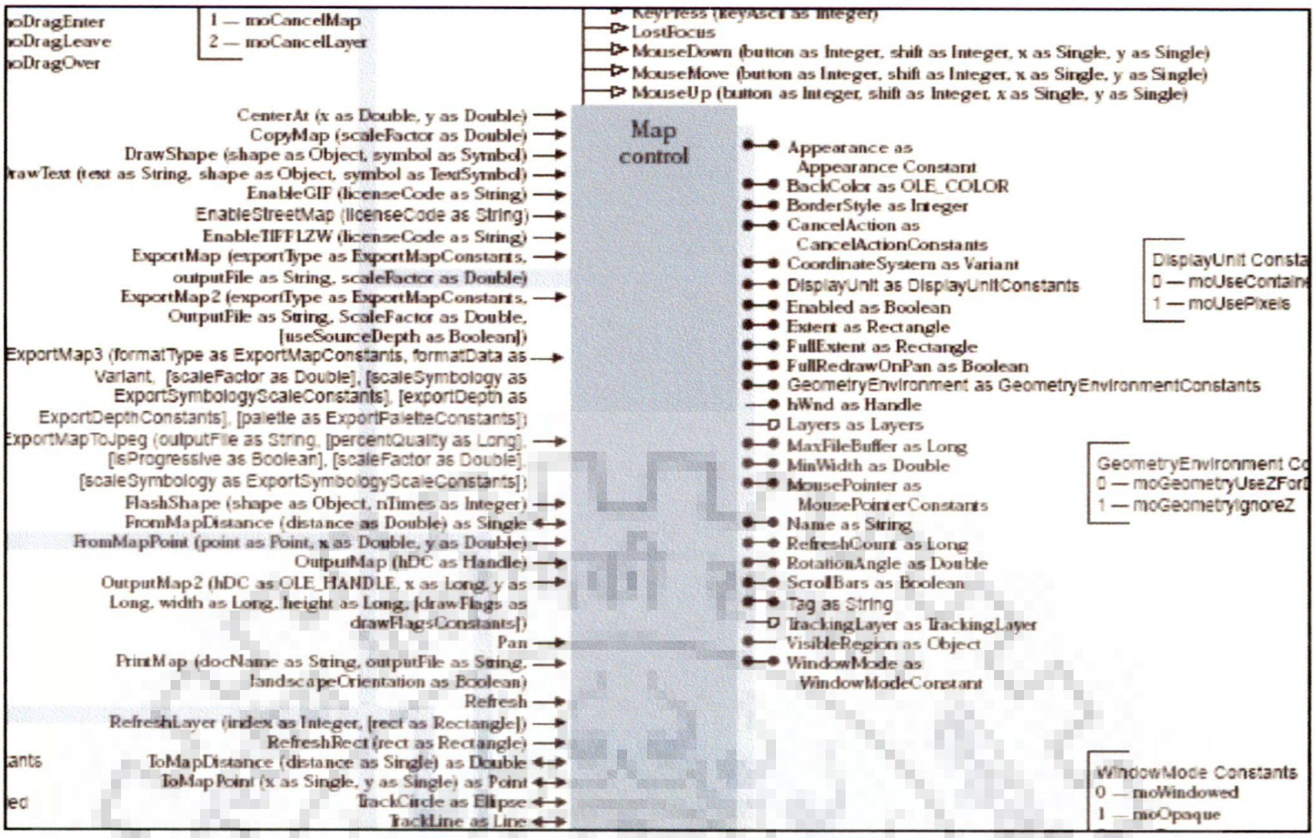


Fig. 7.5 Map Control Object Model

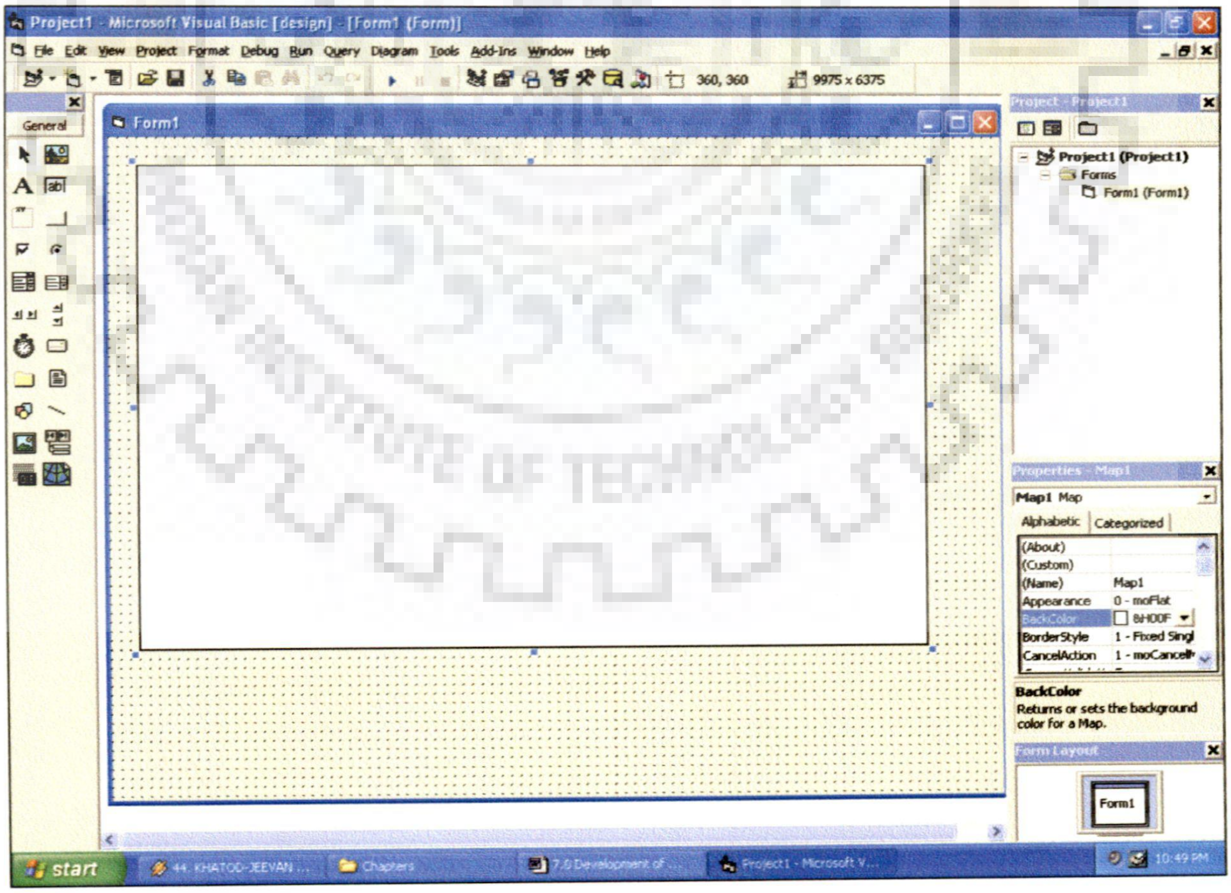


Fig 7.6 Adding map to the Visual Basic form

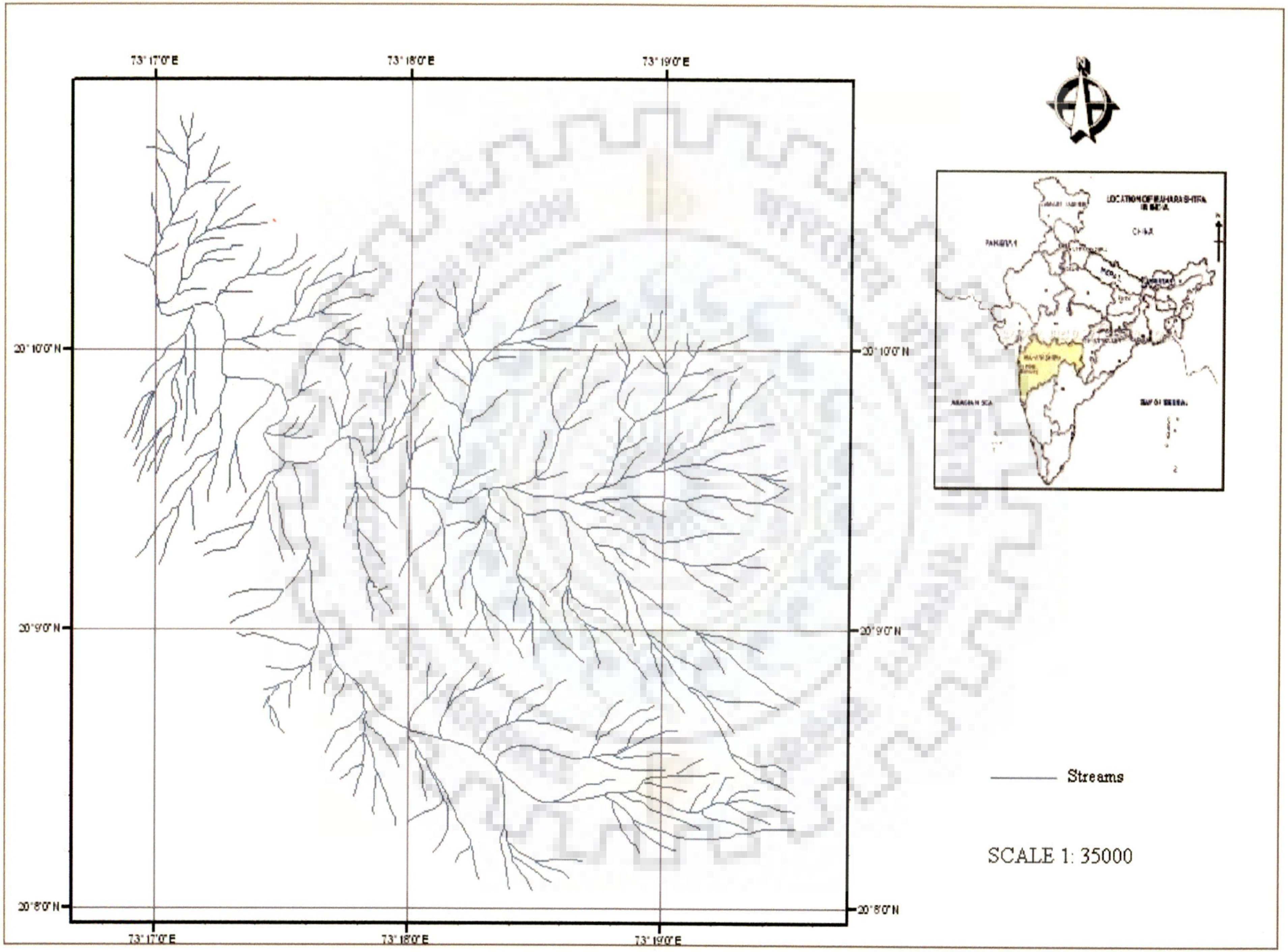


Fig 6.4 Drianage map

7.5 Development of Main Interface of DSS

The main interface represents actual software and tools for interacting with both complete DSS and spatial & temporal data as well as other information. This is independent stand-alone application developed with technologies as discussed in sections 7.2 to 7.4.

The main interface is divided in two parts one comprises a welcome screen giving the details of DSS. This part has two controls; (i) User has to click on screen anywhere to proceed to next main screen and (ii) cancel event, which terminates the DSS application before starting it. The developed software platform is a prototype of the **D**ecision **S**upport **S**ystem for **W**ater **R**esources **P**lanning in **W**atershed, which has been abbreviated and called as **DSS-WRPW**. The welcome screen of the DSS is shown in Fig 7.8.

The second part of main interface is activated with the click on the welcome screen of DSS. The screen shot of this part is shown in Fig 7.9. This interface is designed to support the modules listed below. The controls for these modules have been created using menu editor of Visual Basic. A help menu describing the complete methodology of operation of all the modules and other related information has been developed. Programming codes for these two interfaces have been given in Appendix A1.

1. Basic data
2. Rainfall
3. Evapotranspiration
4. Geomorphology
5. Surface runoff
6. Groundwater recharge
7. Water conservation structures
8. Water use plan
9. Land allocation module
10. Forecasting module
11. Help

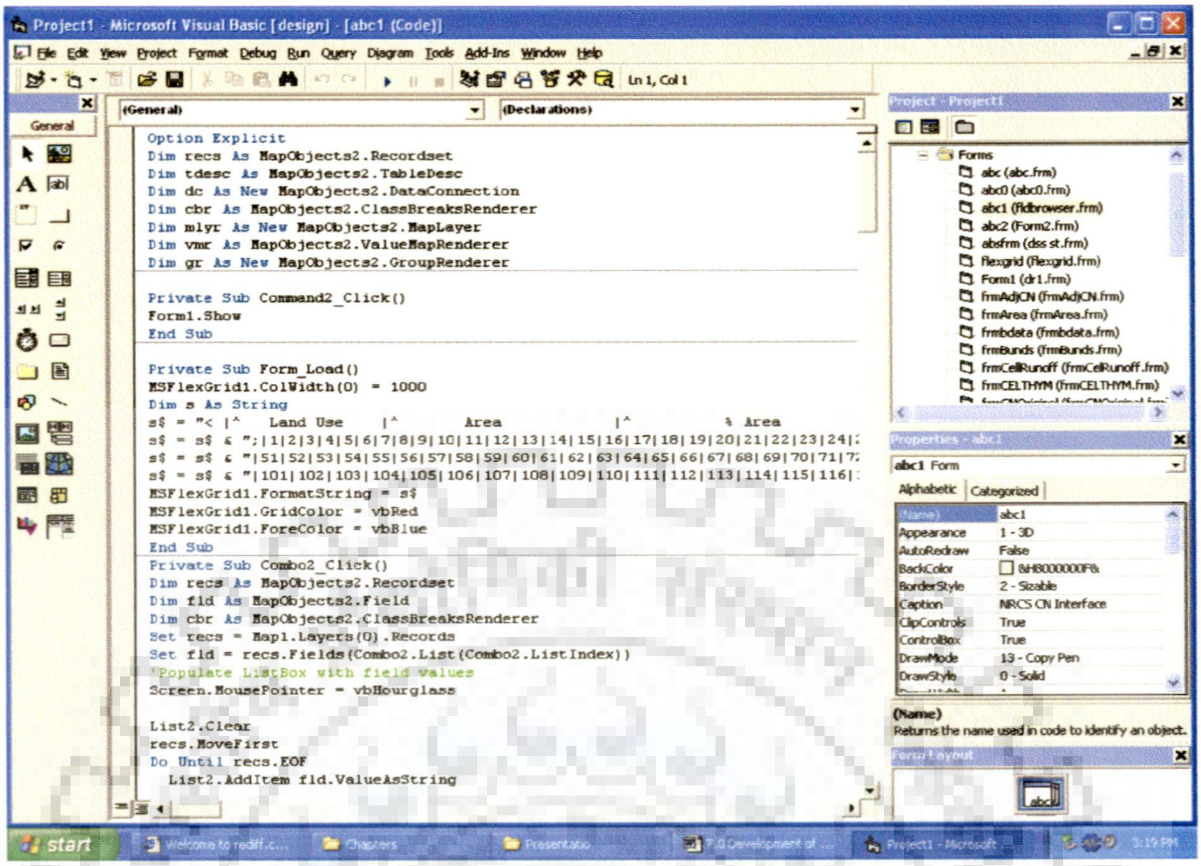


Fig 7.7 MapObjects code operation in Visual Basic

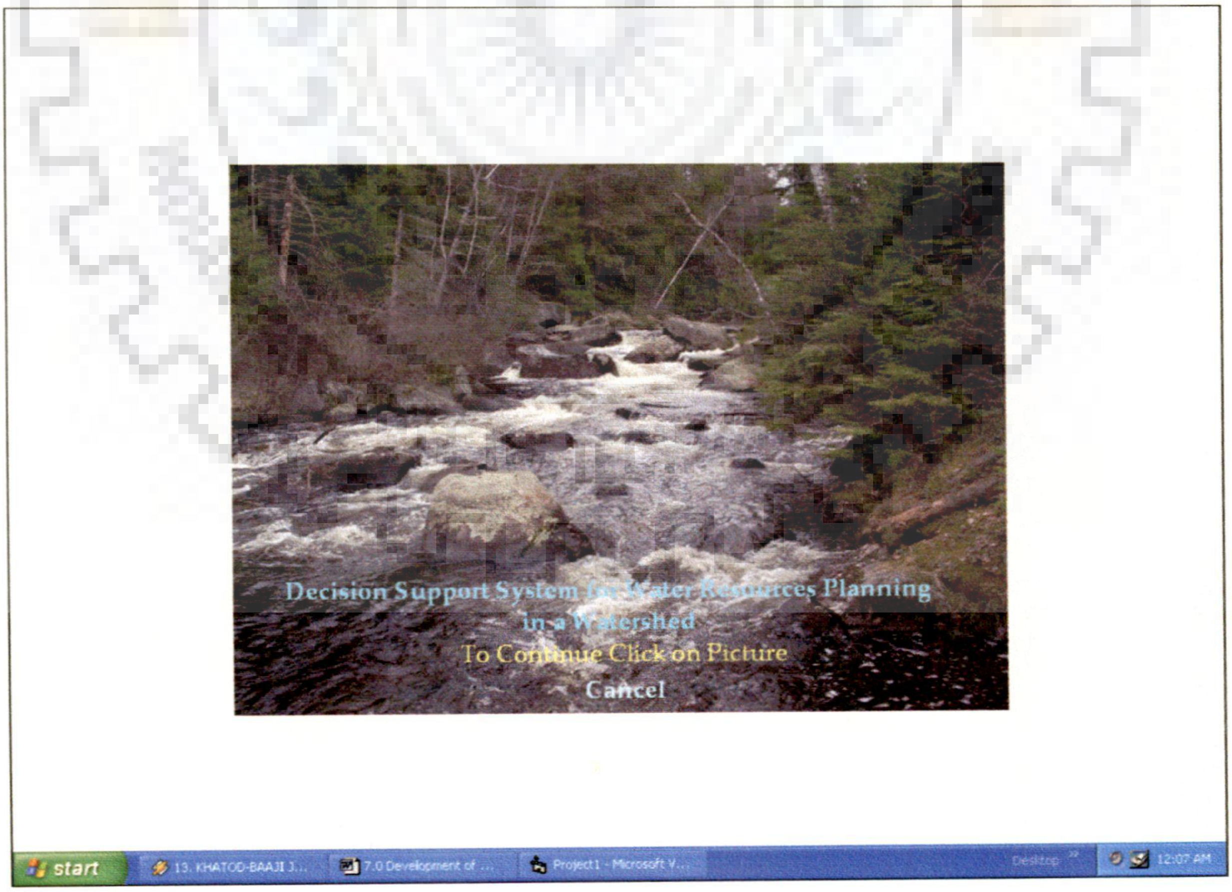


Fig 7.8 Welcome screen of DSS

7.5.1 Basic Data Module

To begin with operation and analysis, one has to click on *Basic Data* of menu bar of main interface, with this event a *Watershed Data* Form (Fig 7.10) appears, which has to inputs of *Location and Demography* details. The different text boxes have been provided in this form or module against the labels of details required.

7.5.2 Rainfall Module

This module takes rainfall data from Microsoft Excel file stored in the same directory in which complete DSS program runs. The Excel file has to be named as *Rain.xls* with the columns arranged in the order of Date, Month, Year and Rainfall. When a user clicks on the *Rainfall* menu in the main interface, the Visual Basic Form *"Rainfall"* (Fig 7.11) appears on window. The code operation of this module is in two parts. First part consists of loading of a control named *MSFlexGrid1*, with 5 columns and 500 rows, which is automatically loaded with the form loading procedure of the Visual Basic. The procedure is supported with Excel application in the Visual Basic, which identifies a date, month as a string from already saved Excel file. Data from the date 1 and month 6 previous year to date 31 and month 5 of subsequent year (e.g. 1st June, 1993 to 31st May, 1994 i.e. Water Year) is called to *MSFlexGrid1* with the click event of command button *Add Rainfall Data*. Programming codes for these two interfaces have been given in Appendix A2.

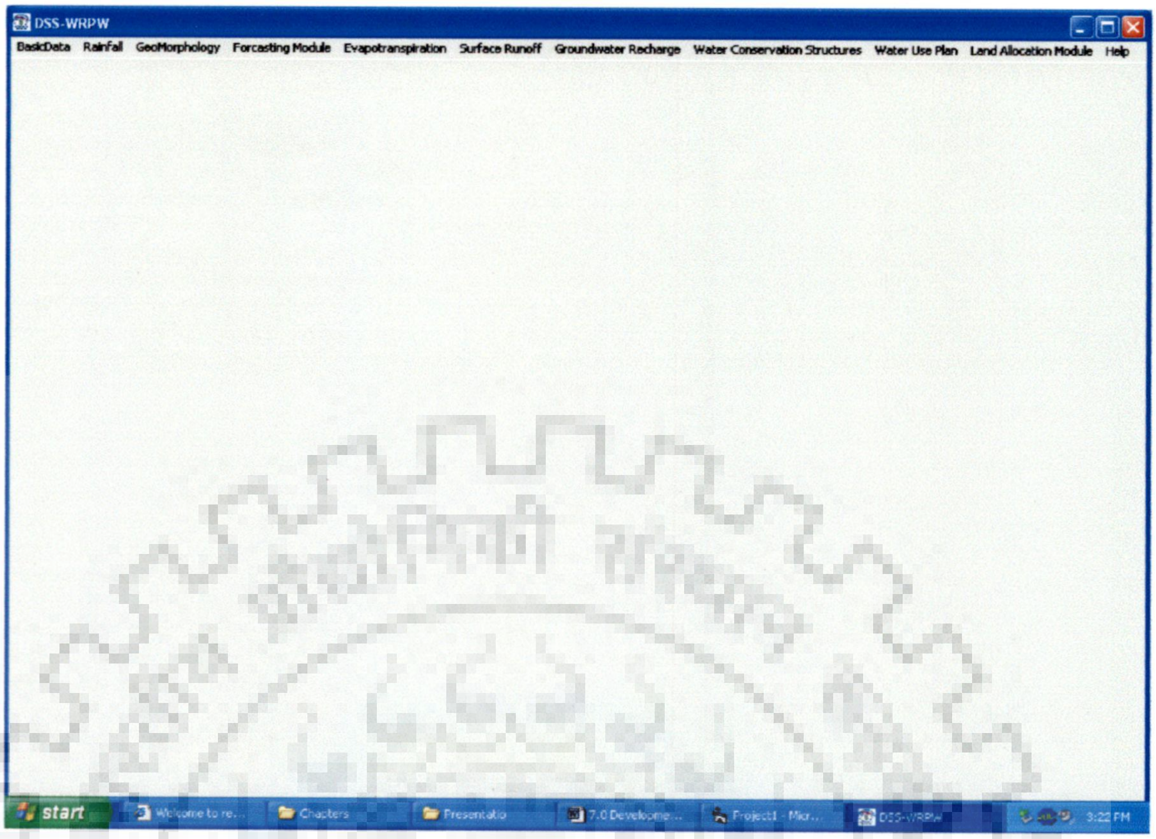


Fig 7.9 GUI Support to different modules of DSS

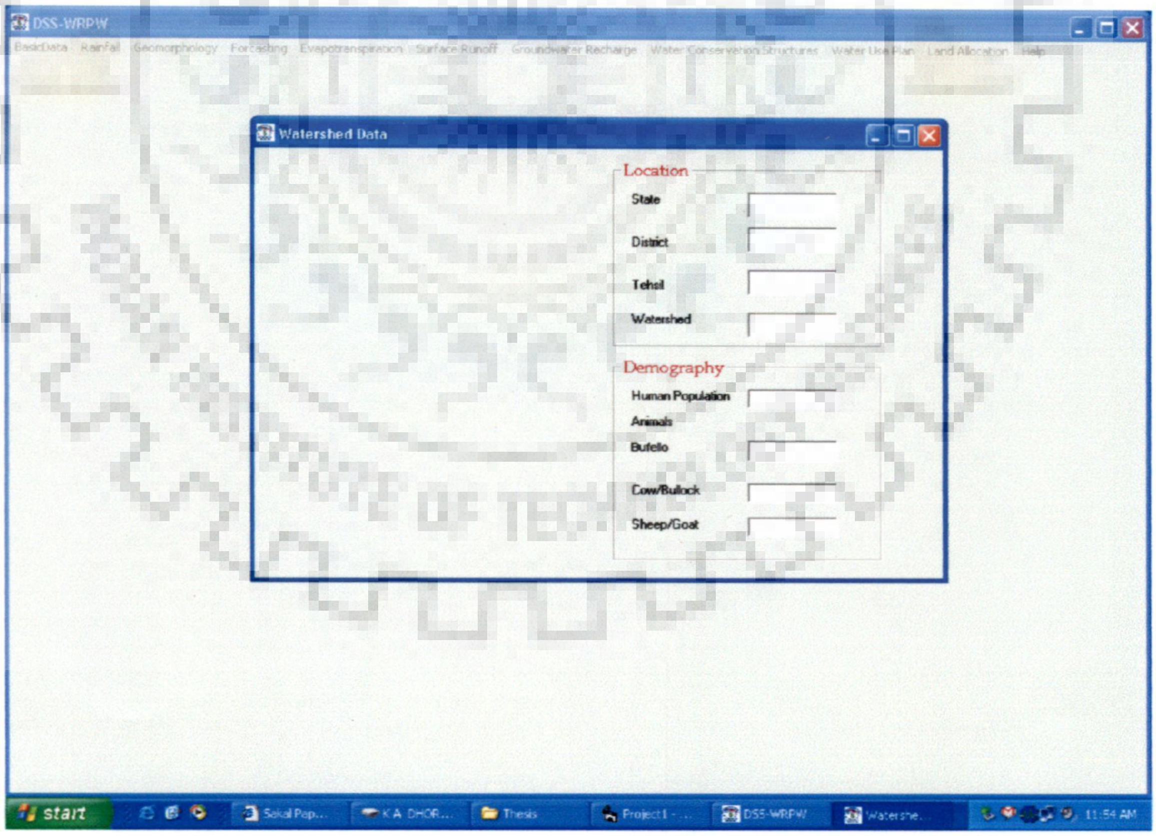


Fig. 7.10 Basic data module

7.5.3 Evapotranspiration Module

This module comprises of three sub-modules; *Monteith Penman, Hargreaves Samani and Crop Water Requirement*. First two modules are used as independent run mode, while later is dependent on the running of either of the former. When user clicks on the *Evapotranspiration* menu in main interface, three sub menus of each of the sub-module appears. User has to select any one of the first two sub-menus to continue the operation. The main menu of this module with main interface is shown in Fig. 7.12. Considering the amount of data in Monteith Penman method, which may not be available with the user in normal circumstances, another method, Hargreaves Samani, may be used. This model requires relatively lesser amount of input data. This has been adopted to make application of DSS more versatile.

7.5.3.1 Penman-Monteith Module

The is one of the important and most comprehensive data requirement modules, which is loaded after clicking on the sub-menu named *"Monteith Penman"*. The module comprises of a single form, which has MSFlexGrid to display the data, two text boxes to input the elevation or MSL and latitude. The module is operated with two command buttons as controls; *Get Meteorological Data* and *Calculate*. The screen shot of this module is shown in Fig 7.13.

7.5.3.1.1 Code Operation

The coding required for running this module with both the events is given in Appendix B1. Initially MSFlexGrid, which consists of 50 columns and 500 rows, is loaded with form load procedure of Visual Basic. The Microsoft Excel file, *ET MP. xls* containing input data is called through the click event of *Get Meteorological Data*. The data in the file has to be arranged in sequence; Date, Month, Year. Tmax, Tmin, RHMax, RHMin, n, J, U2. Data from the date 1 and month 6 previous year to date 31 and month 5 of subsequent year is called to *MSFlexGrid.* Second command button C*alculate* executes all the formulae of the Monteith Penman model of ET estimation as discussed in section 5.4.1. The final values of estimated ET are presented against the Date and Month in the same grid table in 46th column.

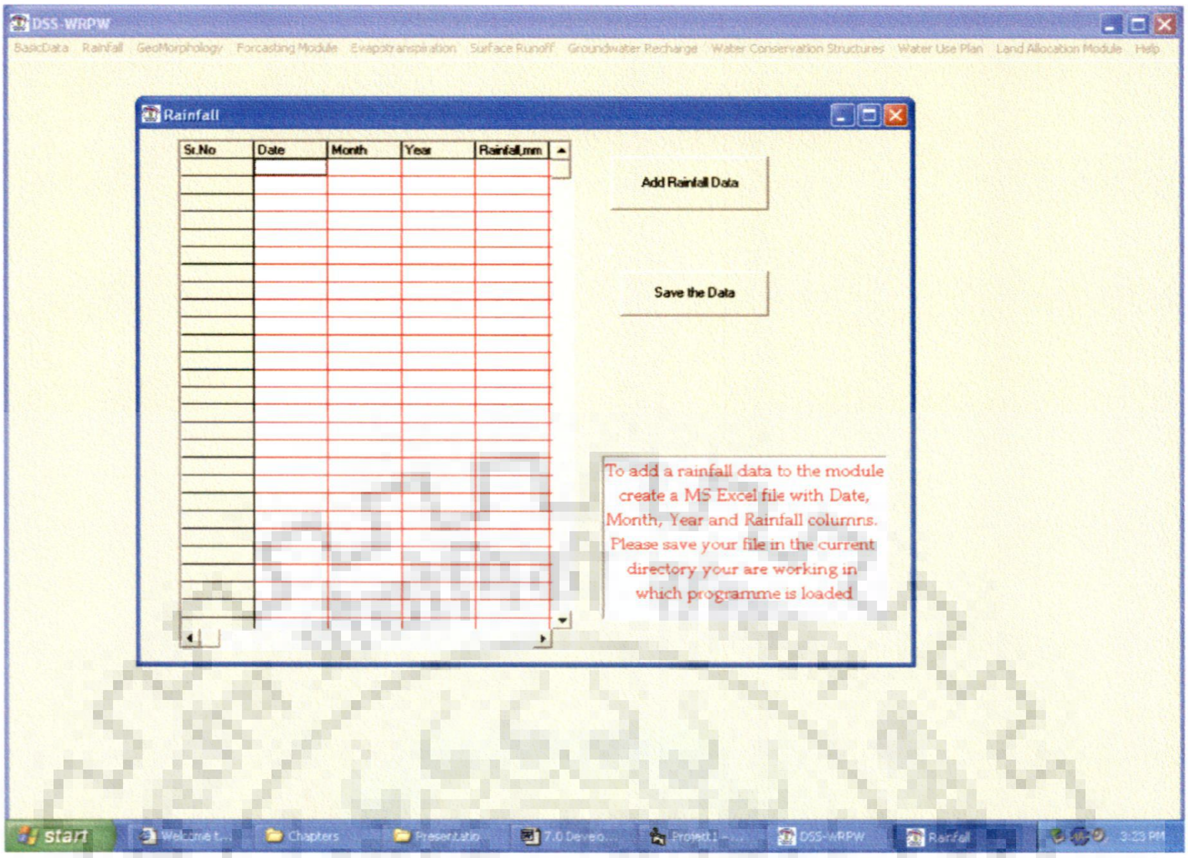


Fig 7.11 Rainfall module screen shot

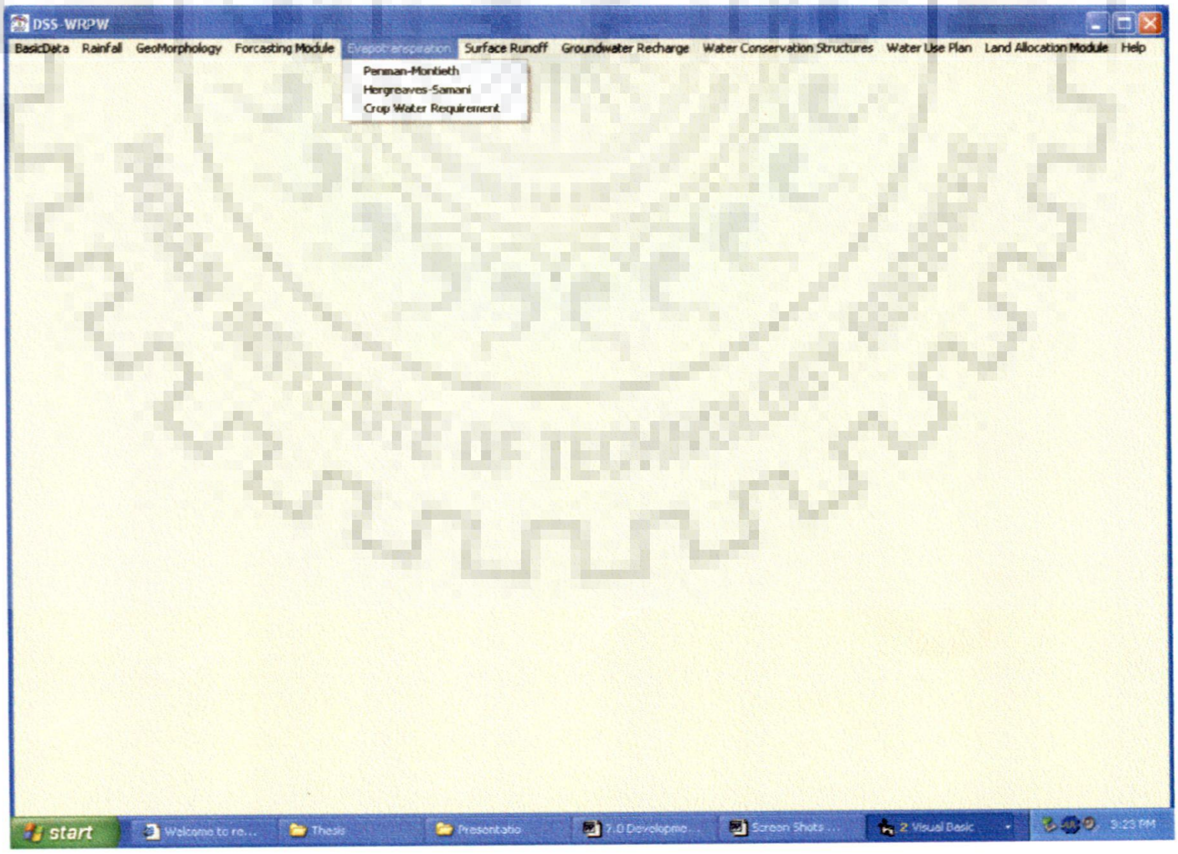


Fig 7.12 Evapotranspiration module

7.5.3.2 Hargreaves Samani Module

Hargreaves Samani method of ET estimation, as discussed in the section 5.4.2, has been used in this module. The module populates with the click on *Hargreaves Samani* sub-menu of *Evapotranspiration* menu of the main interface. The Visual Basic form of this module is shown in Fig. 7.14. The codes for this module operate in the same manner as discussed in the earlier module. The Microsoft Excel file with columns arranged in the order of Date, Month, Year, Tmax, Tmin and Ra is called here to *MSFlexGrid*. This operation is performed with clicking on command button *Get Data*. Another command button "*Compute*" performs all computations of ET. Estimated values of ET by this method will be displayed in 14^{th} column of the grid data table.

7.5.3.3 Crop Water Requirement Module

This is a third sub-module included in the Evapotranspiration module. User has to click on sub-menu "*Crop Water Requirement*" to get this module on the desktop. The Visual Basic form named "*Crop Details*" is shown in Fig. 7.15. This module is divided in two parts; one is *MSFlexGrid*, which takes the data from either of the two modules of ET estimation depending on the user choice given through combo box "*Select ET Model*". The *MSFlexGrid* is loaded with Visual Basic form, with 20 columns, 400 rows, Sr. No in first column and strings of Date, Month, and ET in the first row. Second part consists of selection of crop from 10 combo boxes provided on the left hand side of the module, input regarding the area of individual crop, while user has to choose season from the respective combo box provided in front of each crop.

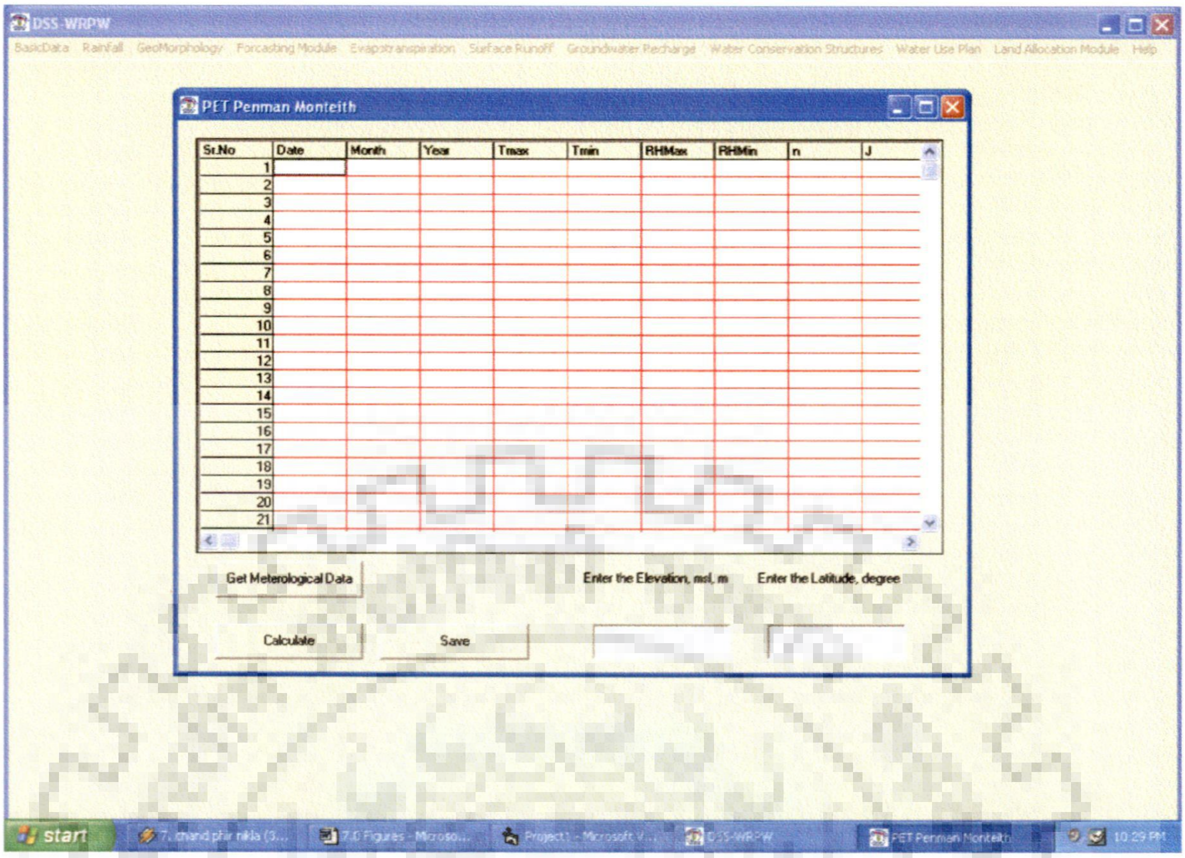


Fig 7.13 Penman-Monteith module

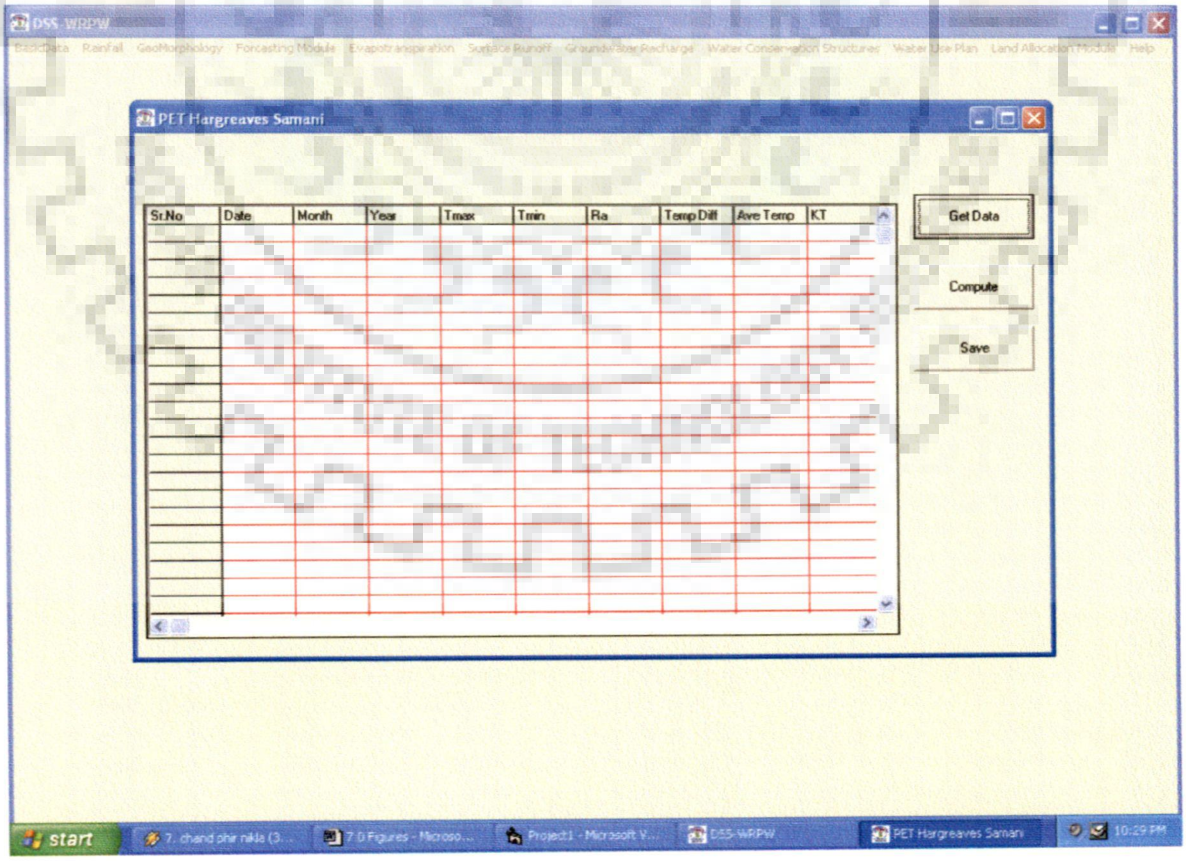


Fig 7.14 Hargreaves Samani module

7.5.3.3.1 Code Operation

The module operates the programming codes (Appendix B3) with selection of crop and its respective season from combo boxes. The name of the crop selected is sent to first row of *MSFlexGrid*. Season of the crop is sent to second row of *MSFlexGrid*. Next controls are operated through the command button "*Compute CWR*". The crop coefficients (Kc) written in the programming codes are taken with the selected crop. These Kc values are then multiplied to the ET values during the particular period of season (column 3 of *MSFlexGrid*). This is the crop water requirement in mm. These values are displayed in the same column in which crop name is displayed. Daily crop water requirement of all crops is summed to 15^{th} column, and then fortnightly values are summed to compute the fortnightly water requirement of crops. These values are called to the *Water Use Planning* module of the DSS in the agricultural demand to compute the net irrigation requirement of crops.

7.5.4 Geomorphology Module

This is an auxiliary module provided in the DSS to have general information regarding the morphometrical characteristics of the watershed. This module has been divided in multiple forms or sub-modules. The sub-module named "*Morphometry*" uses the GIS component MapObjects twice to display the ESRI shape files describing drainage network data. The second sub-module "*Morpho Linear Aspects*" computes linear parameters of geomorphology. The third sub-module "*Areal Aspects*" again uses the MapObjects component to display the ESRI shape file describing the boundary of the watershed. All the three modules are connected through the series. However only first sub-module is populated with the click on the "*Geomorphology*" menu of the main interface. The discussions in the subsequent sections describe each of these modules in detail.

7.5.4.1 Data Display

The shape file describing the drainage network characteristics as discussed in section 6.3.2, is opened to the MapLayer (first white box) through command button "*Open Stream File*". Click on this command introduces a common dial control of windows, which allows to navigate through computer to search the desired shape file. The required shape file is loaded on the MapLayer with click on open button of the common dialogue control. This approach of opening the shape files has been adopted through out the DSS, wherever the DSS needs the GIS data to be displayed. The sub-module is shown in Fig. 7.16.

Once the drainage network file is displayed in the map control, the x and y co-ordinates of each node of every stream with reference to displayed coordinate system in the *MapLayer* are written to the new shape file named "*endpoints.shp*". This event is carried out with the click on command button "*Assign X, Y*". This shape file is stored in the temporary folder of windows for further retrieval in the stream ordering as per the Strahler's configuration, as discussed in section 5.3.1. The new attributes of Fxi, Fyi, Txi, Tyi and stream order are added to the new shape file, while retaining the stream length from original shape file. The new shape is called to display in another form (Fig. 7.17) through click on button "*Order Streams*". List of desired names of attributes fields is displayed in the combo box placed below the MapLayers, using the *Recordset* and *TableDisces* functions of MapObjects. User has to click on the desired attributes in the combo box. The click on button "*Order Streams*" in new form will start ordering the streams. These orders are now exported to previous sub-module i.e data display to get displayed in *MSFlexGrid*. With the click on list item in the combo box, values of attributes pertaining to field ID, stream length of all streams are displayed to *MSFlexGrid* in same window.

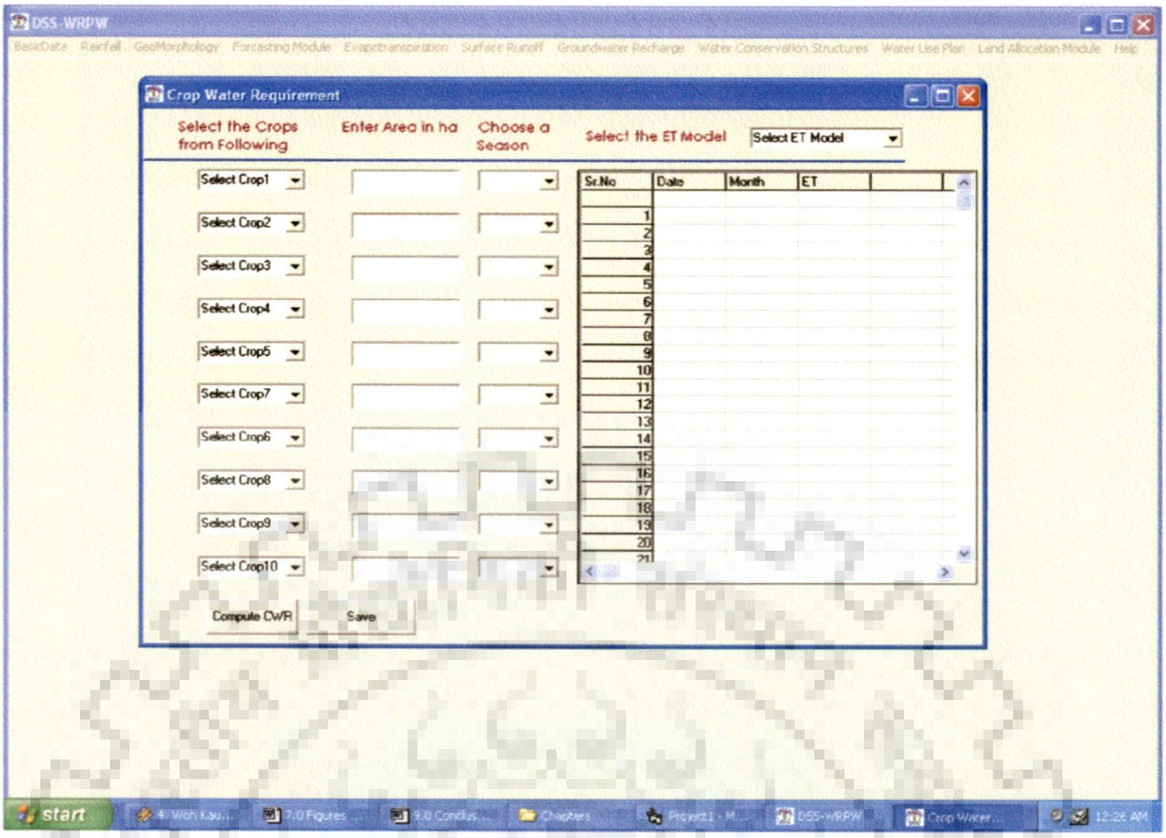


Fig 7.15 Crop water requirement sub-module

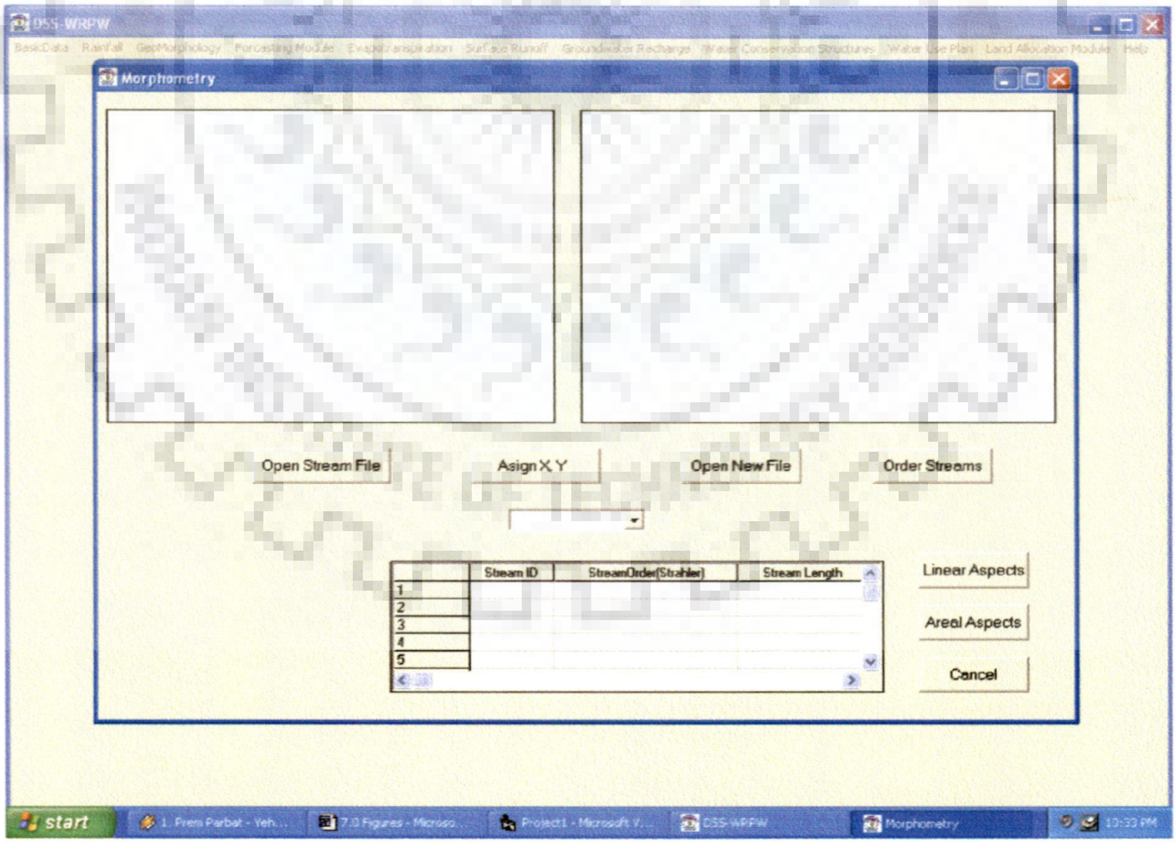


Fig 7.16 Data display sub-module *Morphometry* of geomorphology module

To get all morphological parameters, click on the command button "*Linear Aspects*" pops up another form or window, while "*Areal Aspects*" gives way to window calculating the areal parameters. But before viewing the areal parameters windows user has to complete the linear aspects. The codes that are operating these controls are given the Appendix Appendices C1 & C2.

7.5.4.2 Linear Parameters

The sub-module needed to summerise the linear characters of morphometry is shown in Fig. 7.18. This module actually takes input from the *MSFlexGrid* of the data display window. The module counts streams of each order, and their total length is summed up to get displayed in the *MSFlexGrid* in current window. The total number of streams of each order with its total length is shown in each row from 2nd row onwards. The last row gives the total of particular character. However, the maximum order of drainage streams and total length of the streams are shown in individual text boxes at the start of window. All the computations are done with the command button "*OK*". The algorithms used in this module are given in section 5.3.1 and codes for this sub-module are given in Appendix C3.

7.5.4.3 Areal Parameters

This is sub-module giving the parameters related to area. The module is shown in Fig. 7.19. This is a two-step sub-module, which calls a shape file describing the boundary characteristics of the watershed and calculates the other parameters related to area and perimeter. The shape file is called through the command button "*Open Boundary File*". It takes the area and perimeter of the watershed to calculate various parameters as shown against the various labels from Sr. No. 1 to 14 using formulae discussed in Table 5.7 of section 5.3.1. The command button "*More Parameter*" controls all the operations of this portion of codes, as given in Appendix C4.

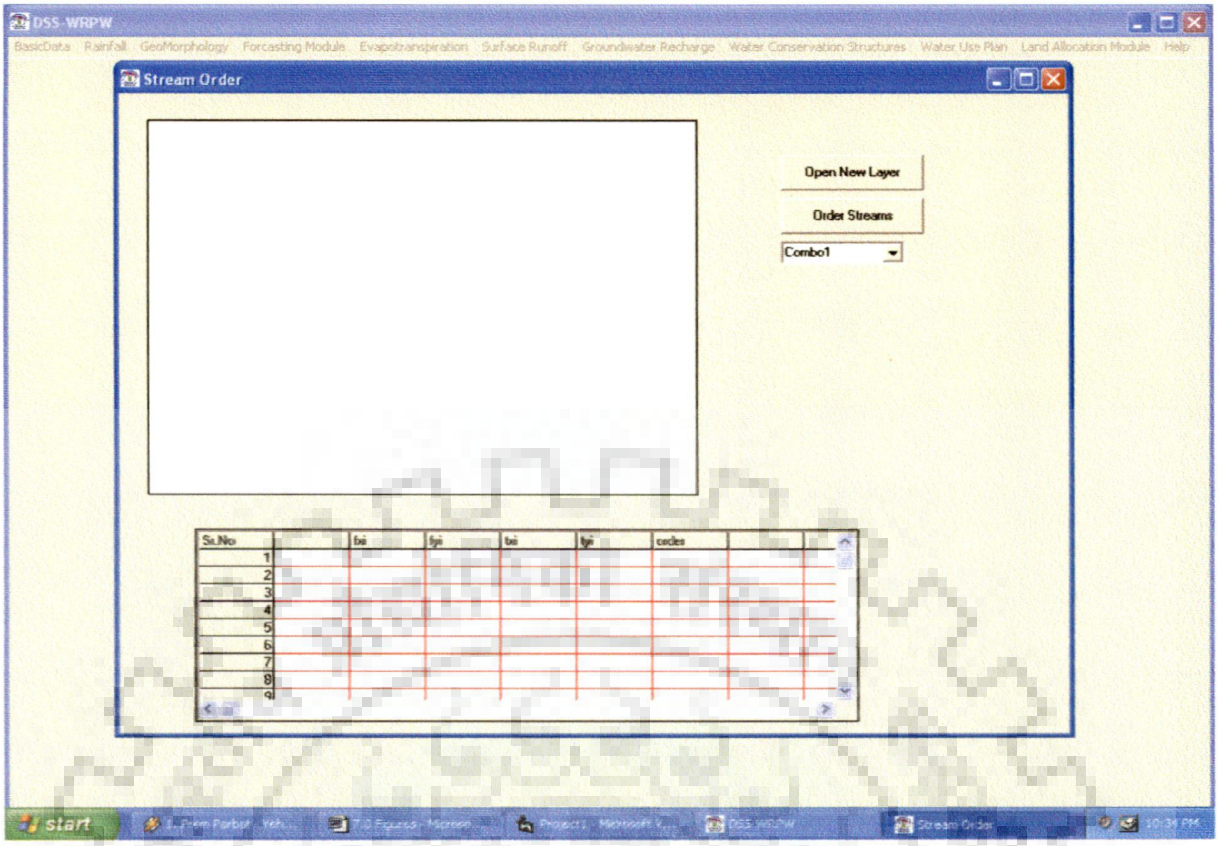


Fig. 7.17 Stream order sub-module

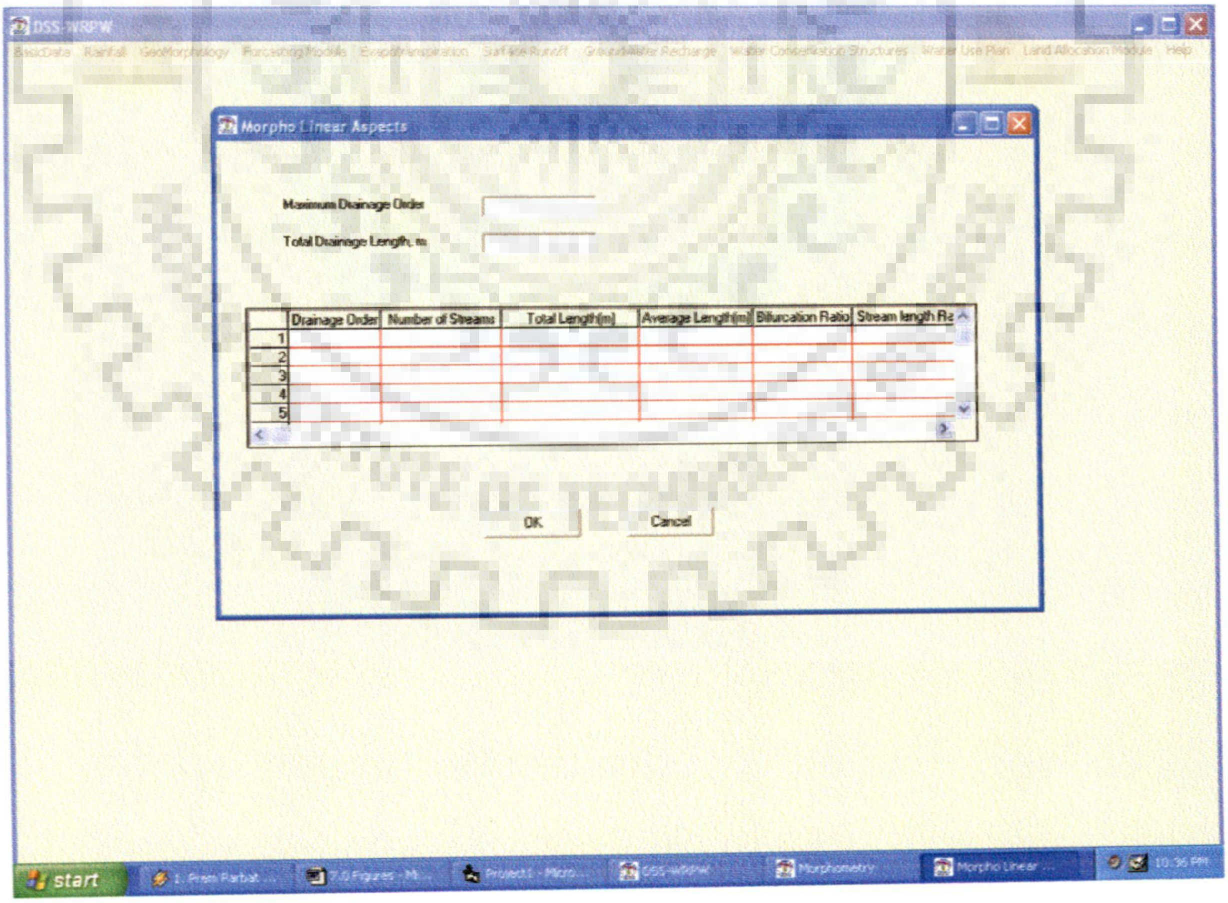


Fig 7.18 Geomorphology sub-module *Morpho Linear Aspect*

7.5.5. Runoff

This is one of the important modules of DSS. The various sub-modules provided in this menu are based on the three popular models of runoff estimation. These models are implemented with the shape files describing various properties of the watershed. Click on the menu "*Runoff*" in the main interface produces the list of sub-modules available in the module (Fig 7.20).

7.5.5.1. Rational Method

The sub-module (Fig 7.21) aims at computing the peak runoff rate for return period given by the user and at the nearest station to watershed. The module takes the shape files describing the contour and slope range as input to compute the distributed value of runoff coefficient. This is the multi-control and multiple data input module, which uses the *MapLayer* property twice and various combo boxes.

The operation is in two steps; in the first step user has to open the two shape files and select other design parameters from the other controls. The combo box provided on the extreme right of the window gives the option to select the nearest station and return period in years to compute the rainfall intensity.

By clicking on command button "*Get Contour Map*" user has to open the contour map. Click event populates the windows common dialogue box to select file from the hard drives. The MapObjects property *RecordSet* is used to get the minimum and maximum elevations from the contour map. The length of the basin is called from the *Areal Aspects* sub-module of *Geomorphology* module. All this information is displayed in the text boxes put under the different labels. The shape file describing (section 6.3.3) the various ranges of slopes required to compute runoff by rational formula is called to a second *MapLayer*. The list of attributes of this shape file is then populated to another combo box provided beside the second *MapLayer*.

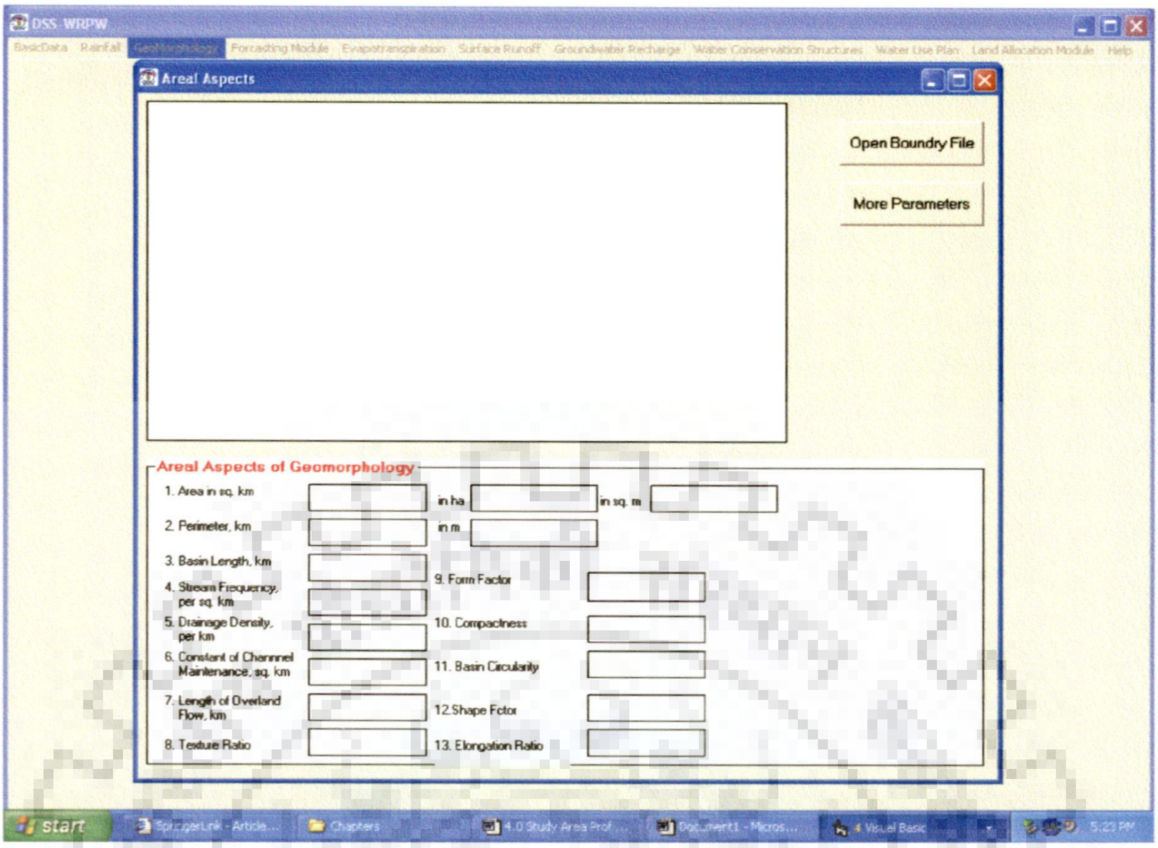


Fig. 7.19 Geomorphology sub-module *Areal Aspects*

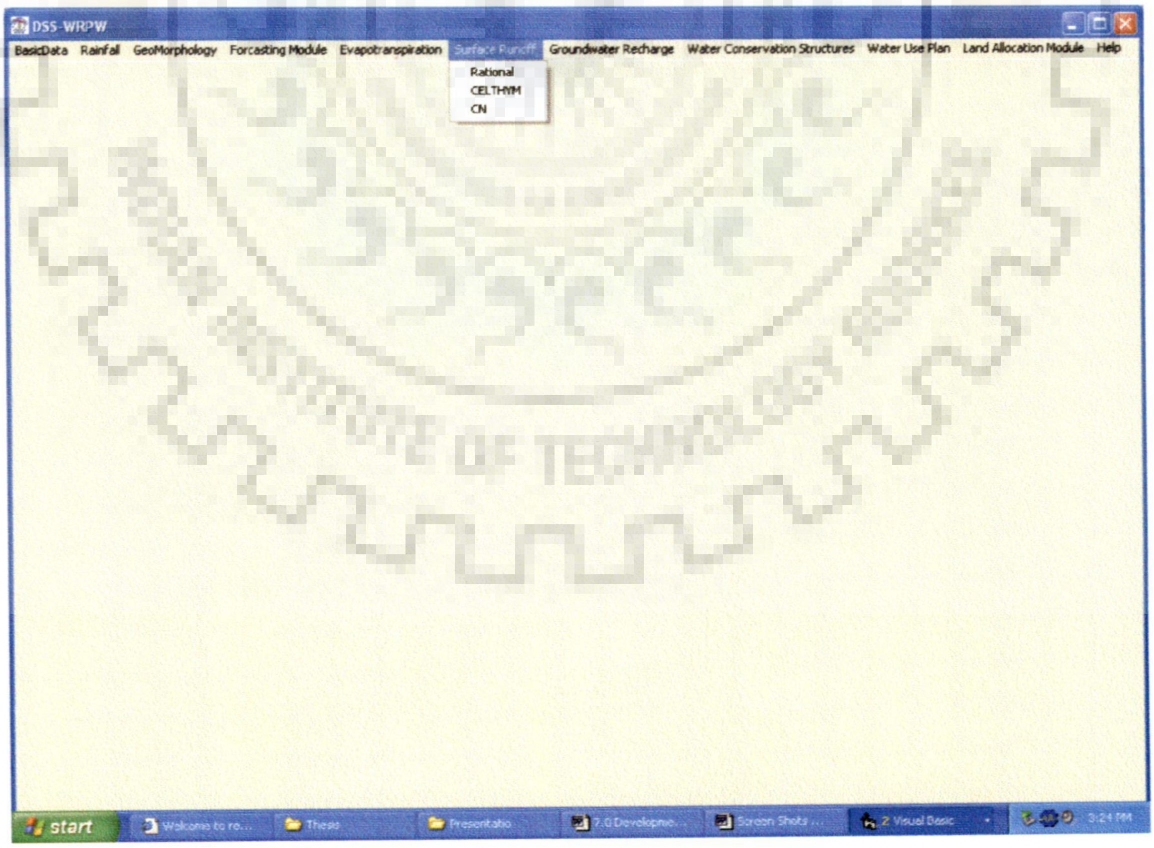


Fig 7.20 Runoff module in the main interface

The desired fields of attributes are then sent to *MSFlexGrid* to compute distributed runoff coefficient. The first column in the *MSFlexGrid* carries attributes fields of slope range in a particular land parcel with landuse in the second column. Runoff coefficient values are then carried out to the third column. The value of distributed runoff coefficient is exported to the text box placed below the label in the main sub-module form.

In the second step of operation, user has to select the nearest station to watershed. The return period has to be selected from the combo box provided against its label. Using this information program computes the rainfall intensity for the nearest station in mm/hr. The text box below the label *Watershed Area* connects to *Areal Aspects* sub-module of *Geomorphology* module to get the area of watershed in hectares. The computed value of peak runoff in m^3/sec is displayed to respective text. The codes of the operation of this sub-module are given Appendix D1.

7.5.5.2. NRCS Curve Number

This is an important interface to popular NRCS curve number model to estimate the daily runoff from the watershed in terms of depth at the outlet. Interface has been implemented as with other models discussed in this Chapter. Interface comprises of two sub-modules; one having *MapLayer* to input the shape file describing the land use, soil type and area of polygons in the watershed, and another sub-module calls data for daily rainfall from *Rainfall* module of DSS.

7.5.5.2.1. Data Display

The sub-module (Fig. 7.22) developed is aimed at computing the distributed and lumped curve number values from a particular watershed. Watershed characteristics affecting the runoff are displayed to *MapLayer* using the shape file of watershed. The command button "*Load Layer*" introduces a windows common dialogue control to browse the shape file in the system. The list of attribute fields is then taken to the combo box below this command. The user has to sort or click on the list items in the combo box to input all values of attribute fields to respective column in the *MSFlexGrid*. This *MSFlexGrid* is shown in the same sub-module, which takes the strings related to landuse in the first column and area in the second column, while the parameters related to soil are in the eighth column. With necessary calculations carried out in the *MSFlexGrid*, the weighted curve number value at watershed scale is then exported to the text box placed below the command button "*Compute*". This event is controlled with the click on this command button. The value of the curve number in this text box is for AMC II condition, which is then taken to the next sub-module in the same interface to estimate new curve number at respective AMC condition. The command button "*Condt*" links the next sub-module with this module. Appendix D2 gives the programming codes for this sub-module.

7.5.5.2.2. Runoff Computation

This is a supplementary sub-module to the runoff interface. Fig 7.23 shows the blank run screen shot of the sub-module. The sub-module takes the rainfall data for the monsoon period to the third column with date and month in the first and second column. Potential evapotranspiration values are imported here from the *Crop Water Requirement* sub-module of *Evapotranspiration* module to fourth row in *MSFlexGrid*. The 5-day preceeding values of rainfall are then calculated via codes as given in Appendix D3 in fifth column, which decides the AMC conditions. The value of curve number at AMC II condition (sixth column) is converted to curve number values at respective conditions in seventh column as discussed in section 5.2.2.1. Using these values of converted CN, potential abstraction and runoff values are computed in the eighth and ninth column respectively. The total daily runoff in each row is then summed up to get the seasonal runoff from the watershed, which is taken to text box below the *MSFlexGrid*. This seasonal value of runoff has been used in the design of water harvesting ponds.

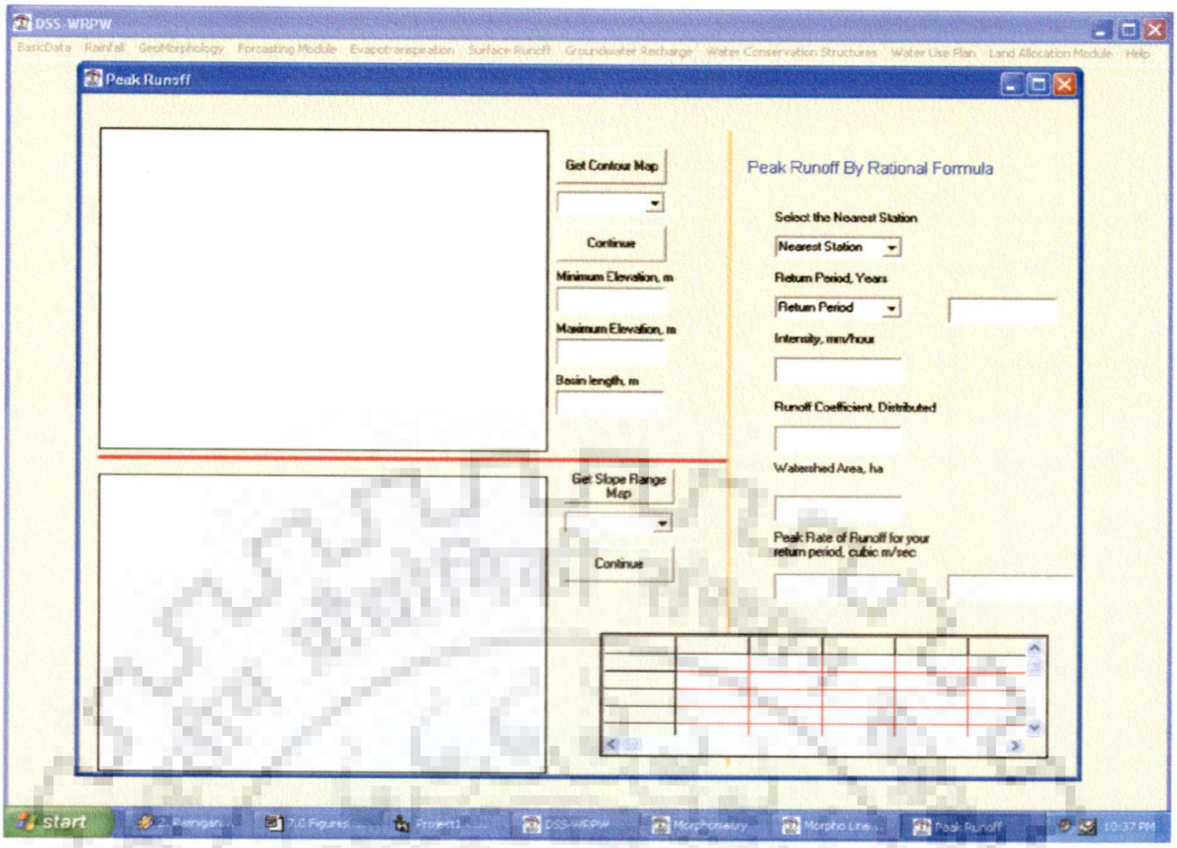


Fig 7.21 Sub-module for rational method of peak runoff estimation

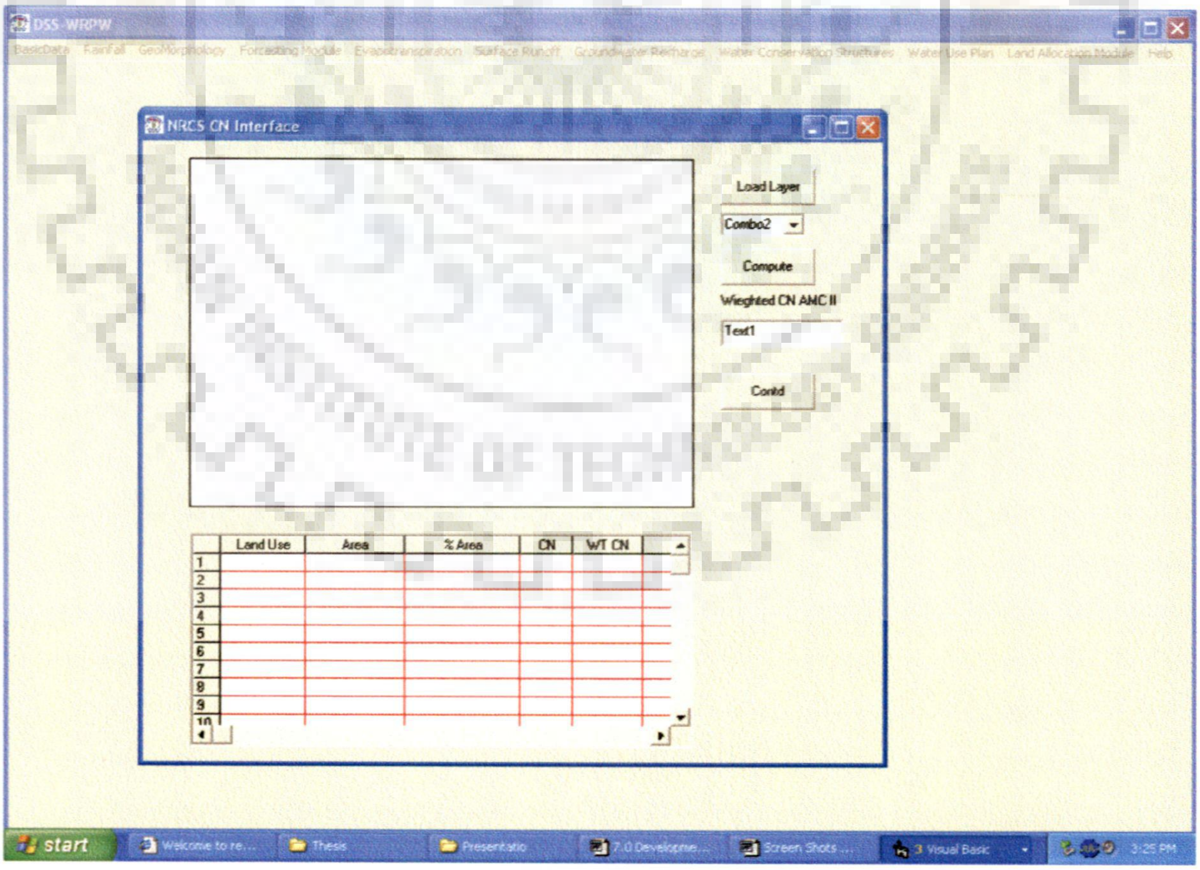


Fig. 7.22 Data display sub-module of curve number interface

7.5.5.3 Interface to CELTHYM

The interface to the CELTHYM model is developed for such case where user has much detailed data of the watershed. The model is discussed in section 5.2.2.2 of the model base component of DSS. The interface is populated with click on CELTHYM sub-menu of the *Runoff* menu in the main interface. The interface is divided into three sub-modules to make it operational. The first sub-module has one MapLayer component, which takes the virtual grid data. The second sub-module "*Runoff Computation*" is linked to this module. Third sub-module "*Computation*" is linked to second sub-module, thus making this interface to run in the series mode. The operational codes of this interface are given in Appendix D4.

7.5.5.3.1 Data Display

This is an important sub-module in the CELTHYM interface. The module takes a GIS shape file in the form of virtual grid, as discussed in section 6.3.1. The module uses the same approach as discussed in earlier sections. The command "*Load Grid Data Layers*" uses the windows common dialogue control. The combo box displays the list of attributes. The various characters, such as area of individual grid, total number of grids and total area of watershed are displayed to respective text boxes at left hand side of the sub-module. The command button *Compute Runoff* connects this sub-module to the next sub-module. Fig 7.24 gives the details of the *"Interface to CELTHYM"*, which is *Data Display* window of the interface. The virtual grid data in the *MapLayer* is classified into the blue coloured pyramid depending on the elevation of the grid scale. This file can be re-displayed using the different attributes in the shape file.

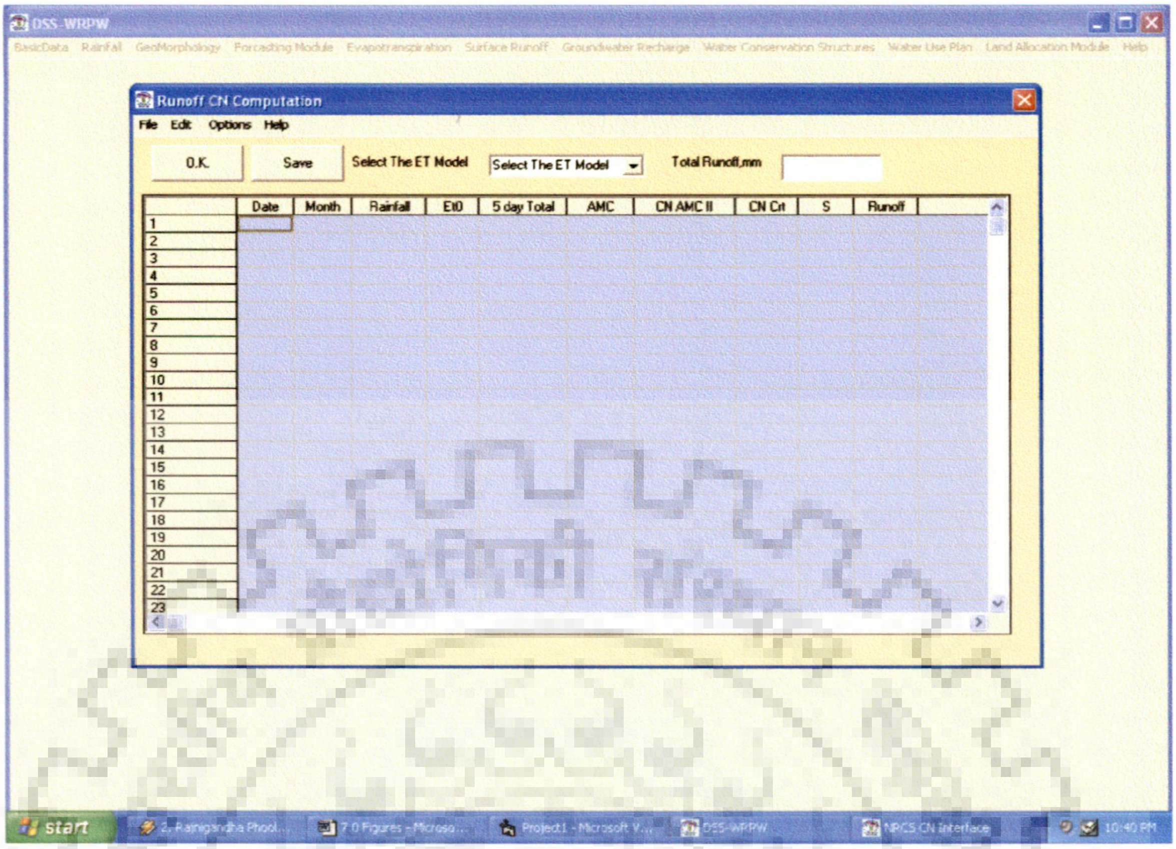


Fig 7.23 Runoff computation sub-module of curve number interface

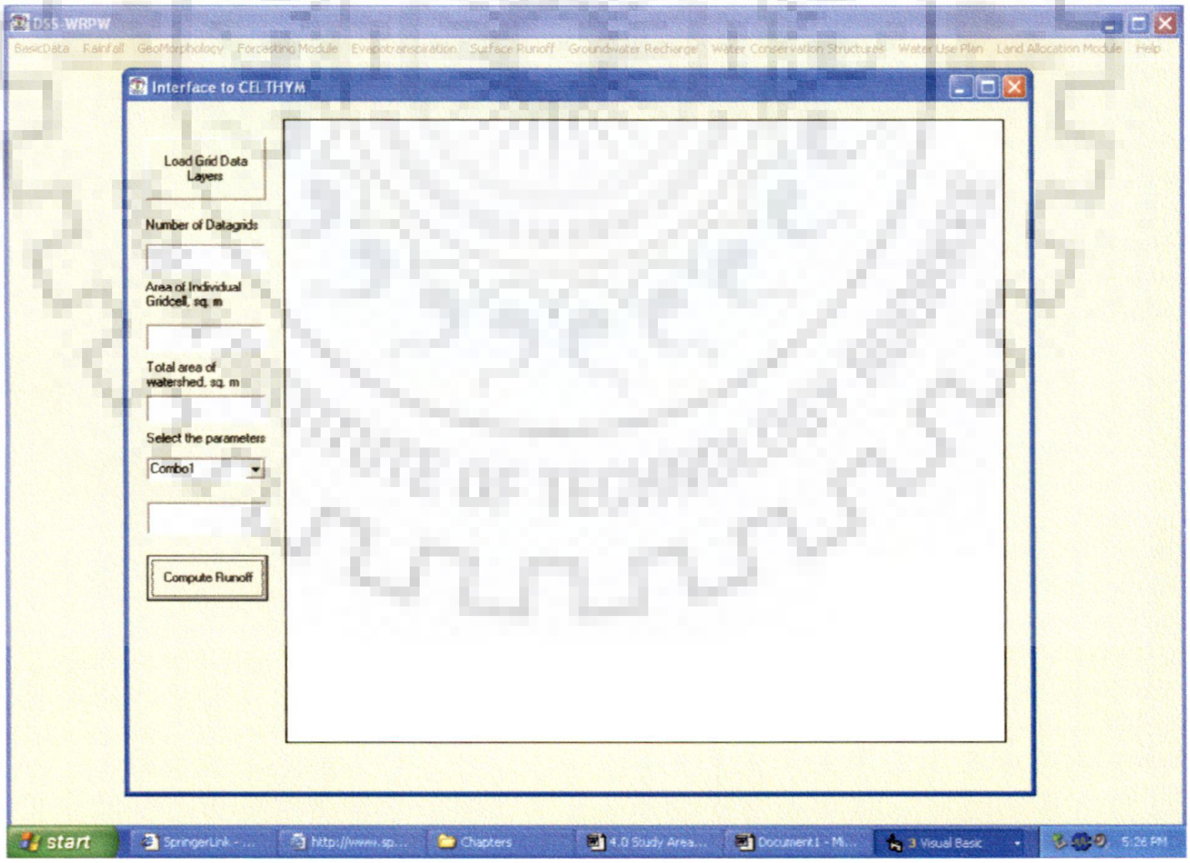


Fig 7.24 Interface to CELTHYM (data display) sub-module

7.5.5.3.2 Parameter Display

This is a two step module, which uses bi-directional data calling to two different *MSFlexGrids*. The first step involves calling of spatial attribute data from data display window for grid numbers with IDs of individual spatial object; second step involves meteorological data calling from *Rainfall* module. This sub-module acts as a data pre- processing module for the computation of runoff in the next sub-module. The sub-module is shown in Fig. 7.25. The codes operating this sub-module are as given in Appendix D5.

7.5.5.3.3 Runoff Computation

This is the main sub-module (Fig. 7.26) of CELTHYM interface, which performs all simulation and calculations of water balance component. This module takes a data from previous sub-module. There are nine flexible grids to calculate all the parameters needed in CELTHYM algorithm. The first grid takes the values from previous sub-module for CN at AMC II and converts it to CN at respective AMC condition for initial days of simulation. The second *MSFlexGrid* computes the factor "*a*" that is used to adjust the CN for new time step depending upon the previous time step. The maximum potential abstraction S is computed in the fourth grid. The soil moisture balance "SM" is computed in the fifth *MSFlexGrid* with runoff for particular day in the sixth *MSFlexGrid*. The next three *MSFlexGrids* simulates the soil moisture retention "SRt", deep percolation "DPt", and soil moisture deficit "DFt". The codes operating this sub-module are given in the Appendix D6.

7.5.6 Groundwater Recharge

Groundwater recharge due to precipitation by Groundwater Resources Estimation Committee (GEC 1997) has been adopted in this module. The *Groundwater Recharge* menu in the main interface initiates sub-menu bar with two options provided. There are two sub-menus (1) rainfall infiltration and (2) water table fluctuation, which operate separately. The menu bar for this in running condition is shown in Fig. 7.27.

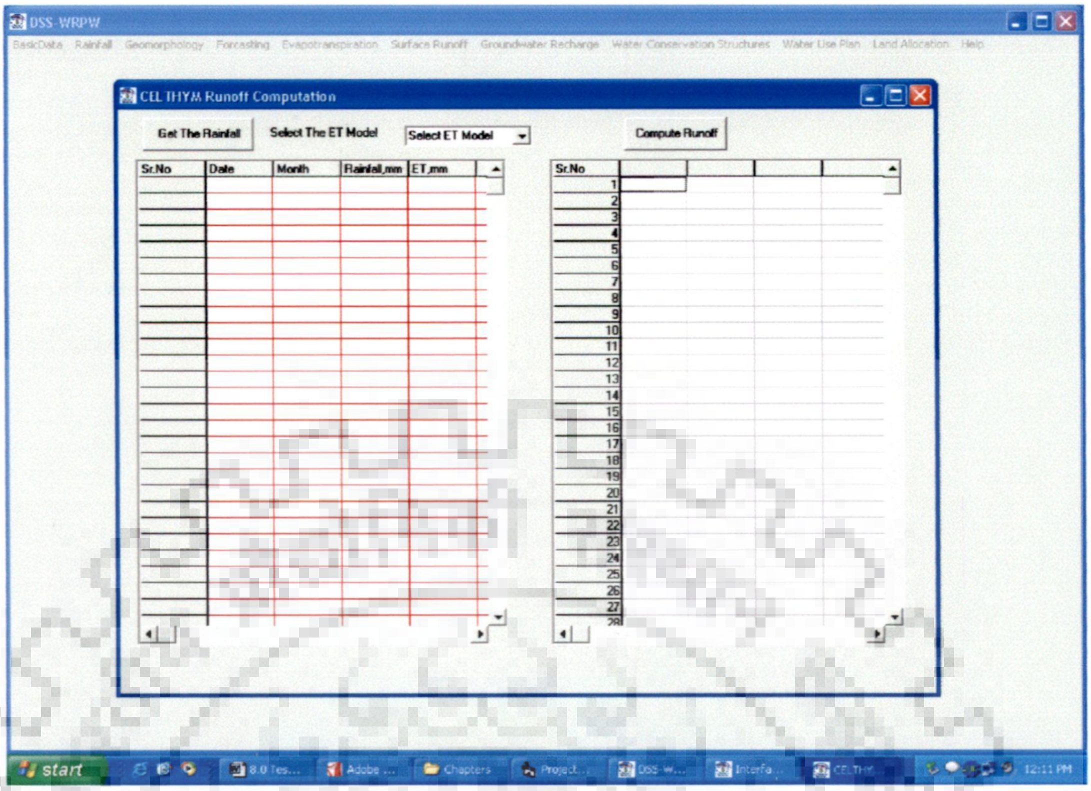


Fig. 7. 25 Parameter display sub-module of CELTHYM interface

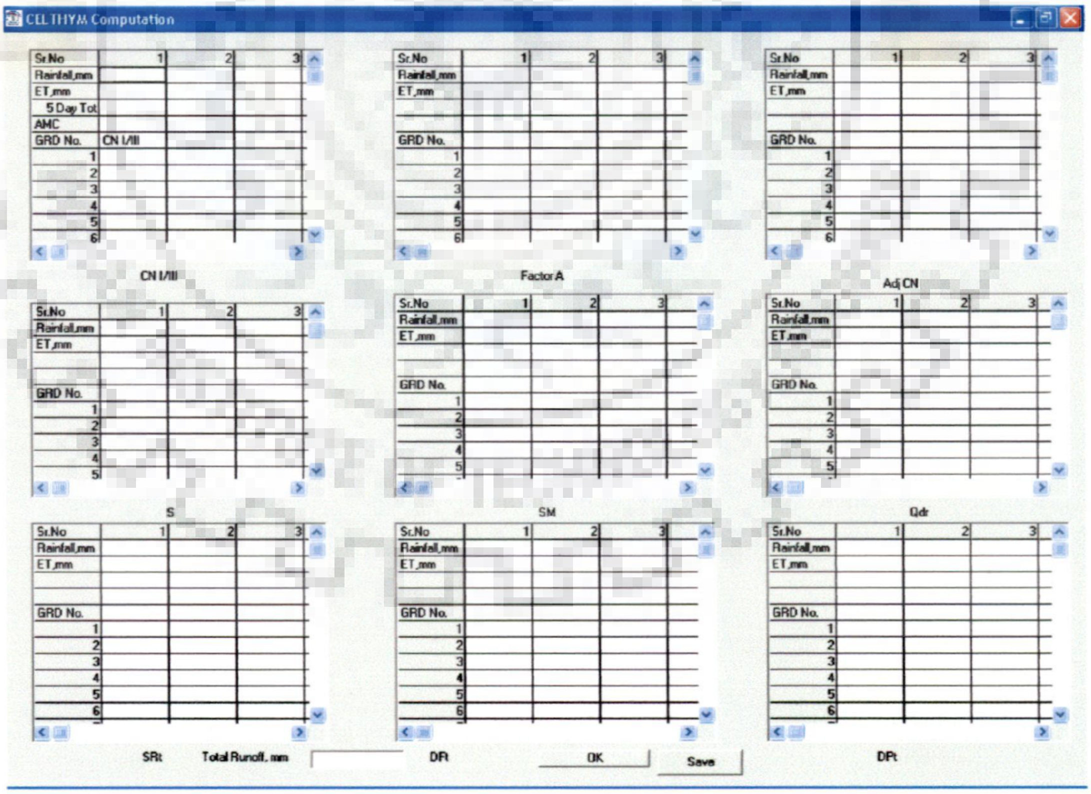


Fig 7.26 Computation form sub-module of CELTHYM interface

7.5.6.1 Water Table Fluctuation

This is one of the sub-modules to estimate the groundwater recharge by water table fluctuation method. The sub-module is shown in Fig. 7.28. The module includes the GIS component *MapObjects* to display the polygon coverage. This coverage needs to have the spatial objects describing the geology of the watershed. The other objects kept in the sub-module are some text boxes, which take input related to the water table levels for pre-monsoon and post-monsoon. The coverage or shape file is opened with the click on the command button "*Open Layer*" through the windows common dialogue. The click on command button "*Compute Recharge*" estimates the recharge using the algorithm given in section 5.7.2. The text box at the bottom of the form displays seasonal recharge for the monsoon period for which data has been entered. The codes for this have been given in Appendix E1.

7.5.6.2 Rainfall Infiltration

This is the alternative method of recharge estimation. The module operates with the click on sub-menu in the main interface. The sub-module form is shown in Fig. 7.29. The module has one *MapObjects* map layer object with eight text boxes to input 15 days rainfall. Other text boxes before the rainfall input boxes give the estimated recharge from rainfall of the respective period. The shape file required to be displayed here is loaded with the click on command button "*Open Layer*" through windows common dialogue box. The other information of the spatial objects is taken using various properties of *MapObjects,* such as *Recordsets* and *TableDisces*. The command button "*Compute Recharge*" estimates the recharge. The computed recharge is used in the water use planning module of DSS. The codes executing this sub-module are given in Appendix E2.

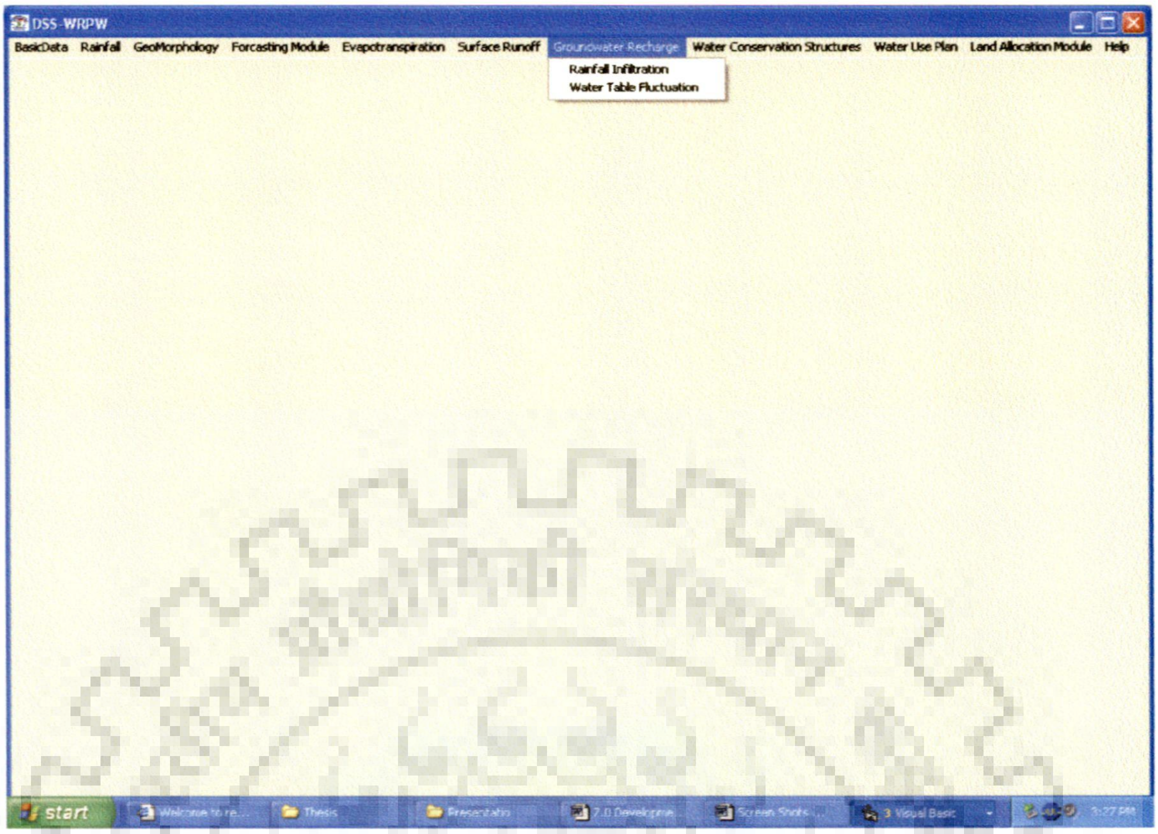


Fig 7.27 Groundwater recharge module in the main interface

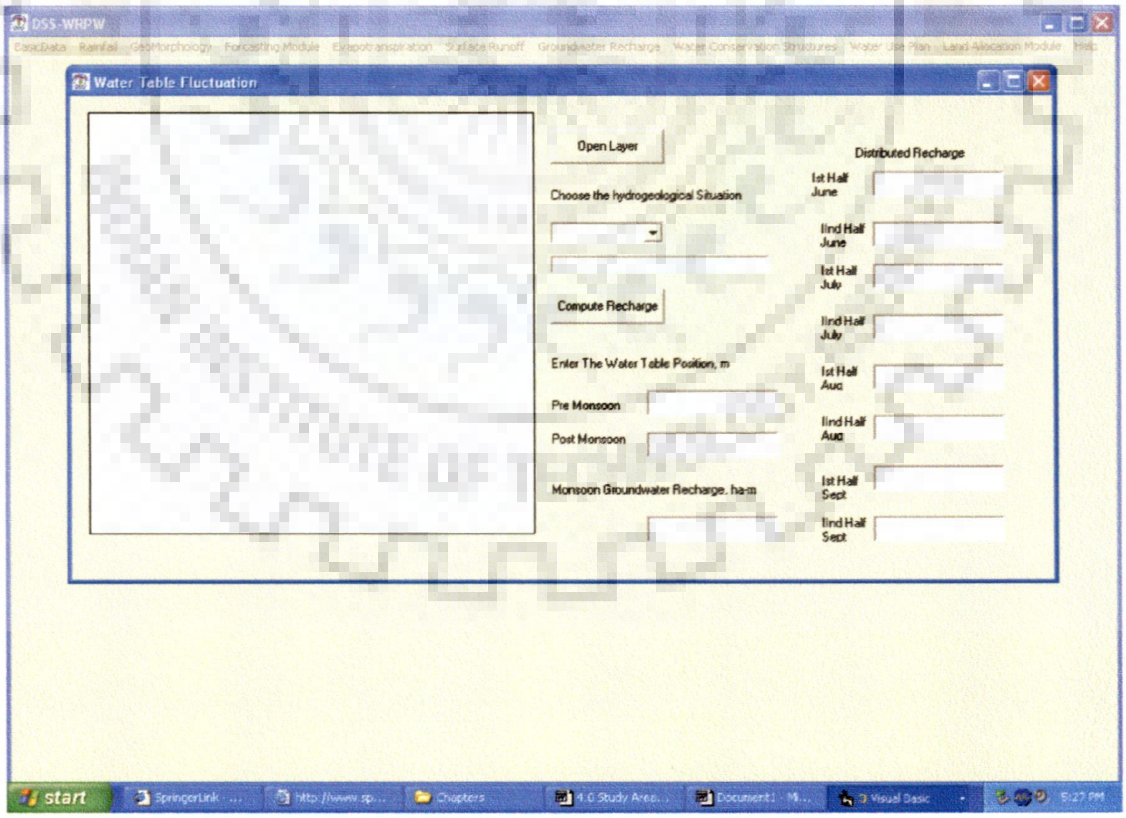


Fig 7.28 Water table fluctuation sub-module of ground water recharge module

7.5.7 Water Conservation Structures

Water conservation structures module is one of the auxiliary modules in the DSS, which gives the number and length of the structures. The module is divided into three sub-modules. The first sub-modules displays spatial data in the form of shape file describing the slope. The second sub-module gives the details of water conservation structures. The third sub-module gives the size of water harvesting pond and its number.

7.5.7.1 Data Display

Selection of soil and water conservation structures depends mainly on the slope and rainfall characteristics of the regions. This sub-module forms an essential object in module. The sub-module (Fig. 7.30) essentially takes spatial data in the form of shape file which is a polygon file with each polygon having slope in percent. The command button "*Open Slope Map*" displays the shape file. The attribute fields are then populated to the combo box below the command button. The two buttons in the form open two different sub-modules. Codes for this have been given in Appendix F1.

7.5.7.2 Structure Design

The decision on the type of structure with respect to value of slope in particular polygon is the objective to design this sub-module. The data from the attribute fields of FID, area and slope are imported from the data display module to the first three columns of the MSFlexGrid in this module. The area is then converted to hectares from the earlier displayed in m^2 in the third column of *MSFlexGrid.* The choice of the structures for individual land parcel with respect to the slope value is then allocated with the click on command button "*Compute*" in the form of sub-module (Fig. 7.31). The sub-module has three text boxes below the MSFlexGrid; which have been used to display the total length of the particular structure. The codes operating this sub-module are given in Appendix F2.

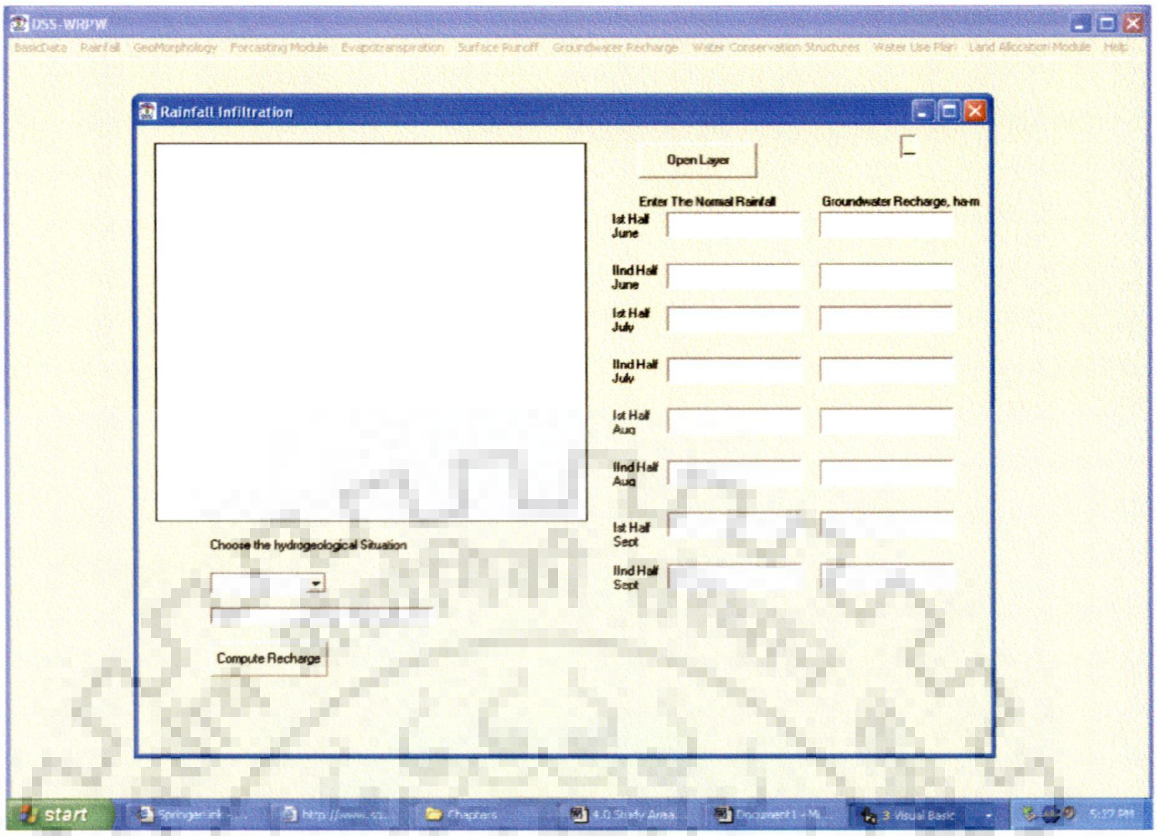


Fig. 7. 29 Rainfall infiltration sub-module of groundwater recharge module

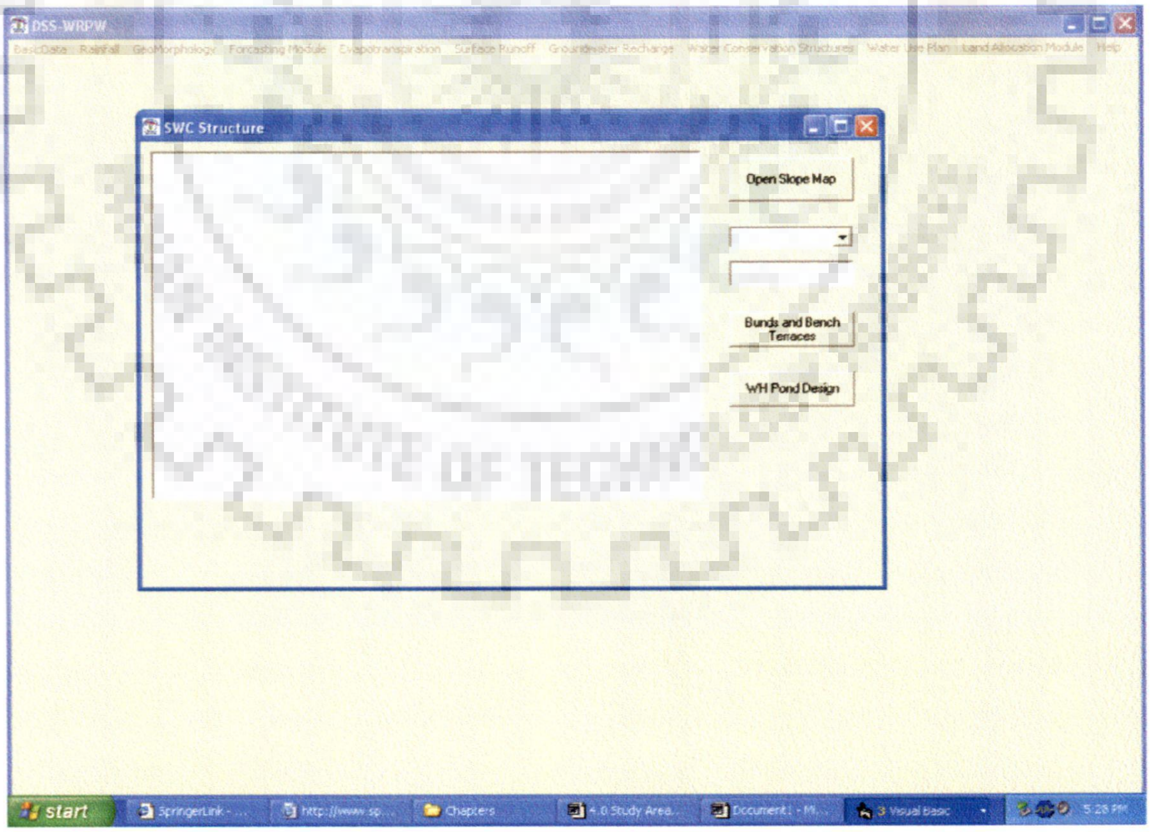


Fig 7.30 Data display sub-module of water conservation structures module.

7.5.7.3 Water Harvesting Pond

This is the third sub-module in water harvesting module of DSS. The simple module contains three text boxes, kept before the labels water harvesting pond capacity, total surface area of ponds and number of ponds required to be constructed in the watershed. The module takes data from the runoff module pre-run and selected by the user. The sub-module screen is shown in Fig. 7.32. The command button "*Pond Water Balance*" controls the running and operation of this sub-module. With the click on this control, all the three values are displayed to the respective text boxes. The codes required to run this sub-module are given in Appendix F3.

7.5.8 Land Allocation Module

This is one of the supplementary modules in the DSS, which is designed and developed for giving the optimized allocation land for agriculture in the watershed. There are two separte modules each for *kharif* (Fig. 7.33) and *rabi*(Fig. 7.34) season respectively. Pull down menu appears on the screen by clicking on *Land Allocation* menu in menu bar of the main interface. The module optimizes the land use depending on the needs of habitants. The The module or the form essentially consists of the single *MSFlexGrid*, having 35 columns and 1000 rows. The algorithm as given in section 5.12 is formulated and solved by linear programming approach of optimization. The module takes the data from forecasting, water harvesting, crop water requirement and ground water recharge module to formulate the linear programming optimization problem. User has to select the crops from the different combo boxes and enter the anticipated productivity of respective crop in the text box placed opposite to combo box. The formulated problem is then displayed to simplex table in the upper area of *MSFlexGrid.* The command button "*Compute*" controls the running of this module, once the user clicks it; the system starts the iterations for solving the problems. The first iteration is displayed in the MSFlexGrid leaving two rows after the formulated problem display.

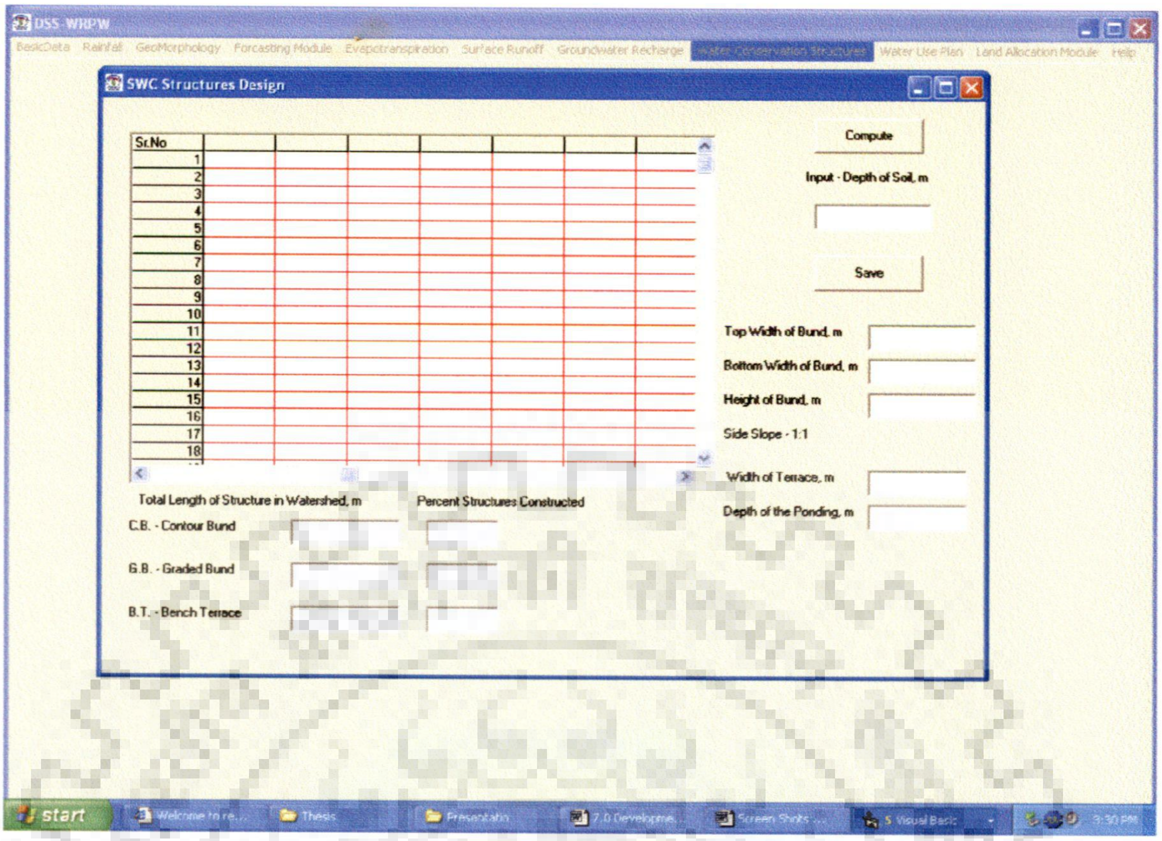


Fig. 7.31 Water conservation structures design sub-module

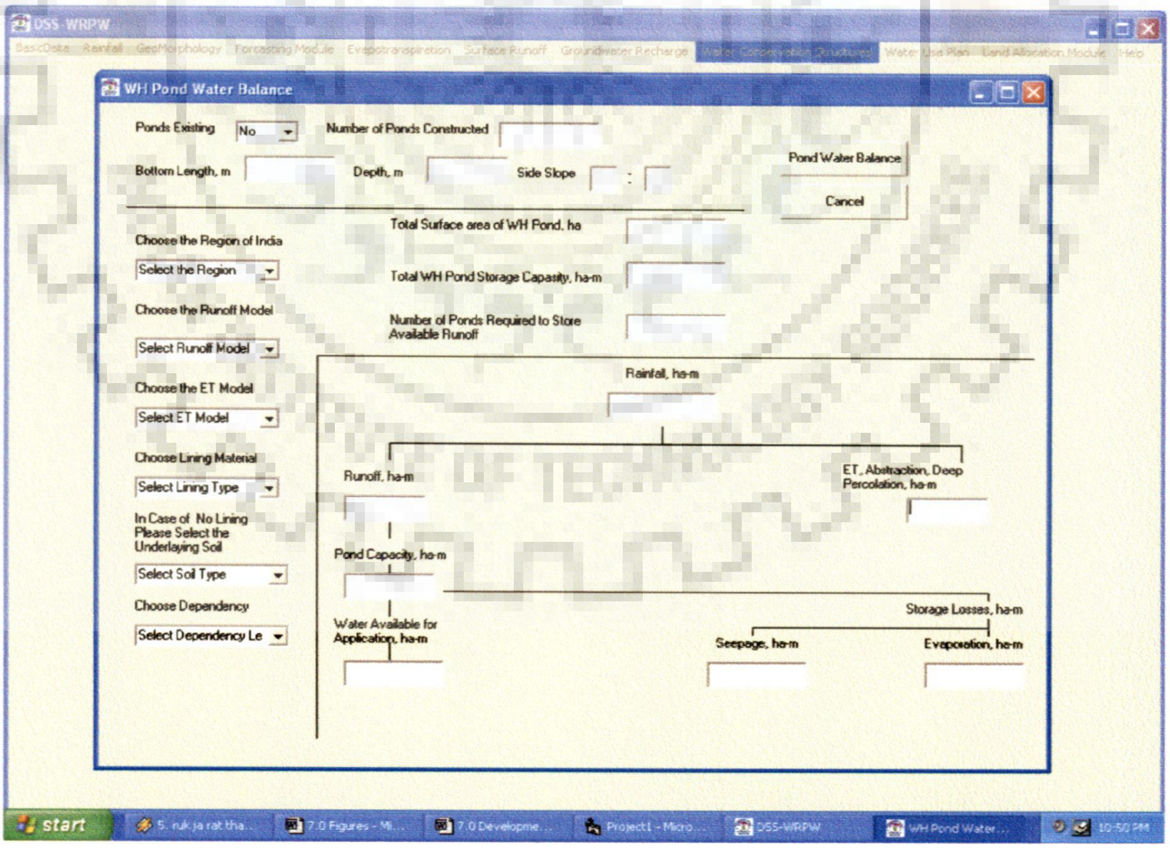


Fig. 7. 32 Water harvesting pond sub-module

The next iterations are displayed in the same manner. System gives the message box *"Optimal Solution Achieved"* once the optimization solution is achieved. The solved form of simplex table can be browsed in the lower most portion of the grid table. The codes written to run this module are given in Appendix G1. These codes are divided in the two parts; (1) form loading procedure to load the required grid table and (2) command button click event to formulate and solve problem. The required values of the land use allocation are then exported to wherever needed.

7.5.9 Forecasting Module

The module is a part of the demand section of DSS. The screen shot of Visual Basic form of this module is given in Fig. 7.35. The module consists of two parts. In first part, user has to enter the information regarding the human and animal population for particular years and desired years of forecast. The next part consists of ten text boxes. The upper most text box at right side of the module gives population growth rate calculated by using the methodology as given in section 5.8. The three text boxes below this, placed horizontally, give the human and animal population forecast. The other six text boxes placed before the respective labels give the water and food/fodder requirement for the period of forecast. This formation is used at many places during the complete running of the DSS. The command button "*OK*" execute the codes required to run the second part. The command button "*Cancel*" terminates the module.

7.5.10 Water Use Planning

Water use planning module is a decision making module in the DSS, which gives the water use plan for each demand sector on fortnightly basis. The module consists of a single *MSFlexGrid*, which contains 14 columns and 25 rows. This is automatically loaded with the form loading procedure of Visual Basic programming methodology. First column in the grid table have the fortnight number in rows starting from 11 to 24 and 1 to 10 i.e. for 1st fortnight of June to 2nd fortnight of the May in the sub-sequent year. This according to the water year is adopted for Indian conditions.

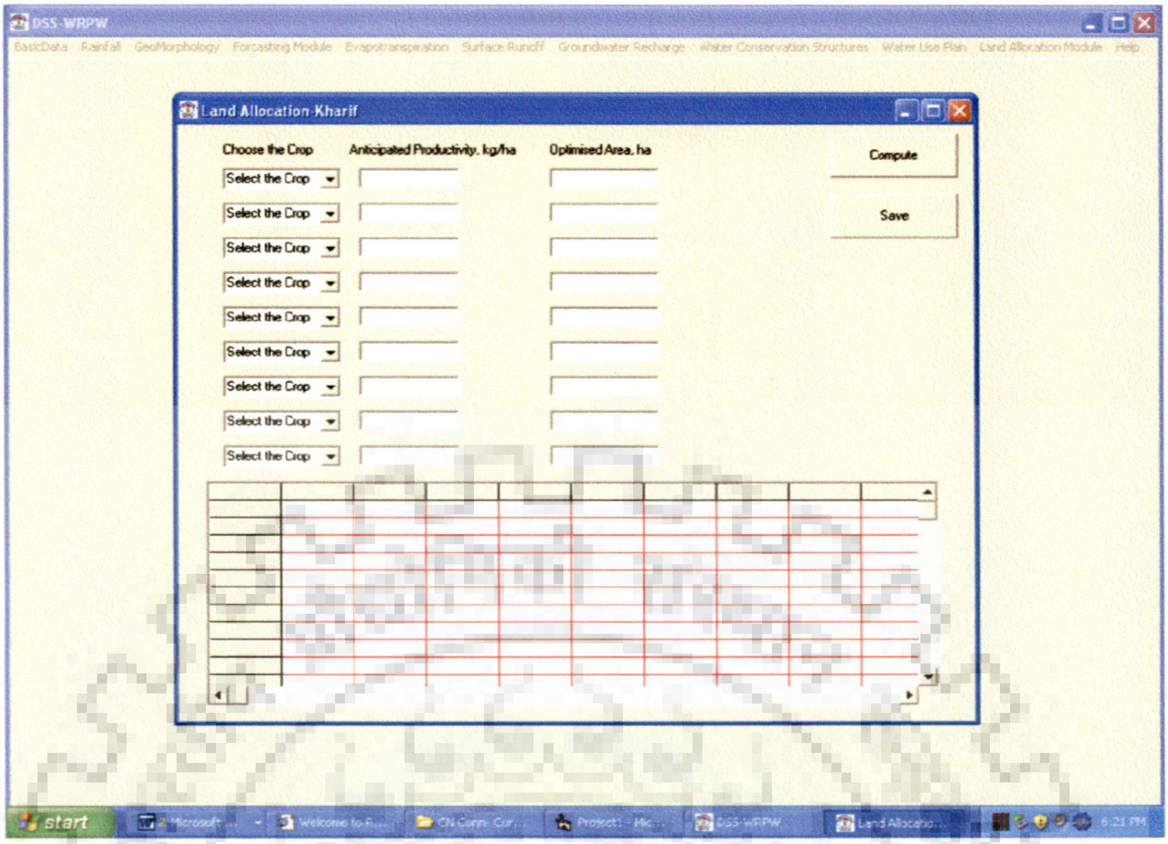


Fig 7.33 Screen shot of land allocation module (*kharif*)

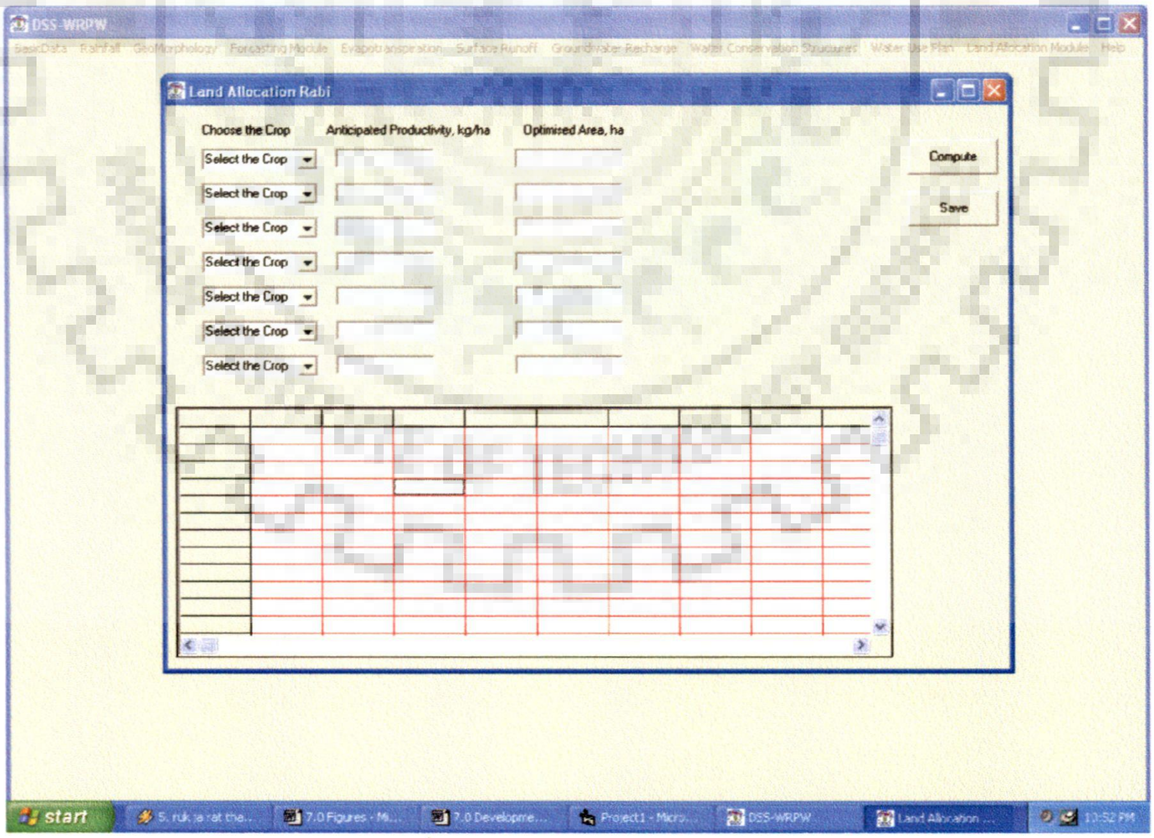


Fig 7.34 Screen shot of land allocation module (*rabi*)

Above procedure needs no running of the module, but to execute the following importing of data, user has to run at least one sub-module from all the modules where there are multiple modules. In case of the single module, user has to complete the operation of all modules. The second column imports the data from crop water requirement sub-module of evapotranspiration of the DSS. The fourth and sixth columns take the data for human and animal water demand respectively from forecast module, and convert it to fortnightly basis from yearly basis. The next column to each these three columns is about the supply source. The text regarding the supply source for demand of each time interval is displayed after the simulation of the scenario. The RF is displayed if the source is rainfall, SW is displayed for surface water and GW is displayed for groundwater recharge. This allocation is done according to the water allocation policy, as formulated by rules in section 5.11.3. Implementation of rules is done with the "*if then*" statement in the programming codes (Appendix I1). The eighth and ninth column gives the evaporation and seepage losses from the surface water sources respectively. The tenth column imports the rainfall data for particular time period from the rainfall module. This rainfall data is then converted to the effective rainfall value in the same column. The eleventh column gives values of surface water available in storage after fulfilling the demand and losses at end of each fortnight. Likewise, the twelfth column gives groundwater available at the end of the particular fortnight after adjusting demands in that period.

Depending on the data availability, and choice of the model run by the user, various scenarios can be generated for which user has to run this module separately. The command button "*Get The Plan*" executes the codes written for this module with the click event. The displayed water use planned can be saved to local drives in the system to make better judgement of each scenario. The blank run screen shot of the module i.e., without clicking command button, is shown in Fig.7. 36.

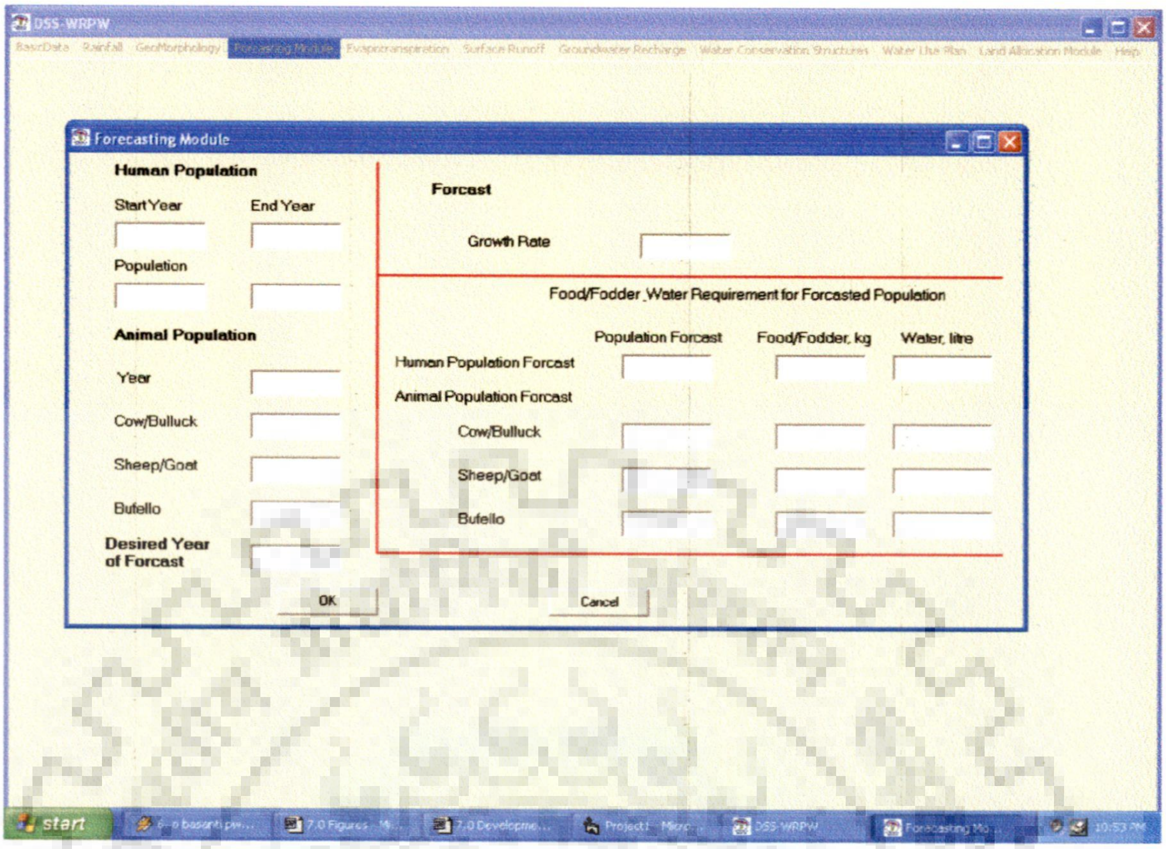


Fig.7. 35 Forecast module screen shot

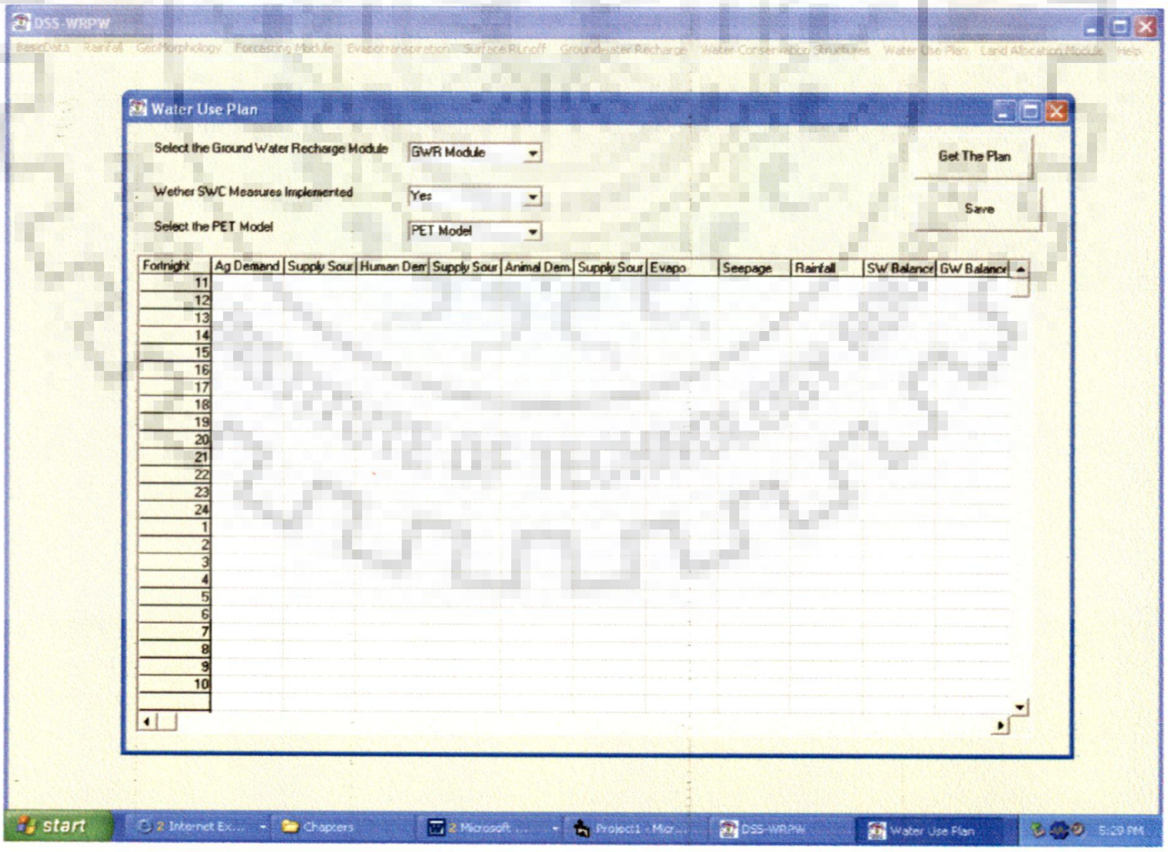


Fig. 7.36 Water use planning module

7.6 Concluding Remarks

In this Chapter the development of the all GUIs of DSS is attempted, including designed and planning in the conceptual framework. The Chapter has been divided into four sections. The first section gives the general idea about the programming environment used with events, procedures and terminologies i.e. MS Visual Basic. The second section gives the details about the GIS component MapObjects. The combination of two programming environments and its use in the development of the GUIs have been explained in third and fourth sections respectively.

CHAPTER 8

DEMONSTRATION OF DSS, RESULTS AND ANALYSIS

8.1 Prelude

There can be a number of scenarios for decision making with application of DSS in water resources planning in a particular watershed selected by the user. The scenario can be generated based on type of operational combination of models or depending upon the present system of water harvesting in the watershed. The model operational scenario depends on the availability of the data required as input for particular combination of the models to arrive at the final output of water use plan.

To illustrate the scenario analysis approach, initially, two cases have been demonstrated in this chapter. The first case is the real physical system, in which DSS has been applied to the Khadak Ohal for the year 2002-03. This year is treated as a normal year. The watershed at present does not have any facility of the water harvesting. All the modules have been tested with the 2002-03 records for selected watershed. The second case is sample, derived from the simple water system using water demand forecast and 75 % probable rainfall. The climatic conditions considered for the present study are average conditions in absence of long-term climatic data.

8.2 Test Case I

The developed prototype DSS has been applied for the selected watershed with all spatial and non-spatial data input available for the year 2002-03. For this year, the gauging data of runoff were used to test the runoff models used in the DSS. With all the modules of DSS in run mode, the final output of fortnightly operational water use plan was taken for the different scenarios of model combinations. The following discussions give the details of the selected watershed for different modules of DSS.

8.2.1 Basic Data Module

The module is an informatory user input GUI, which requires the name of the watershed, *Tahsil*, district and state and human and animal population as input. Fig. 8.1 gives the details of a particular watershed. A GUI has been entered with Khadak Ohal, watershed in Trimbakeshwar *Tahsil* of popular pilgrimage in Nashik district of Maharashtra State. The other population details are also required.

8.2.2 Rainfall Module

Rainfall is an important parameter in any water resources planning study. In the development of DSS, a separate module has been planned required for number of sub-modules and modules. The module (Fig. 8.2) is essentially a single *MSFlexGrid* calling rainfall data from MS Excel file from the system. The daily rainfall data imported to this grid by opening the Excel application in the VB program. For year 2002, daily rainfall can be seen, loaded in the *MSFlexGrid* with date, month and year. This daily rainfall is totaled fortnightly to compute the effective rainfall during each fortnight. Table 8.1 gives the fortnightly rainfall from June to October, whereas in the screenshot (Fig. 8.2) limited number of rows are visible. The entire data can be seen by scrolling down the arrow in *MSFlexGrid* on computer screen. Total annual rainfall is 1748.6 mm, out of 1696.6 mm falling during the June to September. The maximum one day rainfall during the one year period of 129.5 mm occurred on 28th June 2002. There are 58 events having rainfall more than 5 mm per day. The average daily rainfall is 18.70 mm.

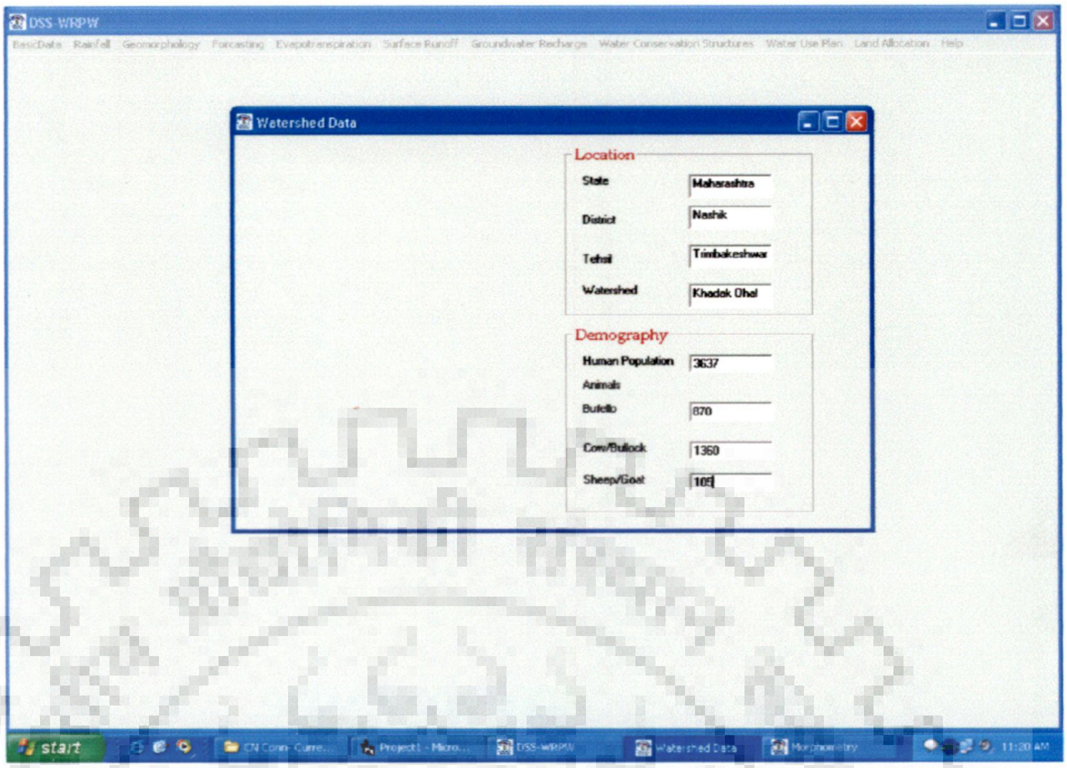


Fig. 8.1 Basic data module

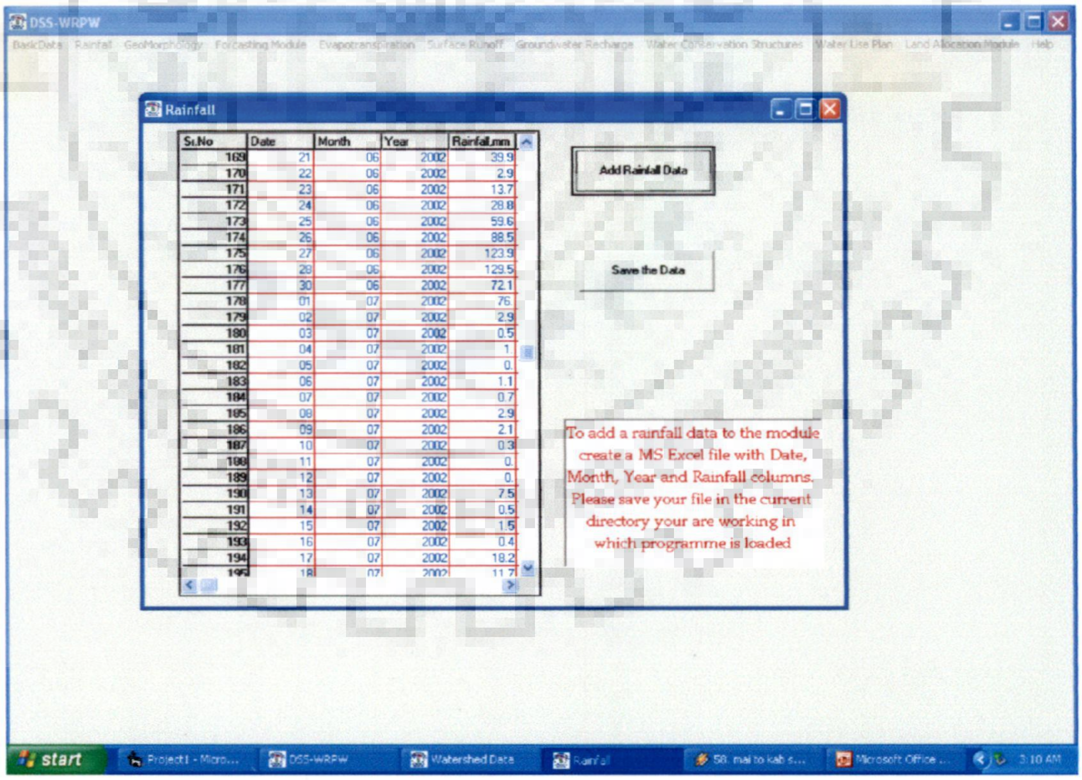


Fig. 8.2 Rainfall module

Table 8.1. Fortnightly rainfall in Khadak Ohal watershed in 2002.

Month	Fortnight	Rainfall, mm
June	I	195.5
	II	501.5
July	I	189.0
	II	302.9
August	I	188.9
	II	305.3
September	I	13.2
	II	0.7
October	I	34.9
	II	0.0

8.2.3 Geomorphology Module

The quantification of watershed's morphology may also be termed as morphometry or geomorphology. These characteristics of watershed provide a means for describing its hydrological behaviour (Bardossy and Schmidt, 2002). A set of four GUIs interact with each other to form the geomorphology module in the DSS. There are (i) morphometry, (ii) stream order, (iii) morpho linear aspects, and (iv) areal aspects. The results obtained from these sub-modules for selected watershed have been presented in following three sub-sections.

8.2.3.1 Morphometry

This is an elementary sub-module in morphometry module of the DSS. The sub-module (Fig. 8.3a) takes the GIS shape file, which describes the drainage characteristics of watershed as input. The new shape file is then created with the help of this shape file. The newly generated shape file has four new attributes of start (Fxi & Fyi) and end (Txi & Tyi) coordinates besides the original attributes of FID and shape length. New shape file is then called to open in the second map layer in the GUI. With these coordinates, ordering shape file is carried out through program as discussed in section 5.3.1(Fig. 8.3b). The *MSFlexGrid* kept below two *MapLayers* gives the stream order, ID of a particular stream with its length. For stream ID-2, length of 178.679 m and stream order-1 can be seen in the table of *MSFlexGrid.* Table 8.2 gives the summary of attributes of original and newly created shape files. As shown in Fig. 8.3a, original drainage or stream map of Khadak Ohal watershed is in the left of *MapLayer* and newly created shape file for the purpose of stream ordering is in the right of *MapLayer*.

This watershed has a total of 467 streams. The mean length of the streams in the watershed is 177.040 m, whereas minimum length of stream is 53.530 m and maximum is 391.970 m.

Table 8.2. Attributes of shape files used in the stream ordering.

Sr. No	Name	Description	Coverage Type	Attributes
1	streamsDC1b.shp	Drainage	Polyline	FID Shape Shape Length F NODE T NODE
2	endpoints.shp	Drainage with end coordinates	Polyline	FID Shape Ori_Length F NODE T NODE Fxi Fyi Txi Tyi

8.2.3.2 Morpho Linear Aspects

With the stream network displayed in the display module (Fig 8.3a), the attributes of FID, stream length and stream order are loaded to the *MSFlexGrid*. These values are further sorted according to stream order in the *MSFlexGrid* of this sub-module (Fig. 8.4) for the computation of linear aspects of geomorphology.

The computed values for linear parameters for the watershed are displayed to this sub-module, as shown in Fig. 8.4. The maximum stream order in the watershed is found to be 5 with a total of 467 streams. The total length of streams in the watershed amounts to be 106.269 km. Over 50% of total streams (231) are of 1st order, having a total length of 66.745 km. There are 132 streams of 2nd order with an average length of 183.728 m, while 50 and 15 streams are of 3rd and 4th order with average length 161.012 m and 248.292 m respectively. The outlet stream of 5th order is divided into 18 segments due to joining many 1st and 2nd order streams. This high stream order reflects the well established drainage network in the watershed.

The bifurcation ratio of number of higher order streams to the number of lower order streams is found to be highest (3.333) for 3rd and 4th order streams with stream length ratio of 0.648. The stream length ratio is similar to bifurcation ratio, with length of streams. The bifurcation ratio is 1.750 for 1st and 2nd order, and 2.640 for 2nd and 3rd order with stream length ratio of 1.581 and 1.135 respectively. It is 0.833 with stream length ratio of 1.232 in case of 4th and 5th order streams. These linear aspects or linear parameters have direct relationship with erodability of the watershed (Biswas et al., 1999, Nookaratnam et al., 2005).

8.2.3.3 Areal Aspects

Areal parameters of morphometry are dependent on the information related to area, perimeter and shape of the watershed. Hence, program needs the shape file describing the boundary of the watershed, which has default attributes of area and perimeter. User needs to click button *Open Boundary file*, which will take to another MS common dialogue box to open the file. Opened file is displayed to separate *MapLayer* here (Fig. 8.5). Various parameters are calculated with click of button *More Parameters*. These are discussed in the following paragraphs.

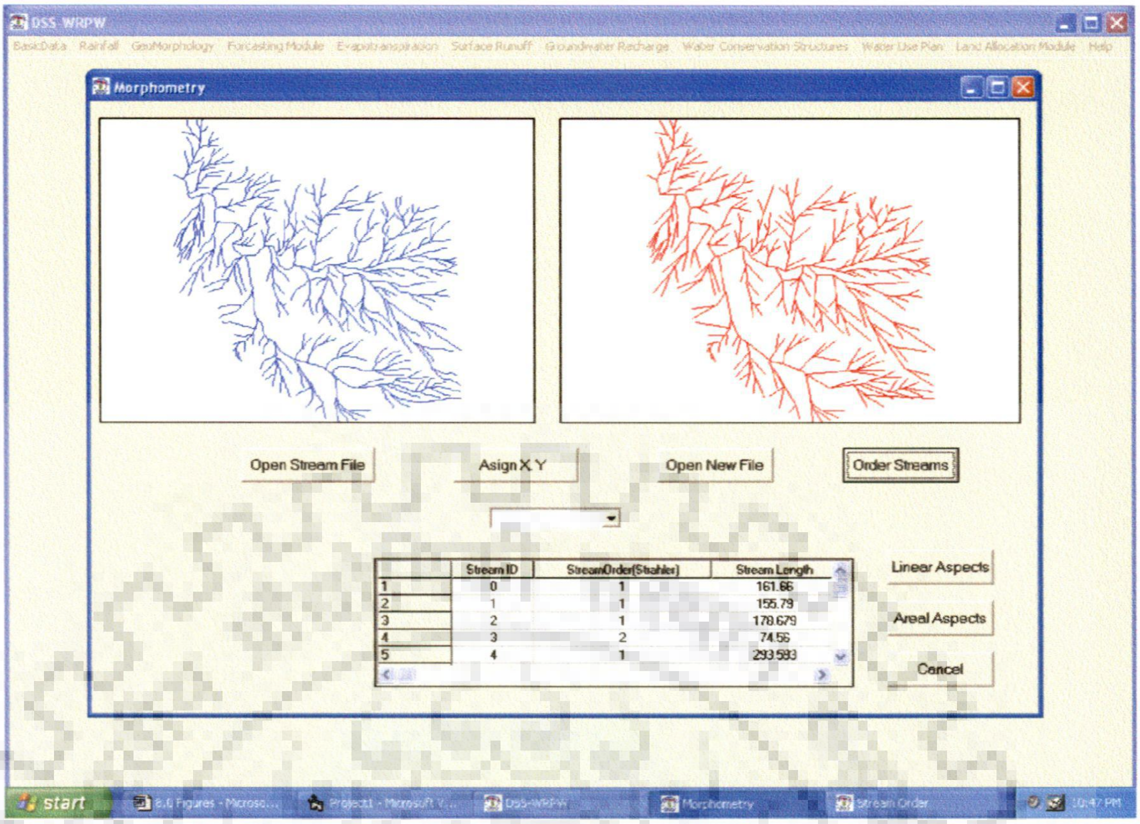


Fig. 8.3a Morphometry sub-module of *Geomorphology* module

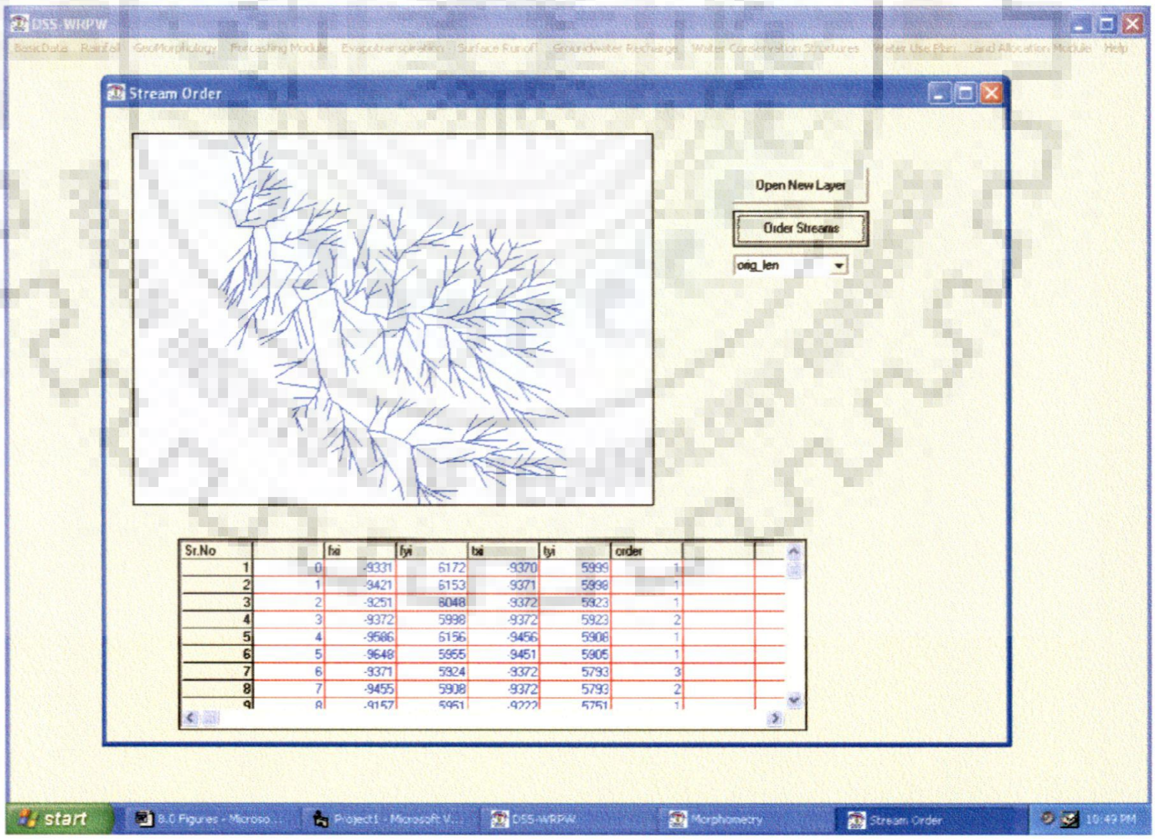


Fig. 8.3b Stream order sub-module of *Geomorphology* module

The area of the watershed in the present study is 17.26 km^2 with perimeter of 18.51 km. Basin length of this watershed is 6.62 km. The watershed has compactness value as 1.32 and basin circularity as 0.57. These two parameters describe the shape of the watershed. It has a form factor of 0.39 and shape factor of 2.56. The elongation ratio of this watershed is 0.71, while texture ratio, a ratio of number of first order streams to the perimeter is 3605.91. Stream frequency, which is the total number of streams per km^2 of the area of watershed, is 25.83. The drainage density is found to be 6.51, which is quite high describing hilly topography of watershed. The length of overland flow in this watershed is 0.08 km, while the constant of channel maintenance is 0.16 per km^2 of the watershed area.

8.2.4 Forecasting Module

To forecast the human and animal population and their future needs of water and food/fodder, this module has been developed. User has to give input as population data for two years, which are used to compute the population growth rate. The forecasted population is computed for the desired year of forecast. The same population growth rate is used to forecast animal population. The different input boxes have been created in the interactive module (Fig 8.6) to input the different data required.

From the records of project and Census data of India, human population in four villages of the Khadak Ohal watershed in Maharashtra State of India was 3637 in 1981, which later increased to 5844 in 2001. There were 1360 cows/bullocks, 870 sheep/goats and 105 buffalos in the year 1981.

As seen from the screen shot of the module, the population growth rate is estimated to be 0.02 %. This computed growth rate is based on the human population records of 1981 and 2001, which is much lower than the overall annual exponential growth rate of India.

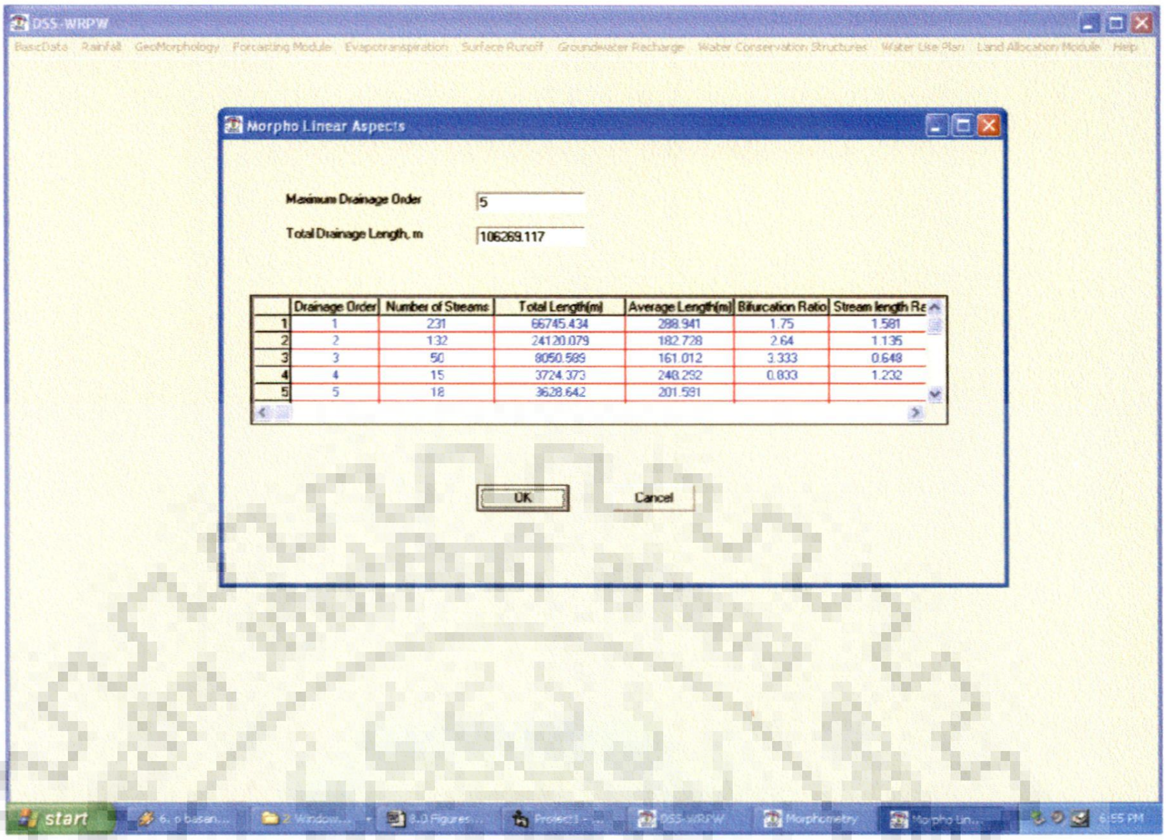


Fig. 8.4 Morpho linear aspects sub-module

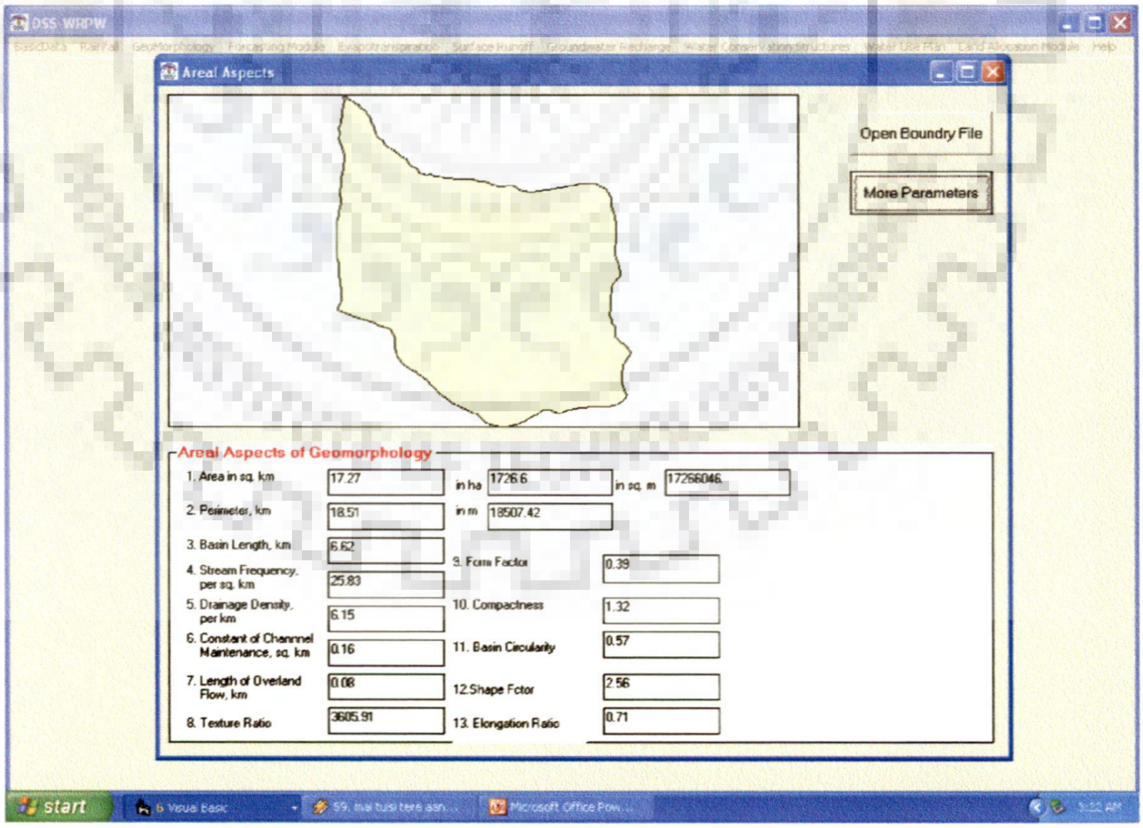


Fig. 8.5 Areal aspects sub-module

For year 2002 (year of forecast), the population forecast is 5984, while with the same growth as of human population, animal forecast includes (i) cows/bullocks (2238 Nos) (ii) sheep/goats (1431 Nos) and (iii) buffalos (173 Nos). In the year of forecast, watershed would need 448180 litres of water and 1388288 kg of food grains. These needs are based on the standard requirements of food/fodder and water (including domestic needs). The food/fodder and water requirements for the year 2002 can be seen in Fig 8.6. This water requirement has been used further in the fortnightly planning of water resources.

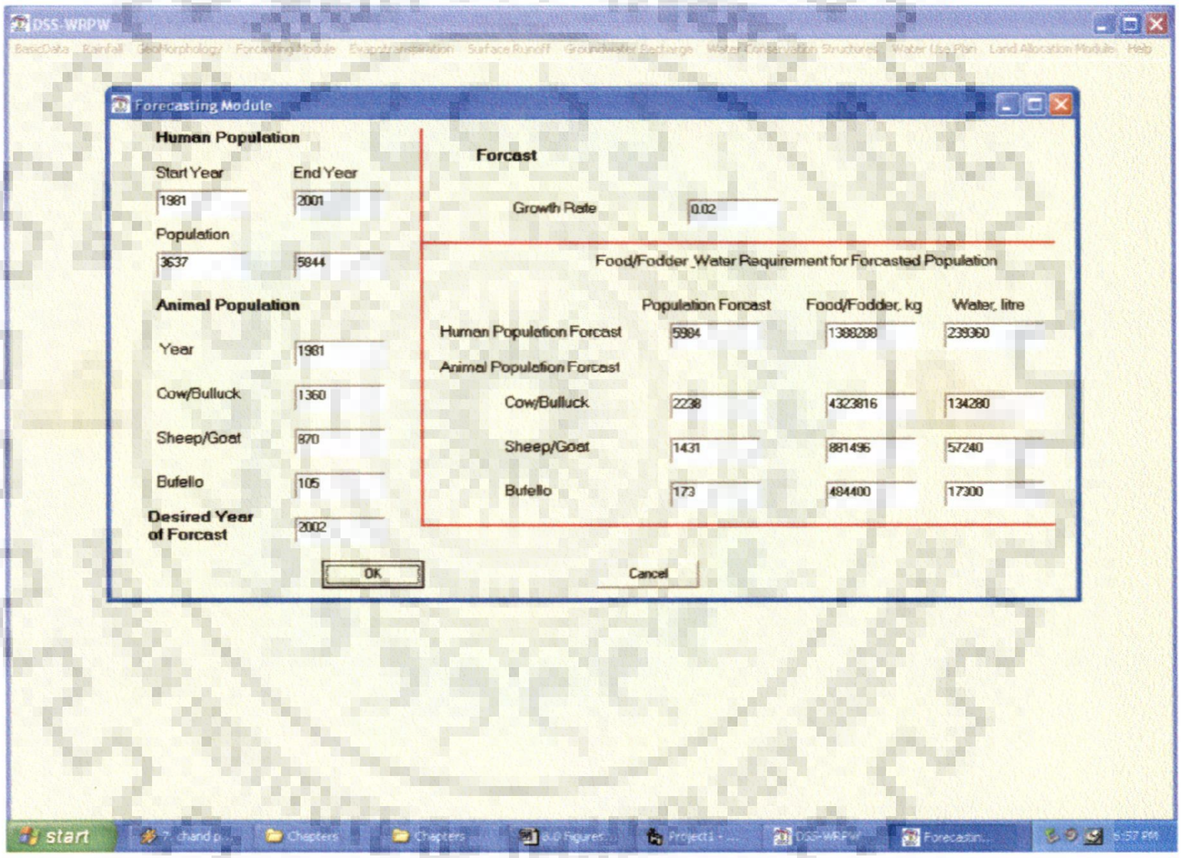


Fig. 8.6 Forecasting module

8.2.5 Evapotranspiration Module

In order to have estimates of crop water requirement, user needs to have potential evapotranspiration (PET). The DSS developed provides two options to user for estimation of PET. The Penman Monteith sub module may be used in case user has detailed climatological data is available. Another sub-module i.e. Hargreaves Samani may be used in case of non-availability of detailed climatological data. Third sub-module provided in this menu is for crop water requirement estimation.

8.2.5.1 Penman-Monteith Sub-module

The Penman-Monteith method of estimating PET was found accurate to represent PET (Allen et al., 1998). Therefore, this method is included in the DSS with an alternative option of Hargreaves-Samani method.

The Penman-Monteith method as discussed in section 5.4.1 has been implemented in the sub-module via GUI, which takes climatological input data from external file, as discussed in the section 7.5.3.1. User has to give additional input of elevation of station and its latitude. The computed values of daily PET are displayed in the 47 column of the *MSFlexGrid* in the GUI of sub-module (Fig 8.7). The Khadak Ohal watershed elevation is 565 m from MSL situated at 20^0 N. With this and other input parameters (Table 8.3), the program computes the daily PET for the period June 1^{st}, 2002 to May 30^{th} 2003. The total annual PET during this period was found to be 1445.304 mm, with an average daily PET of 4.07 mm/day for the same period. The maximum value of the same is observed on 5^{th} April 2003, which is 7.45 mm/day, while minimum of 2.089 mm/day is on 18^{th} December 2002.

Due to non-availability of observed daily PET data, these computed values of PET are converted to hourly basis for summer, monsoon, and winter season. These converted values are compared with the available per hour PET values of three seasons at another station in Nashik district. Table 8.4 gives both the values of observed PET and computed PET for comparison. For the year 2002-03, it is observed that during the monsoon, the PET is 0.36 mm/hr, and there is no much difference during the average observed value of PET during this period (0.31) at

Niphad. For winter and summer seasons, the values are 0.30 mm/ hr and 0.43 mm/hr respectively, while observed values of PET are 0.2 mm/hr and 0.29 mm/hr respectively. There is quite difference in these two values, particularly in the summer, which may be attributed to the topographical difference between two stations and grape orchards with very good irrigation facilities during summer at Niphad.

Likewise, the Penman-Monteith sub-module was run for three years from 1999 to 2002, for which input data are available. The estimated seasonal hourly PET values of these years have given in Table 8.4. The Penman-Monteith method of estimating PET may be used in the arid and semi-arid conditions if all climatological data are available to the user.

8.2.5.2 Hargreaves-Samani Sub-module

The Penman-Monteith method of PET estimation is widely recommended because of its detailed theoretical base and its accommodation of small time periods. However, the detailed climatological data required by the Penman-Monteith are not often available, especially in developing nations. Considering the paucity of such climatological data and the impact of microclimates on weather parameters, it is desirable to be able to estimate ET_0 for locations where the full range of reliable climatological data is not currently available. The most important parameters in estimating PET are temperature and solar radiation. The Hargreaves-Samani method of PET estimation, as discussed in section 5.4.2, is based on these parameters, which has been implemented in the current DSS with sub-module or GUI (section 7.5.3.2). With the required input data given from external file to the programme, sub-module computes the PET on daily basis for the length of data provided by the user. The computed values of PET are displayed in the 11^{th} column of *MSFlexGrid,* as shown in Fig. 8.8.

For the Khadak Ohal watershed, input data given to this sub-module are corresponding to the water year 2002-03 (Table 8.3). The PET estimates by this method produce total annual value of 2334.163 mm. The lowest of 2.63 mm/day is observed on 27th June, 2002. The average PET in monsoon is found to be 4.84 mm/day, while 6.82 mm/day and 8.35 mm/day are for winter and summer season respectively.

As compared in Penman-Monteith sub-module, the seasonal hourly values of PET obtained from the daily estimated PET values are compared with the observed PET data. In the year 2002-03, for monsoon period, seasonal hourly PET value is found to be 0.37 mm/hr, while 0.48 mm/hr and 0.73 mm/hr are for winter and summer season respectively. The sub-module was re-run for three years of available climatological data from 1999 to 2002. The seasonal hourly PET values thus obtained from the daily PET values are given in Table 8.4.

Table 8.3 Input parameters required for PET computation

Method	**Scale**	**Parameters**
Penman-Monteith	Daily	Date, Month, Year. Maximum Temperature, Minimum Temperature, Maximum Relative Humidity, Minimum Relative Humidity, Sunshine Hours, Julian Day, Wind Speed at 2 m height, Elevation from MSL, Latitude
Hargreaves-Samani		Date, Month, Year, Maximum Temperature, Minimum Temperature, Solar Radiation

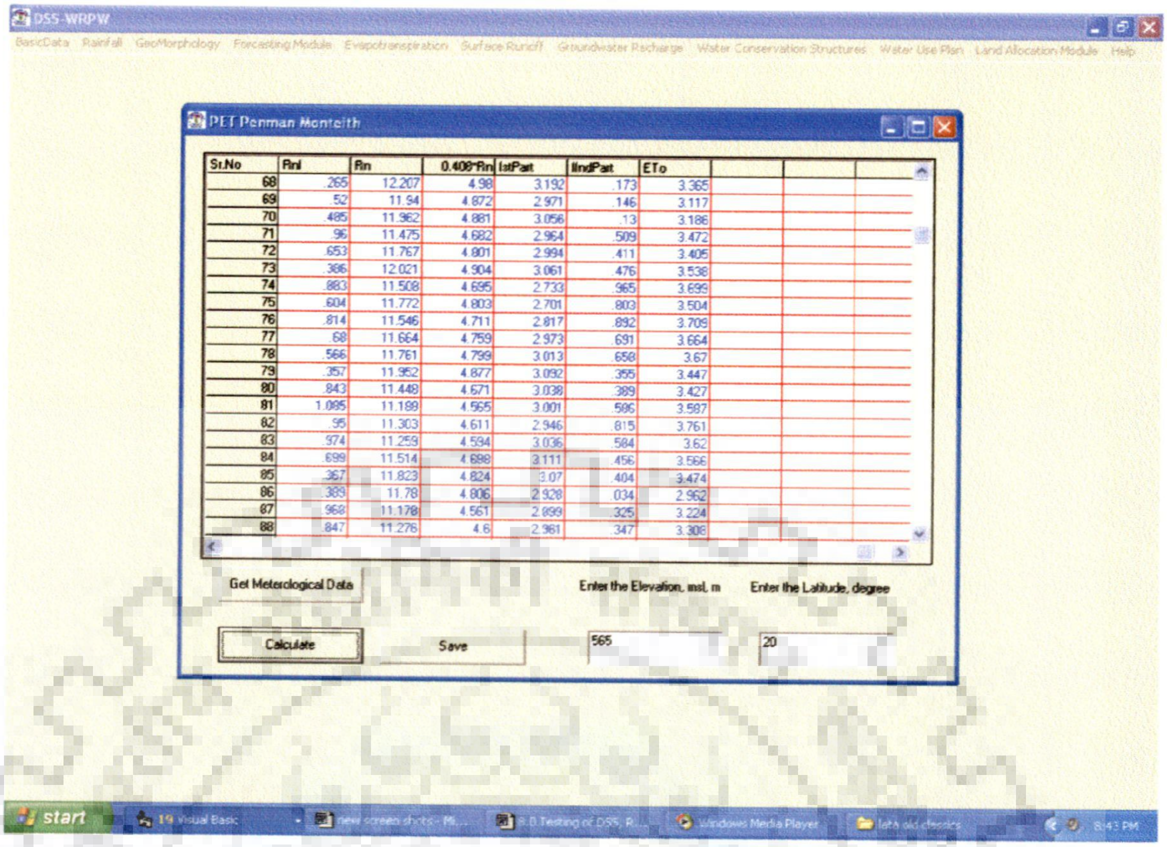


Fig. 8.7 Penman-Monteith sub-module

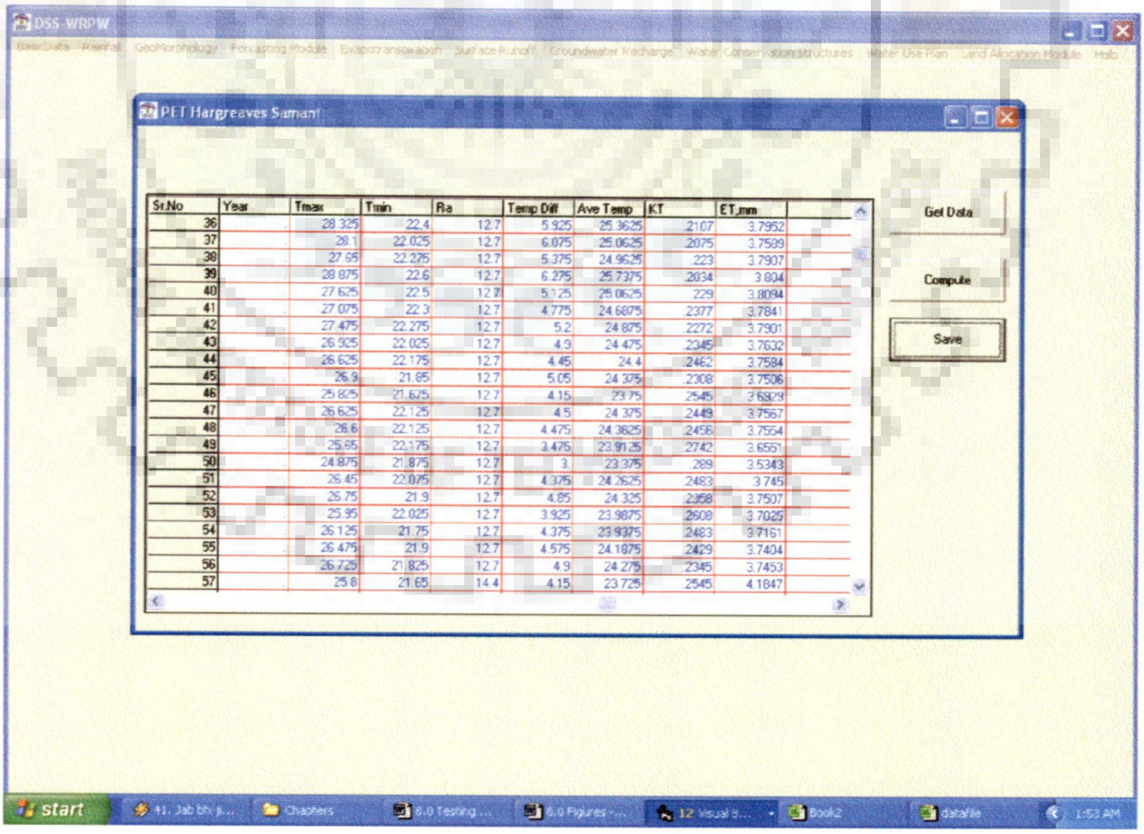


Fig. 8.8 Hargreaves-Samani sub-module

Table 8.4 Seasonal hourly estimates of PET by Penman-Monteith and Hargreaves-Samani method.

Season / Year	Monsoon	Winter	Summer
PET mm/hr (Penman-Monteith)			
1998-1999	0.395	0.330	0.407
1999-2000	0.375	0.300	0.383
2001-2002	0.318	0.277	0.355
2002-2003	0.36	0.30	0.43
PET, mm/hr (Hargreaves-Samani)			
1998-1999	0.346	0.601	0.863
1999-2000	0.351	0.623	0.942
2001-2002	0.350	0.621	0.936
2002-2003	0.373	0.481	0.734
Average PET(mm/hr) at Niphad (Anon, 1998)	**0.310**	**0.200**	**0.290**

8.2.5.3 Crop Water Requirement Sub-module

Crop water requirement is mostly dependent on PET and crop coefficients during the different growth periods. The sub-module is developed with GUI (7.5.3.3) having number of combo boxes and text boxes in left side to enter the crops, its area and growing season. The main computations are carried out in *MSFlexGrid* provided in the right side of the GUI. Before clicking on the control button to compute the crop water requirement during the period, user has to select the PET estimation method from the combo box provided on the top portion of GUI. This will load the PET data for the period of one year from June to May in the *MSFlexGrid*. Daily crop water requirement is summed up and divided with the overall efficiency of irrigation (60% in this case) in last column to get fortnightly values of irrigation water requirement of all crops.

Existing cropping pattern in the study area has 28 ha area under Paddy, 195.7 ha under Finger Millet, 40 ha under Common Millet, 30.3 ha under Red Gram, 17 ha under Black Gram, 15 ha under Horse Gram, Groundnut on 30.5 ha area and 23.5 ha under Niger. All these crops are grown during the monsoon or *Kharif* season. The crop water requirement estimation by using the Penman-Monteith method is shown in Fig 8.9, while Fig 8.10 gives its values by using alternative method i.e. Hargreaves Samani method. The fortnightly values of irrigation water requirement (IWR) in ha-m are given in Table 8.5.

From Table 8.5, it can be seen that DSS generated irrigation water requirement values for both of the models i.e. using Penman-Monteith method and Hargreaves-Samani method, don't have any significant difference for the monsoon season of year 2002. Some difference in the values for June indicates the efficiency of Penman-Monteith method with the estimation of PET. The more relative humidity at the start of monsoon season i.e. June is producing higher PET values than temperature based Hargreaves-Samani method. Relative low values of IWR in the later half of the season indicate maturity of some crops, such as millets and legumes.

Table 8.5 Fortnightly irrigation water requirement (IWR) of all crops

Month	Fortnight	IWR(ha-m) Penman-Monteith Method	IWR(ha-m) Hargreaves-Samani Method
June	I	49.768	35.92
	II	40.009	29.77
July	I	39.361	35.95
	II	34.828	36.93
August	I	18.673	22.04
	II	16.321	19.46
September	I	16.653	19.48
	II	16.114	18.99
Total IWR, ha-m		231.69	218.54

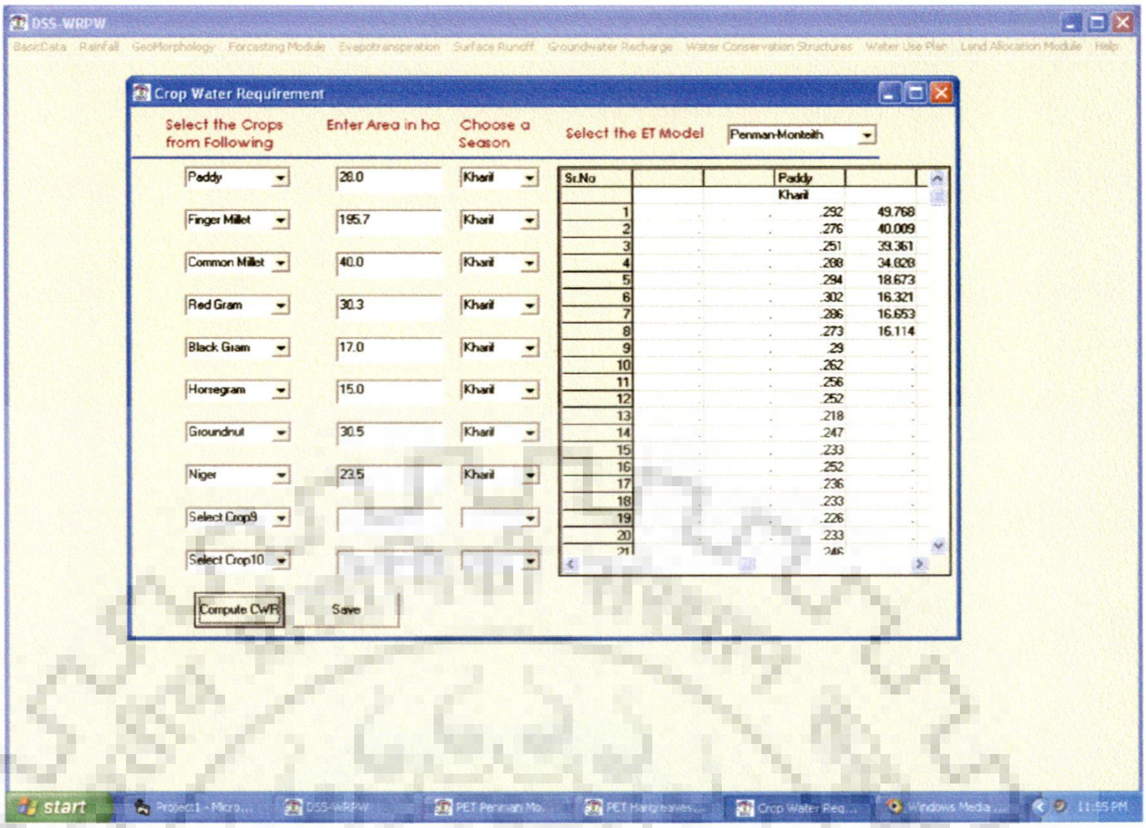


Fig. 8.9 Crop water requirement (Penman-Monteith) sub-module

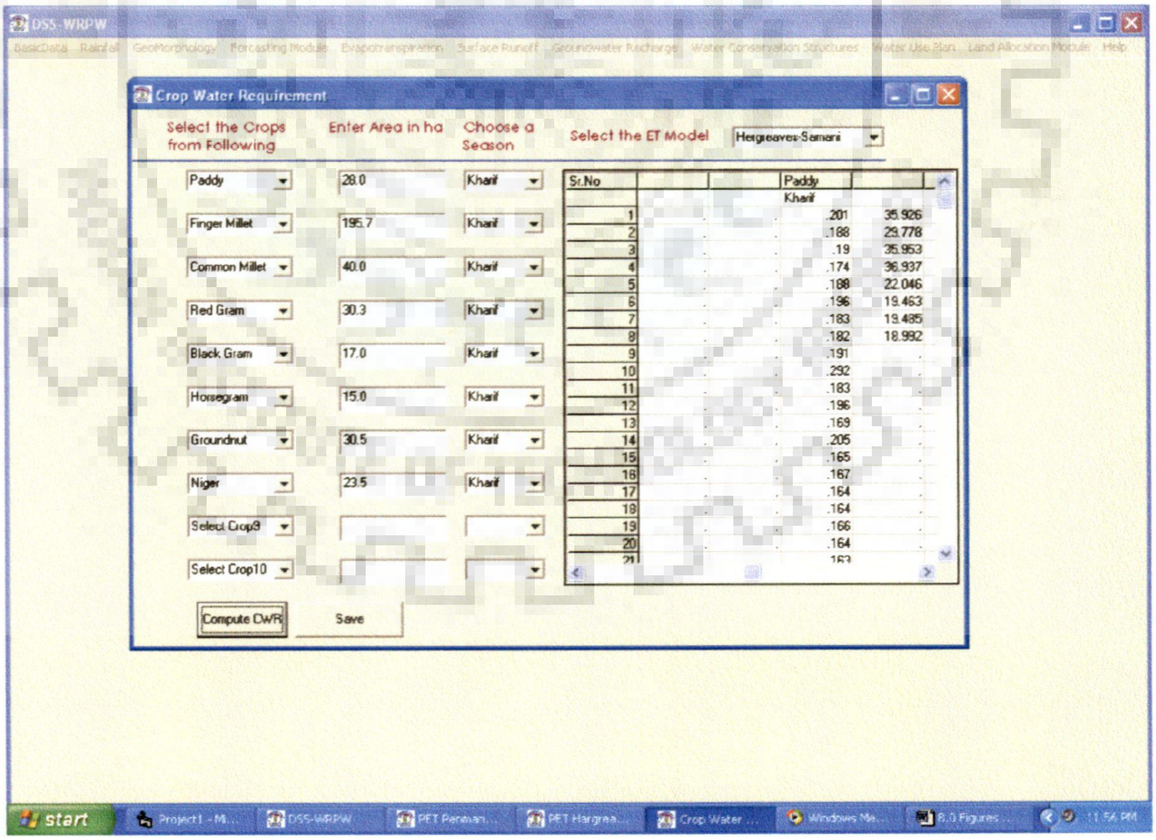


Fig. 8.10 Crop water requirement (Hargreaves-Samani) sub-module

8.2.6 Runoff Module

There are two models (NRCS CN and CELTHYM) implemented in this DSS through GUI, which takes the spatial and non-spatial data as input to the module. The performance of working of these two modules have discussed in the next two sub-sections.

8.2.6.1 NRCS CN Interface

As discussed earlier, the NRCS CN model is quite popular in many parts of the world due to its minimum data requirements (SWAT, 2002). The model has been implemented in the present DSS in GIS based GUI, which principally takes input as shape file (as Polygon), having a land use and soil type in the respective land use class (Fig. 6.2). The default attribute of the area of individual polygon is used to get the lumped value of the CN at AMC II condition. Table 8.6 gives the summary of input GIS data to this module.

Table 8.6 Principal input coverage

Name	Description	Coverage Type	Attributes
Landuse.shp	Land Use Classification	Polygon	ObjectID Shape Shape Area Shape Length Land Use Soil Type

8.2.6.1.1 Parameter Estimation

The sub-module named *NRCS CN interface* takes the required shape file to the GUI. Once a file is loaded in the map layer, user has to send all the attributes to the *MSFLexGrid* to compute the lumped CN value. For Khadak Ohal watershed, input shape file can be seen in the screen shot of the module in run mode (Fig. 8.11). Sorted list of all attributes described in Table 8.6 can be seen in the *MSFlexGrid* below the map layer displaying the land use. The CN values at AMC II condition are assigned in the third column of *MSFLexGrid* by running the codes written to implement this sub-routine. This is obtained with click on the button *Compute*. The CN values for Khadak Ohal watershed ranged from 61 to 91 for the AMC II condition, while the lumped value of CN at this AMC is 68 (Text box in the Fig. 8.11).

8.2.6.1.2 Runoff Computation

The lumped value of CN at AMC II is exported to the next sub-module of the same module of DSS with the click on the button *Contd.* Fig 8.12 gives the picture of runoff computation interface in the running mode. The rainfall data is called to the *MSFLexGrid* in this sub module. The AMC condition is assigned for each day by computing the 5-day preceeding rainfall. The Khadak Ohal watershed has most of the AMC III condition during the peak monsoon period. The lumped value of 68 of CN at AMC II is converted to 83 at the AMC III and 47 at AMC I. The last column in the *MSFLexGrid* in Fig. 8.12 gives the runoff produced from the rainfall of each day (in rows). The total runoff is computed and placed in the text box (in top of the Fig. 8.12). The year 2002 produced 467 mm of runoff out of 1748.6 mm rainfall from the Khadak Ohal watershed. The computed runoff agrees well with the observed data of runoff of this period with the R^2 value of 0.70 between observed and computed values. Fig. 8.13 gives the plot of observed and predicted runoff in the monsoon period of 2002.

8.2.6.2 CELTHYM Interface

Analysis of runoff in an agricultural watershed by CELTHYM involves providing input parameters for each of the cells that represent the entire watershed. To facilitate the implementation of CELTHYM in the DSS, a windows based interface was developed to integrate the CELTHYM model and GIS data input facility. The basic data required for CELTHYM interface include shape file describing the land use, soil database in the grid format besides rainfall and evapotranspiration data.

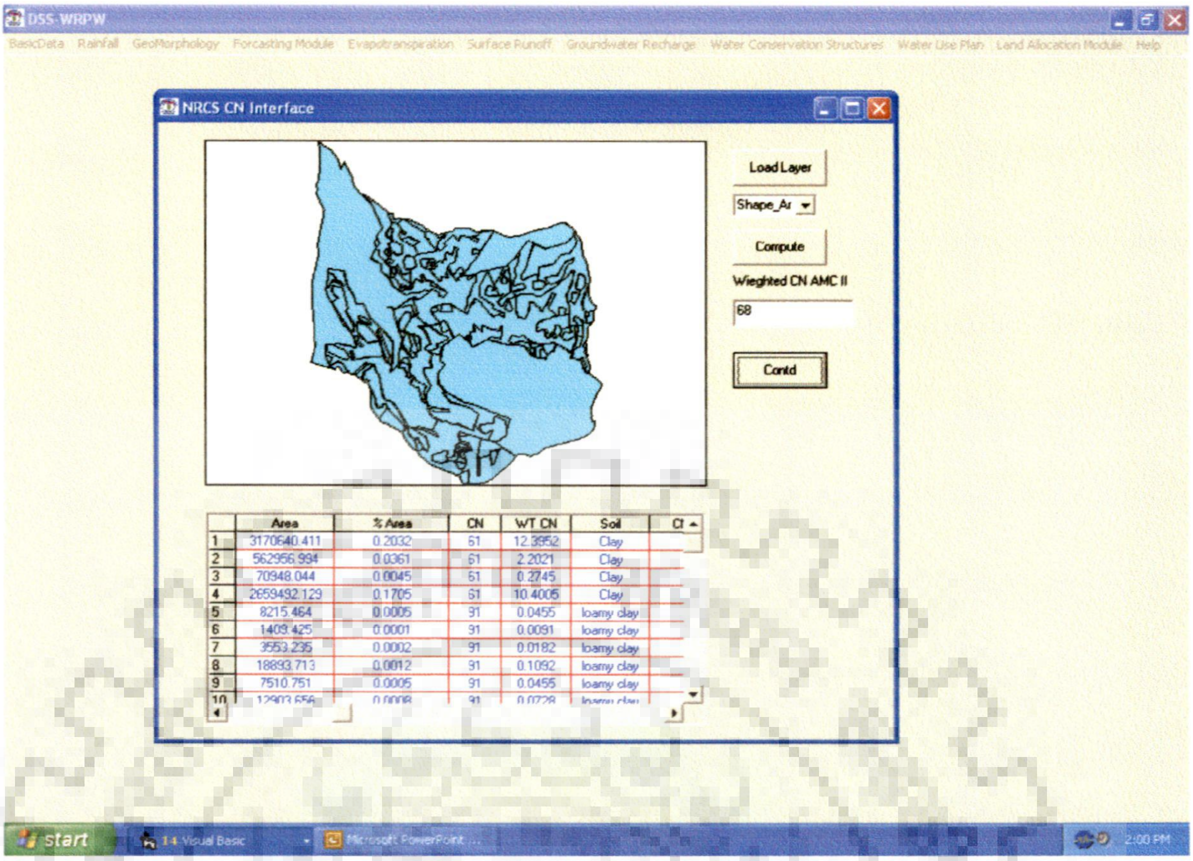


Fig. 8.11 NRCS CN interface in the run mode

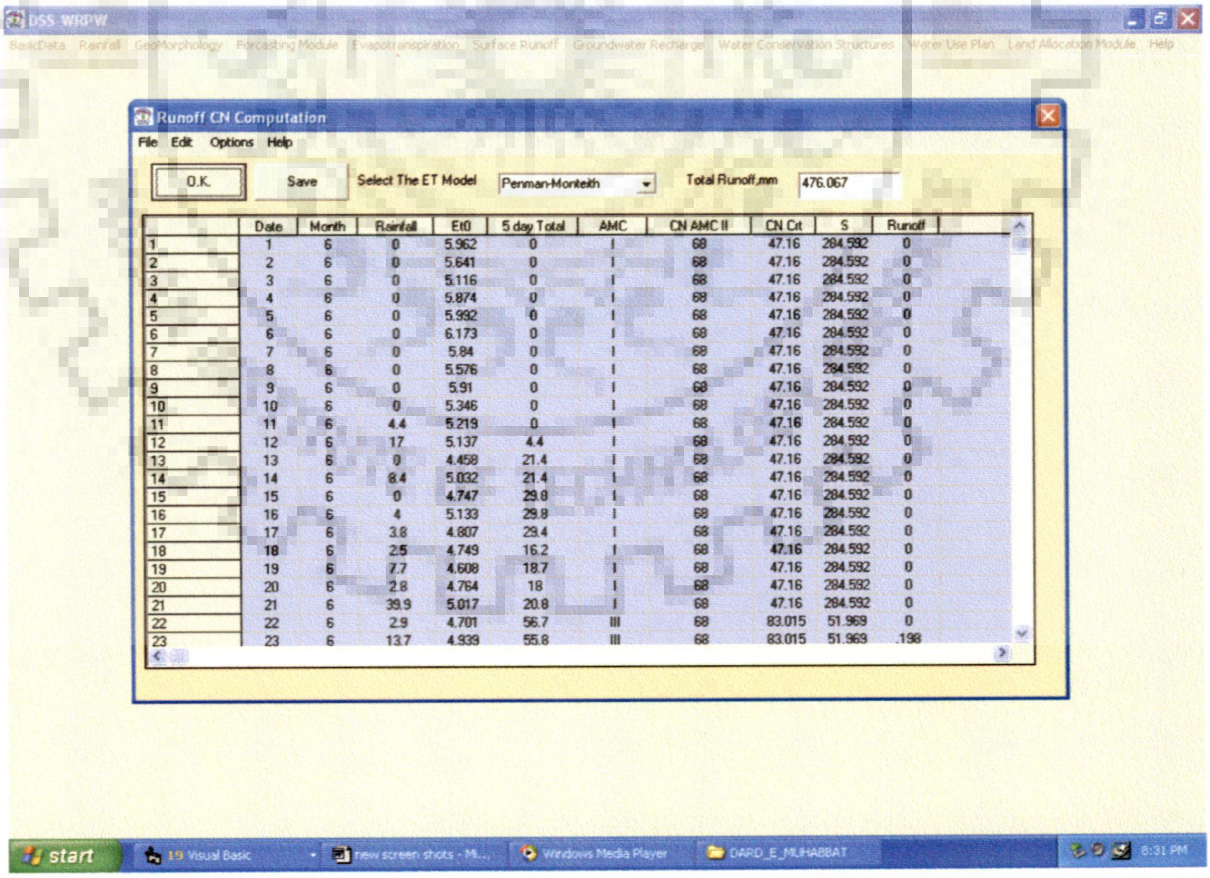


Fig. 8.12 Runoff computation sub module of NRCS CN interface.

The input shape file was prepared, as discussed in the section 6.3.1. The land use map for the Khadak Ohal watershed converted to grid based map and additional attribute of soil type was added against each of the Cell ID. This was done to avoid the number of layers to be generated. The land use map in the vector format was converted to grid map of 100 m X 100 m. The required shape file (Fig. 6.3) was again converted to vector format taking each grid as polygon. Table 8.7 summarises the input GIS data for this model.

Once the input files are ready, the interface can generate the required parameters in the separate sub-module. The CELTHYM interface has been developed and implemented through three sub-modules; one for reading GIS data, another to generate the input parameters from GIS data and final to simulate the runoff.

Table 8.7 CELTHYM input coverage

Name	Description	Coverage Type	Attributes
Landusegrd.shp	Land Use and Soil Classification	Polygon	ObjectID Shape Shape Area Shape Length GRIDCODE Cov.Type Land Use Soil Type

8.2.6.2.1 Data Input

The CETHYM interface provides a facility to open shape file through Window's common dialogue control, which displays the required GIS data in the *MapLayer*. As shown in Fig 8.14, user has to open the file and sort out the attributes of the displayed GIS file to send to the parameter generation module. The test box below the *Open* button in the GUI gives the number of data grids present in the spatial data. There are 1726 grids of 100 m X 100 m in the Khadak Ohal watershed. Click on the control button *Compute Runoff* lead to open another sub-module in the CELTHYM interface, which displays the input parameters required to simulate the runoff.

8.2.6.2.2 Parameter Generation

The sub-module (Fig. 8.15) generates the parameters on the basis of spatial and rainfall data. As CELTHYM is a CN based model, the interface for which has to take land use and soil type of the selected watershed to assign CN values at AMC II. There are essentially two *MSFlexGrids* in this sub-module. The right side grid table takes the rainfall data from file for the year of interest. There are 150 rows of data in this table, where daily rainfall is displayed. The left grid table imports the parameters of the selected attributes of the shape file. There are a total of 1703 rows in this table. Each of the rows represents the value of particular attribute of particular grid in the watershed. For example, serial number 13 grid has a land use of *Row Crop Straight* with soil type *clay loam*. The fourth column in this grid table displays the average value of infiltration rate. Based on this, CN value at AMC II is assigned. The simulation of runoff begins before the start of runoff. This is required to simulate the soil moisture conditions. The complete simulation of runoff with all other parameters is carried out in the next sub-module.

8.2.6.2.3 Runoff Computation

The CELTHYM model operates on the basis of daily soil moisture routing from the watershed. This is used to change CN values before starting of runoff computation for the particular day. The model algorithm, as discussed in section 5.2.2.2, has been implemented by developing the program in DSS.

There are nine *MSFlexGrid* tables in this sub-module (Fig. 8.16). In the first *MSFlexGrid* table, the top row in the sub-module takes the input of CN value at AMC II from parameter generation sub module. The rainfall is also exported from the previous sub-module. This has been arranged in the first row for monsoon period (1st June to 30th October). Thus, there are 150 columns in the each *MSFlexGrid.* Similarly, ET values are called from the respective sub-module, which the user selects in previous sub-module.

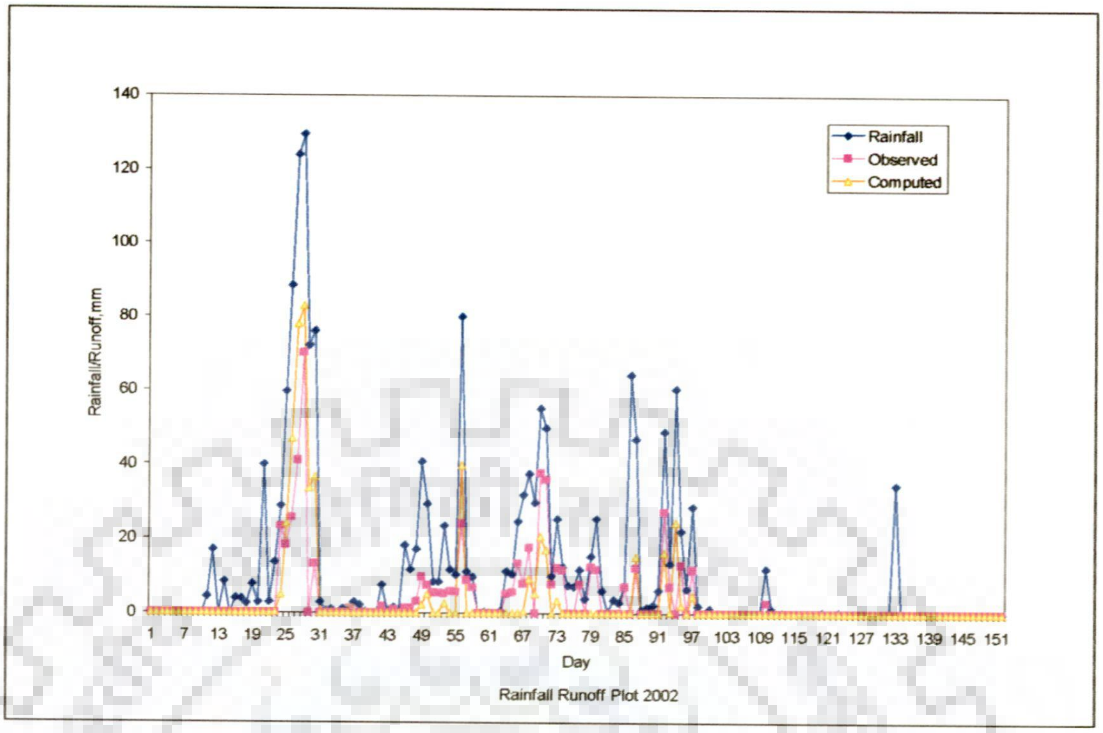


Fig 8.13 Plot of observed and computed runoff for year 2002

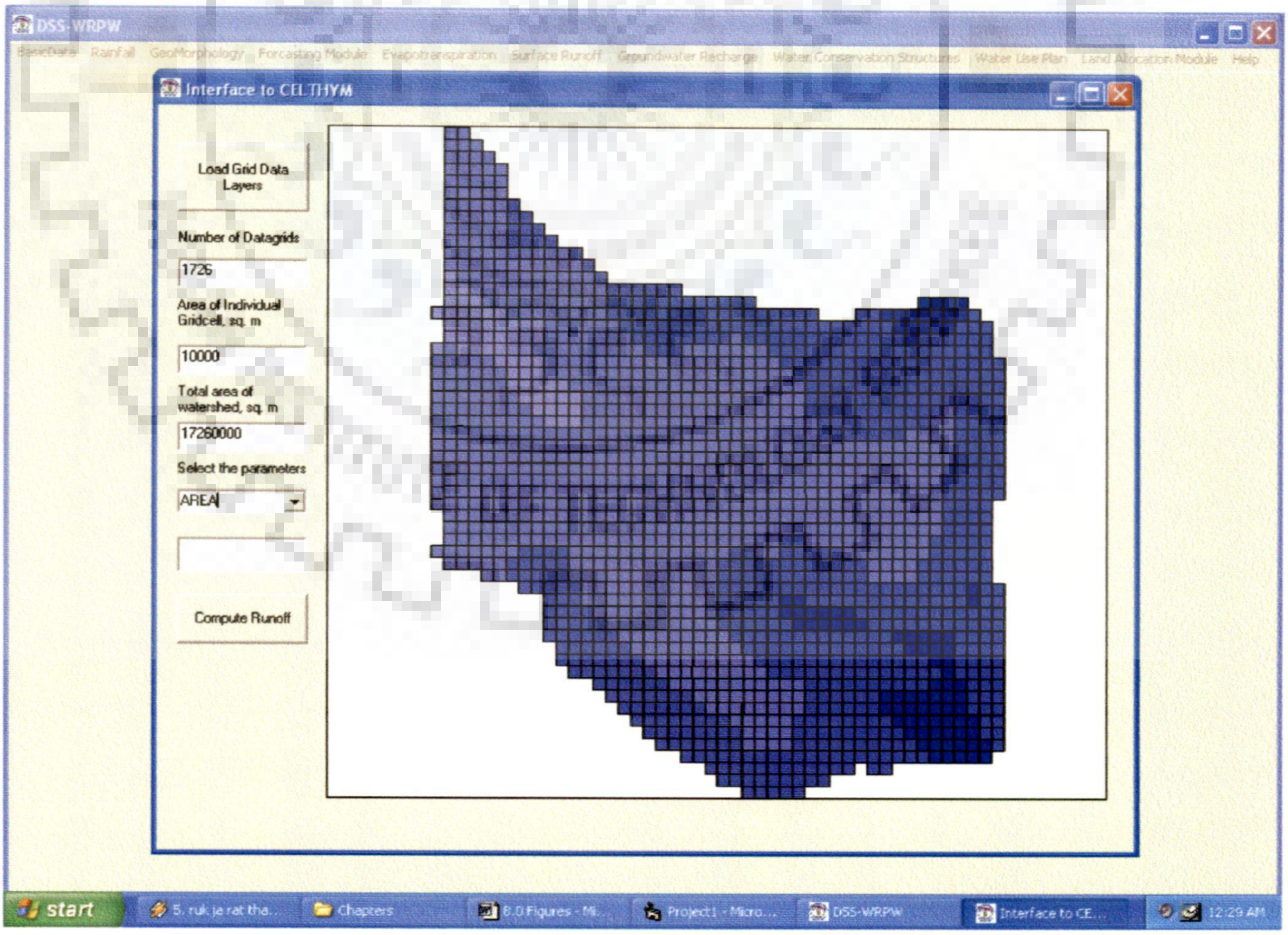


Fig. 8.14 CELTHYM interface with input GIS file

The third row displays 5 day preceeding total rainfall, on the basis of which the CN value at AMC II is converted to AMC I /AMCIII. From fifth row to 1707 row, converted values of respective AMC condition are displayed. For first grid and first day rainfall, AMC II value of CN 58 has been converted CN 37, which is value at AMC I. The CN conversion factor "a" (Eq. 5.12 & Eq. 5.14) for each day and each grid of watershed is displayed in the second *MSFlexGrid.* Using this factor "a", new values of adjusted CN after soil moisture routing is displayed in the similar manner as that of factor "a". For the first grid and second day rainfall, the adjusted value of CN is 79. The fourth *MSFlexGrid* table computes the maximum potential retention, S, using the adjusted CN value. The runoff is finally displayed in the sixth *MSFlexGrid* for each grid. The other soil moisture balancing variable, such as soil water retention (SRt), soil moisture deficit (DFt) and deep percolation (DPt) are displayed in the lower most three *MSFlexGrids.* The soil moisture available (SM) after accounting these parameters for the previous day is displayed for each grid or cell in watershed in the fifth or middle *MSFlexGrid.* The total runoff available from the watershed is summed up and displayed in the text box near the click button "OK". This is the summation of runoff produced from each cell or grid for all the monsoon period.

For the monsoon period of 2002, the CELTHYM model estimated the total runoff of 311.748 from total rainfall of 1748.6 mm. This is around 18% of total rainfall whereas NRCS CN interface estimated around 27% runoff from the Khadak Ohal watershed. The rainfall-runoff plot for this interface is shown in Fig. 8.17. This estimated runoff agrees well with the observed runoff records for the year 2002 with R^2 value of 0.91. The reasonable difference in the estimates of runoff between two methods may be attributed to some rainfall events, with small to moderate amount of rainfall, which have not been taken into consideration in CELTHYM after soil moisture balancing.

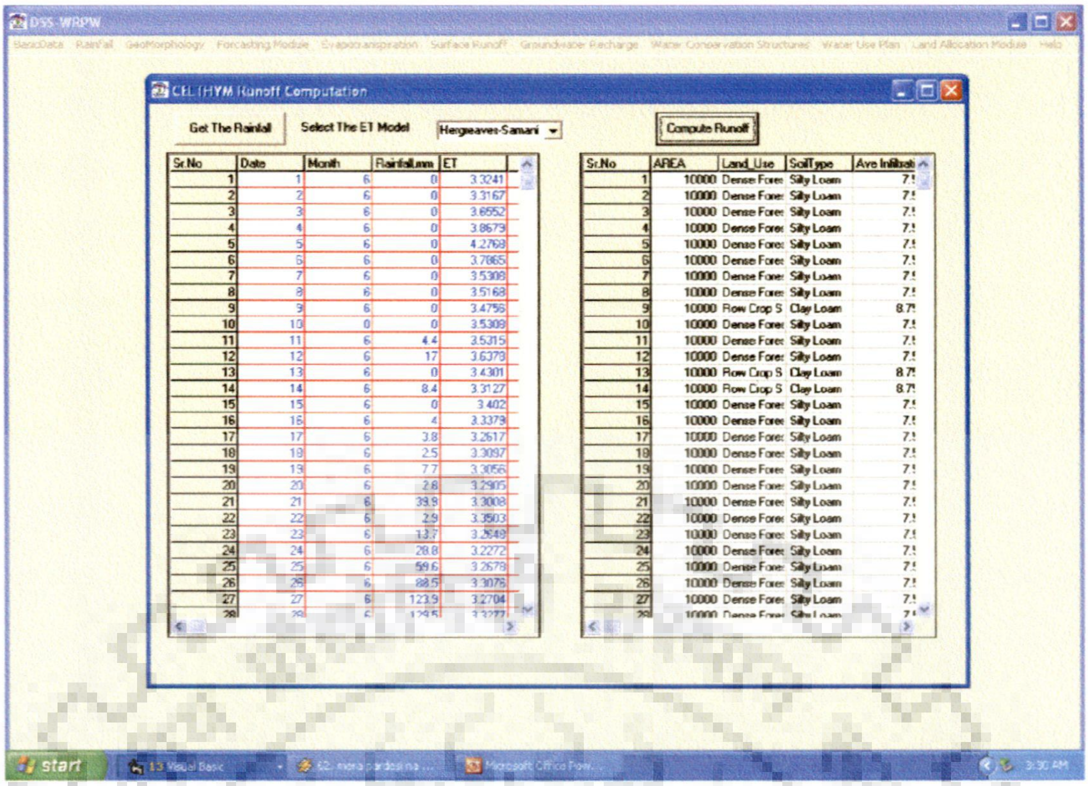


Fig. 8.15 Parameter generation sub-module of CELTHYM interface

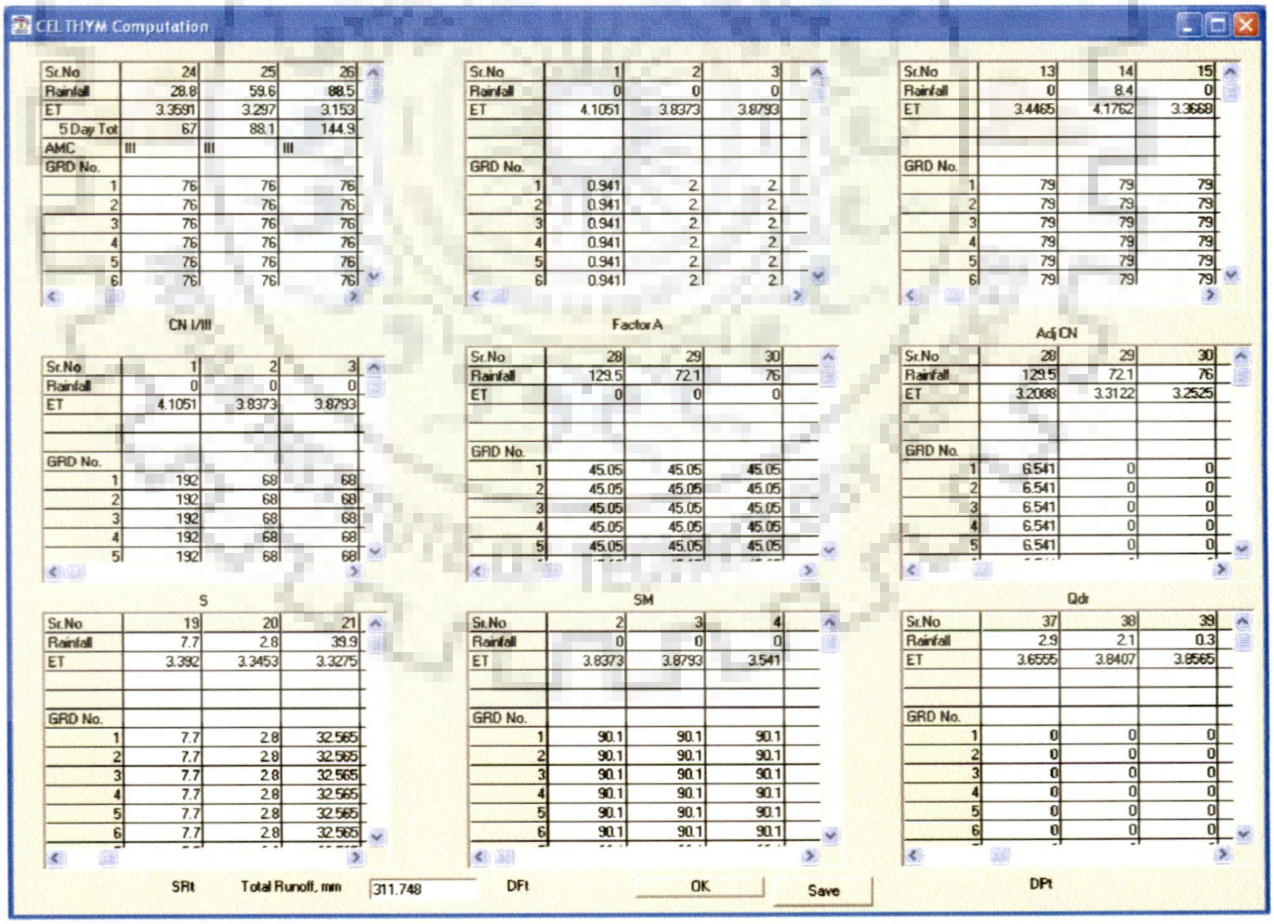


Fig 8.16 Runoff computation in CELTHYM interface

Similarly, both of these modules i.e. NRCS CN and CELTHYM have been tested with the rainfall records of 2001 and 2003 (Appendix J1). This estimated runoff was compared with the observed runoff for these years, and R^2 computed between estimated and observed runoff has been given in Table 8.8. The computed values of R^2 are in the acceptable range and suggest good agreement with both of the datasets. It may be concluded from this table that any of two modules may be applied depending upon the data availability.

Table 8.8 R^2 values between observed and computed runoff

Year	NRCS CN	CELTHYM
2001	0.95	0.92
2002	0.7	0.91
2003	0.84	0.53

8.2.6.3 Rational Module

The popular rational formula has also been implemented in this module. Module (Fig. 8.18) is compatible of taking GIS data for the spatial parameters using Rational formula, whereas the other parameters are based on the user input. As described earlier, module has two map layers; (i) for taking contour data and (ii) for taking slope range data with land use and soil type in the particular slope class.

To start with, user has to open the contour map to display in the first *MapLayer* and slope range map in the second *MapLayer*. The minimum and maximum elevation values are displayed in the text boxes.

For the Khadak Ohal watershed, contour file (Fig. 6.9) can be seen in the top most *MapLayer* in the module, which shows the watershed, has minimum elevation of 140 m, and maximum elevation of 500 m above msl. This forms a total elevation difference of 360 m. The length of watershed is imported here from the *Geomorphology* module. Khadak Ohal watershed has a length of 6620 m. If rainfall intensity data for the desired return period is available with the user, it may be entered in the respective text box. But in general, this data availability is major constraint in India. The alternate approach has been used in this sub-module, in which a user has to select the nearest station to watershed of the interest from the combo box placed below the respective label. For this watershed Nandurbar is nearest station. All above information along with the user defined return period is used to compute the rainfall intensity. This is very helpful, when rainfall data is not available for the particular return period. The 50 year return period rainfall intensity is estimated as 87 mm/hr.

In the next step, user has to open the slope range map (Fig. 6.12) to get the distributed value of runoff coefficient for the watershed. The file opened in the second *MapLayer* is slope range map. This GIS data file contains land use, soil type attributes besides the slope range. Table 8.9 gives the summary of two shape files used as input to this module.

Using information extracted from these attributes, the module computes the distributed value of runoff coefficient. For selected watershed, this value was estimated as 0.496. The area of watershed is called from the *Morphometry* module in the DSS. Now using the area, runoff coefficient and rainfall intensity, finally peak rate runoff for 100 year return period is computed as 240.266 m^3/sec.

For 10 year return period, peak runoff is 149.869 m^3/sec. The peak runoff rate is 180.794 m^3/sec and 206.962 m^3/sec for 25 and 50 year return periods respectively. Fig 8.18 shows the results of this module for 50 year return period.

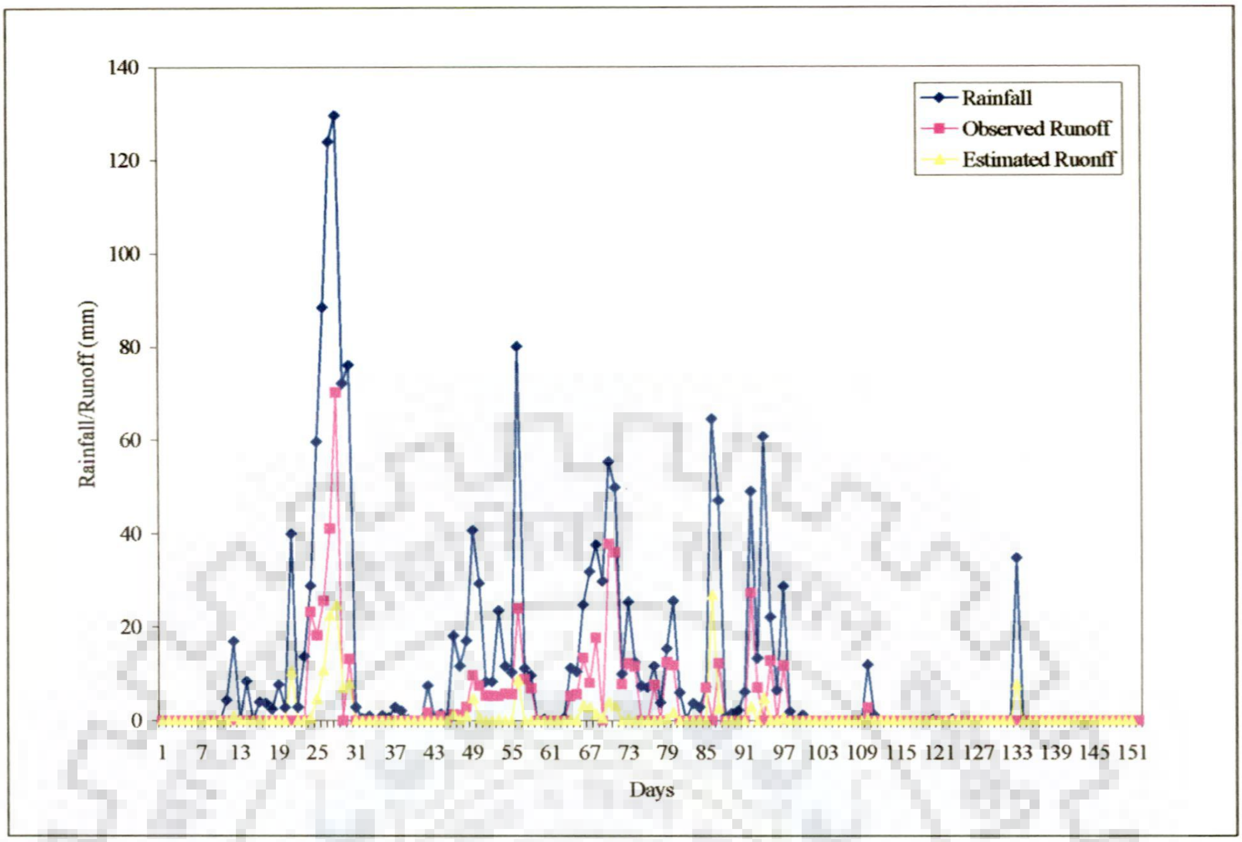


Fig. 8.17 Observed and estimated runoff for year 2002 by CELTHYM

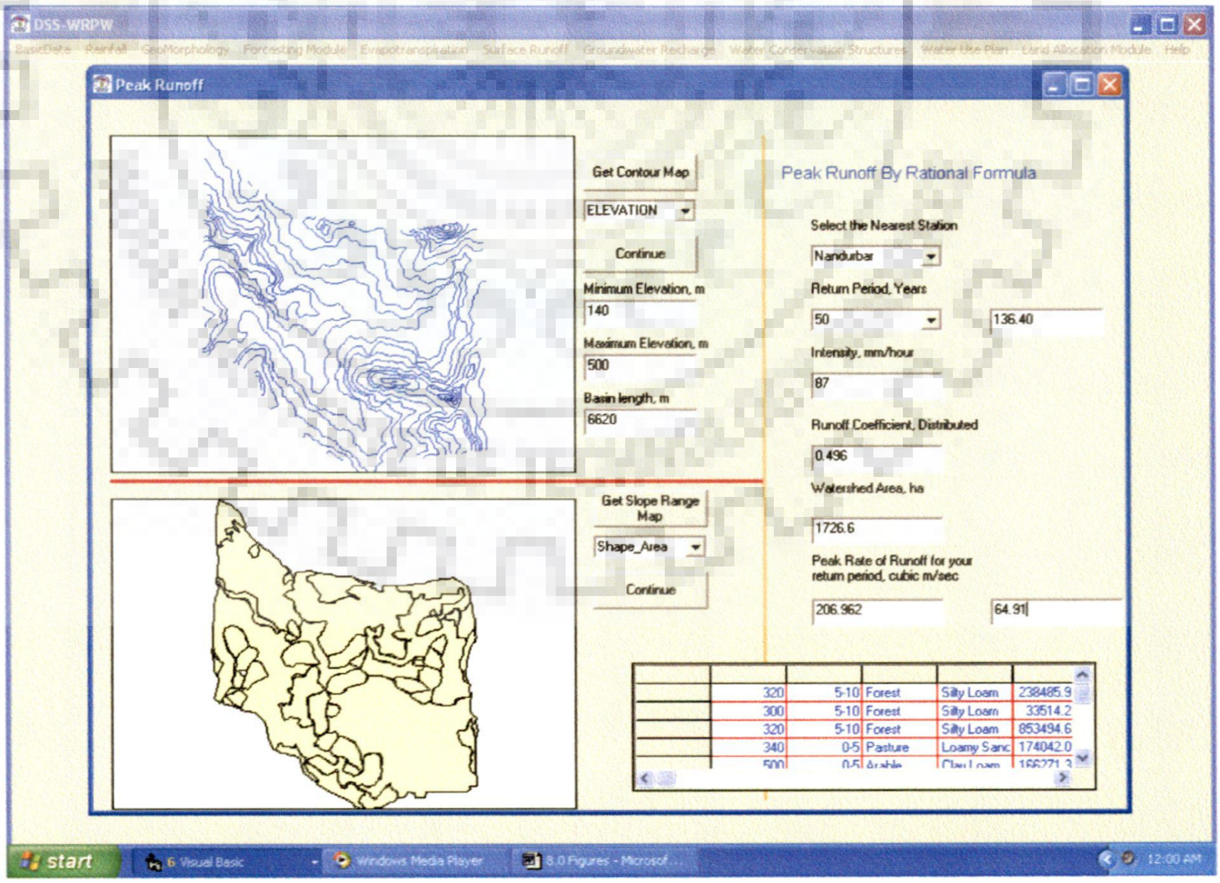


Fig. 8.18 Rational module applied to Khadak Ohal watershed

Table 8.9 Summary of input shape files for rational sub-module

Sr. No	Name	Description	Coverage Type	Attributes
1	ContourDC1b.shp	Contour	Polyline ZM	FID Shape Shape Length Elevation
2	Sloperange.shp	Slope Range Land Use Soil Type Classification	Polygon	ObjectID Shape Shape Area Shape Length Slope Range Land Use Soil Type

8.2.7 Groundwater Recharge Module

Groundwater is most important part of any water resources system. In order to have estimation of groundwater recharge from the watershed, two methods have been used in the present DSS, as given by Groundwater Resource Estimation Committee (GEC, 1997) viz; (i) rainfall infiltration and (ii) water table fluctuation method. Both of these methods are mostly dependent on underlying geology of the area. Applications of both these methods have been demonstrated for Khadak Ohal watershed in next two sections with two separate sub-modules developed.

8.2.7.1 Rainfall Infiltration Sub-module

The groundwater recharge available is estimated as a fraction of rainfall. This fraction varies according to the geology of watershed. The sub-module (Fig. 8.19) takes the input of shape file describing the type of geological formation in *MapLayer*. The type of geological formation is then exported to the text box. Another eight text boxes need to be entered with the fortnightly effective rainfall. The estimated values of recharge for each fortnight are displayed in the text box opposite to these text boxes. Khadak Ohal watershed has vesicular and joint basalt in its geological formation. This formation is found in consistent throughout the hilly tract of Nashik

District, hence there is no variation in the geological formation in the watershed. The effective rainfall computed for the first fortnight is 113.4 mm, while highest is found in the second fortnight of June. The groundwater recharge from this highest rainfall is 52.60 ha-m. Total recharge from 1748.6 mm of rainfall in the watershed of 1726 ha area by this method is computed as 158.10 ha-m. The fortnightly estimated groundwater recharge is given in the Table 8.10. This method can be applied in case of water table fluctuation data is not available.

8.2.7.2 Water Table Fluctuation Sub-module

The water table fluctuation in the watershed is best judgement of groundwater recharge availability. Underlying geological formation with water table fluctuation data gives the usable amount of groundwater from total recharge. This method, as discussed in section 5.7.2, has been implemented in this DSS with sub-module (Fig 8.20) or GUI having MapLayer to open the geological GIS data. The other inputs user has to give in this sub-module are the average values of pre and post monsoon water-table levels in the watershed. The same shape file describing geological formation, as opened in the earlier sub-module, can be opened in the *MapLayer* of this sub-module. The program gives the total available recharge from the monsoon. To get the fortnightly recharge, the total recharge is distributed according to the proportion of rainfall in each fortnight during the monsoon period.

Underlying geological formation of vesicular and joint basalt, pre and post-monsoon average groundwater levels of 6.5 m and 1.9 m respectively produced total recharge of 196.10 ha-m in the Khadak Ohal watershed. The fortnightly distributed groundwater recharge in accordance with the percentage of rainfall has been displayed in the text boxes below the label distributed recharge. These values are given in Table 8.10.

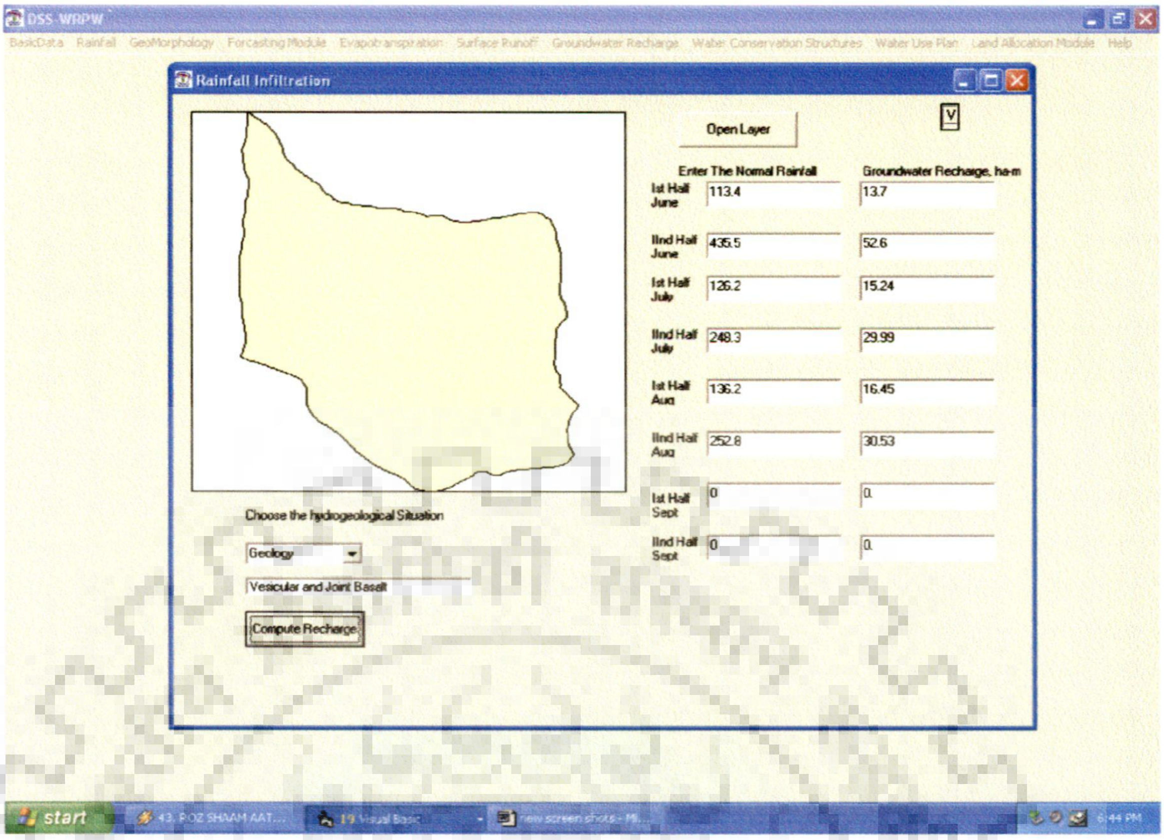


Fig. 8.19 Rainfall infiltration sub-module

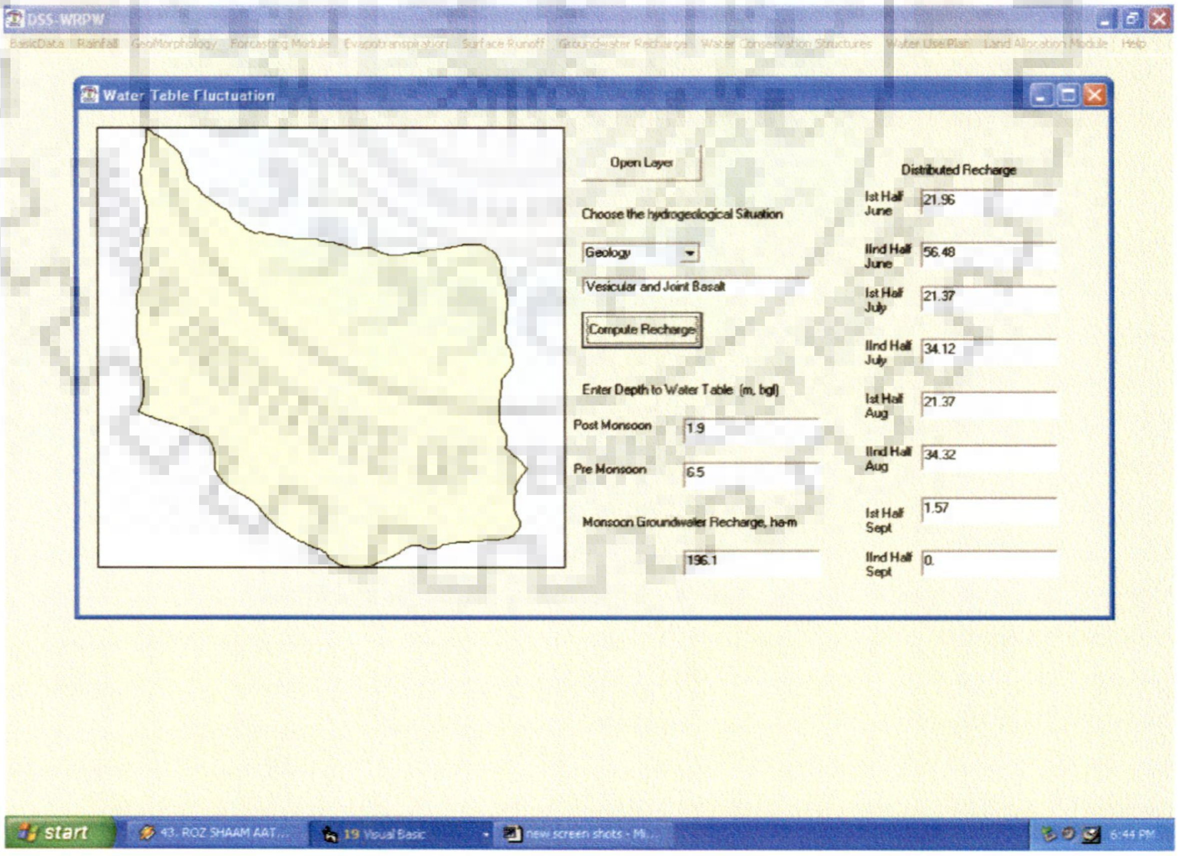


Fig. 8.20 Water table fluctuation sub-module

Table 8.10 Fortnightly ground water recharge estimation (ha-m) in the DSS.

Month	Fortnight	Rainfall Infiltration	Water Table Fluctuation
June	I	13.70	21.96
	II	52.60	56.48
July	I	15.24	21.37
	II	29.99	34.12
August	I	16.45	21.37
	II	30.53	34.37
September	I	0	1.57
	II	0	0
Total (ha-m)		158.51	196.10

8.2.8 Scenario Generation

The scenario generated in this case i.e. real physical system, where an existing conditions of watershed are considered. All the discussions covered so far in this chapter are all about the running different modules and generating required output to start the water use planning module. This module works as an agent to generate the decision support with fortnightly water resources planning. In the present case of simulation, all the data for the year 2002 have been used. There are no soil and water conservation structures constructed in the Khadak Ohal watershed. The existing cropping pattern for the year 2002 has been used in this case. Hence, there is no need to run the *Land Allocation, Water Conservation Structures* Module in the present case of simulation, and therefore runoff modules are not considered. These modules would give the water harvesting potential, number of water harvesting pond required to be constructed, length of water conservation structures such as bund and terraces required depending on the topography of the watershed. This can be considered as an additional support created in the decision making out of present DSS. Based on the combination of modules run, four scenarios are possible in the present case. These scenarios have been illustrated in Fig. 8.21. The scenarios have been numbered from I to IV, and have been discussed in subsequent sections.

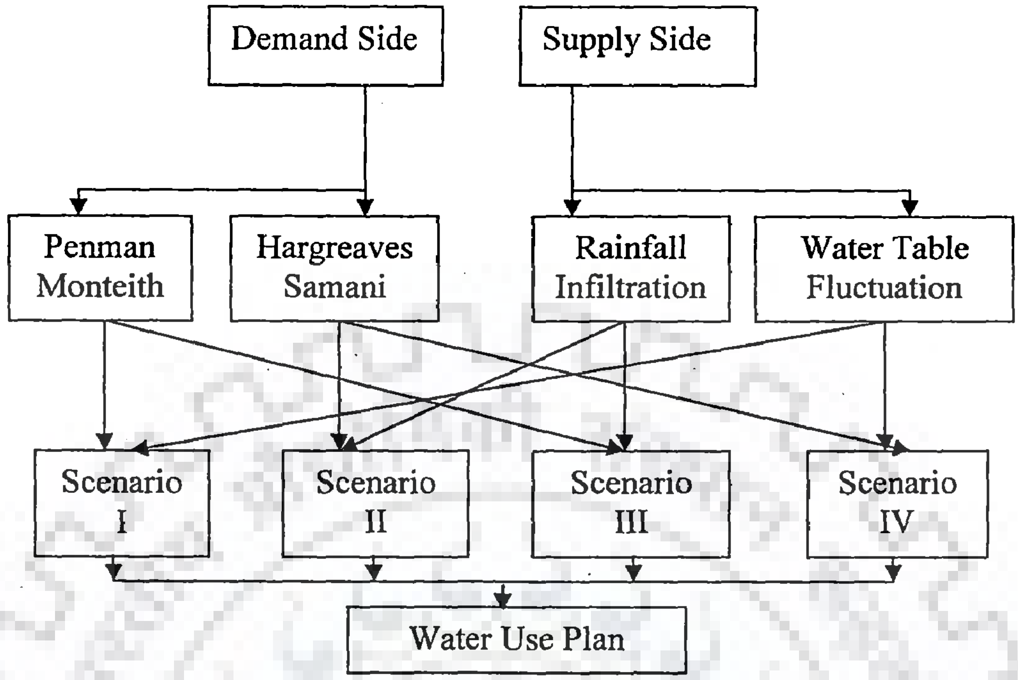


Fig. 8.21 Scenarios based on module combination for case I

8.2.8.1 Scenario I (Case I)

Out the four choices available for combination of module run, user has to select the Penman-Monteith and Water Table Fluctuation option in the combo scroll of GUI. This means that the user has opted for the agricultural water demand estimation by Penman-Monteith method and ground water availability from the module that uses the Water Table Fluctuation method. Prior to generate this scenario, user has to run all the required modules. The scenario generated by this combination is shown in Fig. 8.22.

As shown in Fig. 8.22, the annual human and animal water demand has been distributed equally in 24 fortnight periods in the rows numbered from 11 to 24 and 1 to 10. The 11th fortnight is the serial number of 1st fortnight of June, while 10th fortnight is serial number of last fortnight of May. The human and animal water demand in each fortnight works out to be 0.001 ha-m for each demand sector.

The agricultural demand as estimated in the Crop Water Requirement module is called here and values displayed fortnightly. Present cropping pattern in the Khadak Ohal watershed is rainfed, hence no water demand is displayed after the eighth row in the GUI of module. Agricultural water demand in the case of real physical system in the year of 2002 varies from 16.114 ha-m to 49.768 ha-m. Maximum water demand is found in the first fortnight of June, whereas minimum is found in the last fortnight of September. This reduction in the water demand by crops may be attributed to the reduced crop water requirement due to maturity of legumes and pulses.

On the water resources availability side, the effective rainfall that can be utilized by crops as shown in the first six rows. Maximum rainfall (752.04 ha-m) is available from the second fortnight of June. In the month of September, there was no rainfall in the watershed, hence the total available rainfall in the entire monsoon period less than the annual average rainfall in the watershed. The minimum amount of rainfall was observed in the first fortnight of June.

The groundwater resource in the watershed can be seen increasing throughout the first six fortnights i.e. monsoon period. The incremental recharge from each fortnight is added to next row after fulfilling demand in the respective time interval. There is no recharge in the month of September as a result of proportional distribution of recharge with respect to rainfall. The available groundwater at end of 18th fortnight is 256.837 ha-m.

As per allocation policy formulated (Section 5.11.3), the DSS suggests that all the human and animal water demand can be met out from the groundwater. As there is no surface water available for storage in the watershed, the losses side of seepage and evaporation are showing zero values. The agricultural water demand in the first six fortnights can be fulfilled from available rainfall. Thus DSS has shown RF (Rainfall) in the supply source against these demands. There is considerable agricultural water demand in the month of September, in which there is no rainfall. In absence of any surface water availability, DSS has allocated this demand to groundwater. The string GW (Groundwater) is written against the supply source in these time periods. After fulfilling all the demand, there is still availability of considerable amount of groundwater (256.805 ha-m). This suggests that the additional crops can be grown in the *Rabi* season with this amount of utilizable groundwater, and the watershed can protect atleast one season crops in the moderate drought year. The scenario generated here can be said the best, because of the popularity of these two models.

8.2.8.2 Scenario II (Case I)

This scenario is generated when user opts for the Rainfall Infiltration module for ground water recharge estimation and Hargreaves-Samani module for evapotranspiration (ET) estimation. User is expected to get the crop water requirement and effective rainfall by using ET estimated by this method.

As human, animal population and their water demand are constant in this scenario, there is no change in fortnightly water demand for these two sectors. The GUI of module (Fig. 8.23) shows 0.001 ha-m in both the case in every fortnight period.

Agricultural water demand using Hargreaves-Samani method is different than that of earlier scenario. This is because of the difference in the ET estimated by two methods. The maximum agricultural water demand (36.937 ha-m) is found at 14th fortnight, while minimum (18.992 ha-m) is found at 18th fortnight.

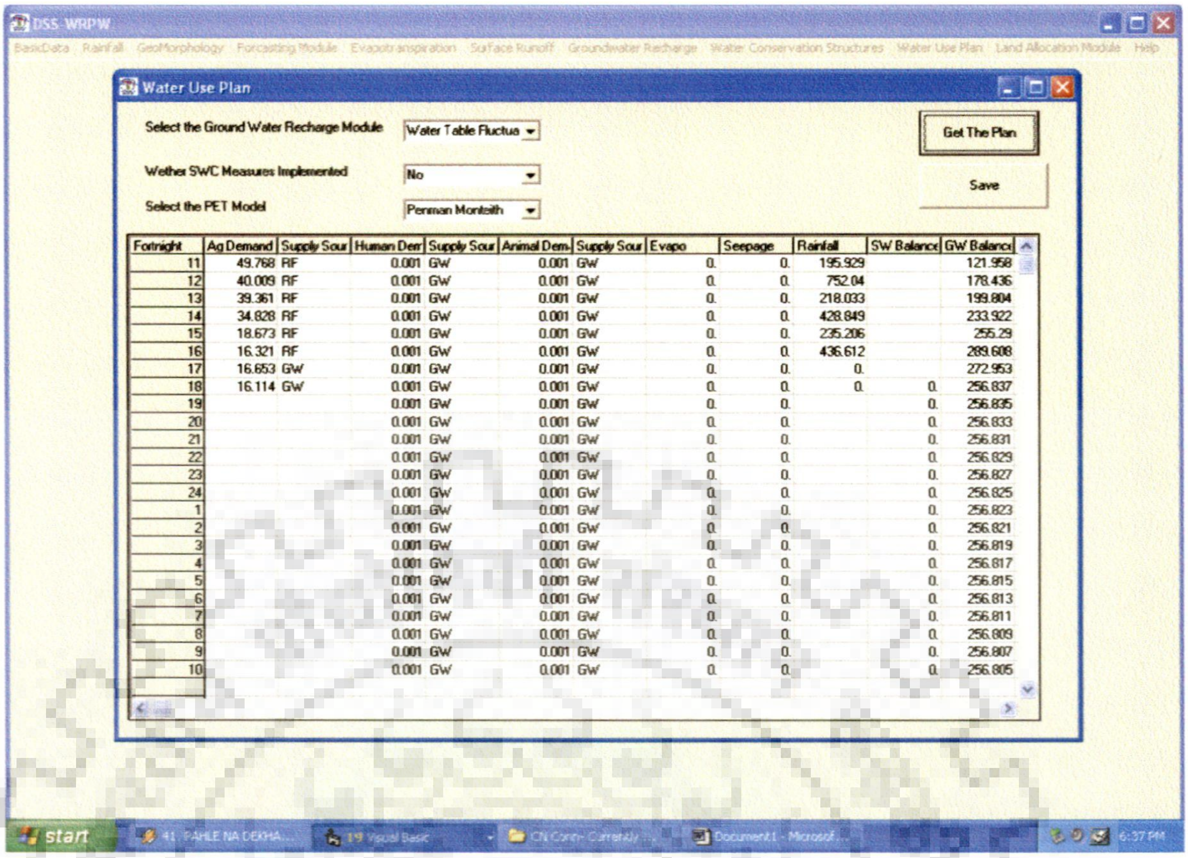
In the water availability side the effective rainfall is maximum (738.783ha-m) in the 12th fortnight, while it is minimum (168.085 ha-m) at 16th fortnight. Whole of the September month did not produce any effective rainfall. The ground water availability is increasing from 11th fortnight till 18th fortnight. At the starting fortnight, it is 113.698 ha-m, while at the end of 18th

fortnight, 220.017 ha-m of groundwater is available for utilization. Last two fortnights during the monsoon period don't have any recharge.

Decision support generated from this scenario suggests that the groundwater may be used to fulfill human water demand. This is according to water allocation policy formulated in the development of the DSS considering the water quality constraints. The animal water demand has been marked with supply source GW i.e. groundwater. This allocation is according to second frame of policy i.e. the animal water demand may be met from groundwater if surface water is not available.

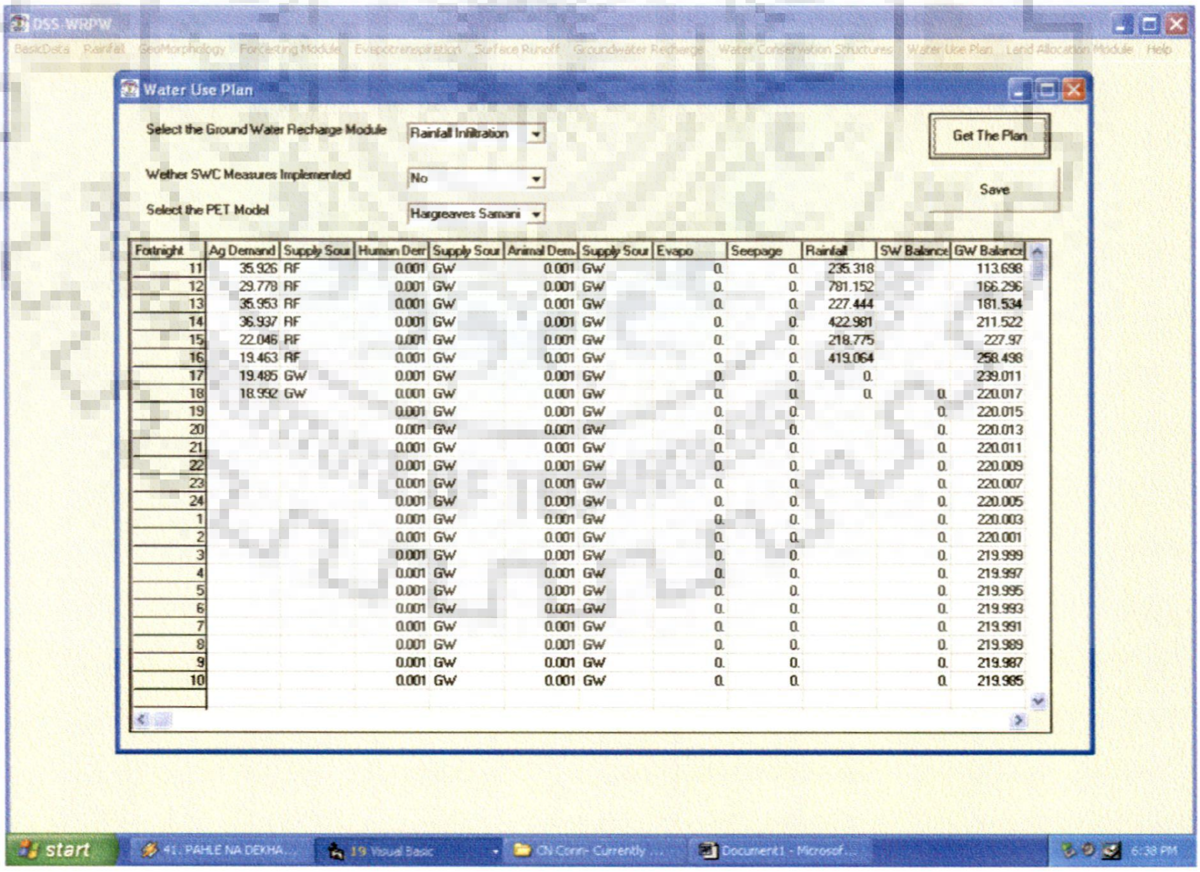
There is sufficient effective rainfall available in the watershed to meet out the water requirement of all crops during *kharif* season atleast in first six fortnights of monsoon. After balancing the demand and effective rainfall available, DSS has allocated the supply source rainfall (RF). In case of 17th and 18th fortnights there is neither effective rainfall available that can be used by crops nor surface water storage available to irrigate the crops. In such case, the policy suggests the demand may be balanced from the groundwater to save the crops from lengthy dry periods. Thus, the string GW is displayed against these demands (Fig. 8.23, Column 3, rows 7 & 8).

The considerable amount of groundwater is available in the Khadak Ohal at the end of May i.e. before the start of the next monsoon. At the end of May, this surplus groundwater is around 219.985 ha-m. This provides a scope to utilize the additional groundwater for other purposes such as growing crops in the *rabi* season.



Fortnight	Ag Demand	Supply Sour	Human Dem	Supply Sour	Animal Dem	Supply Sour	Evapo	Seepage	Rainfall	SW Balance	GW Balance
11	49.768	RF	0.001	GW	0.001	GW	0.	0.	195.929		121.958
12	40.009	RF	0.001	GW	0.001	GW	0.	0.	752.04		178.436
13	39.361	RF	0.001	GW	0.001	GW	0.	0.	218.033		199.804
14	34.828	RF	0.001	GW	0.001	GW	0.	0.	428.849		233.922
15	18.673	RF	0.001	GW	0.001	GW	0.	0.	235.206		255.29
16	16.321	RF	0.001	GW	0.001	GW	0.	0.	436.612		289.608
17	16.653	GW	0.001	GW	0.001	GW	0.	0.	0.		272.953
18	16.114	GW	0.001	GW	0.001	GW	0.	0.	0.	0.	256.837
19			0.001	GW	0.001	GW	0.	0.		0.	256.835
20			0.001	GW	0.001	GW	0.	0.		0.	256.833
21			0.001	GW	0.001	GW	0.	0.		0.	256.831
22			0.001	GW	0.001	GW	0.	0.		0.	256.829
23			0.001	GW	0.001	GW	0.	0.		0.	256.827
24			0.001	GW	0.001	GW	0.	0.		0.	256.825
1			0.001	GW	0.001	GW	0.	0.		0.	256.823
2			0.001	GW	0.001	GW	0.	0.		0.	256.821
3			0.001	GW	0.001	GW	0.	0.		0.	256.819
4			0.001	GW	0.001	GW	0.	0.		0.	256.817
5			0.001	GW	0.001	GW	0.	0.		0.	256.815
6			0.001	GW	0.001	GW	0.	0.		0.	256.813
7			0.001	GW	0.001	GW	0.	0.		0.	256.811
8			0.001	GW	0.001	GW	0.	0.		0.	256.809
9			0.001	GW	0.001	GW	0.	0.		0.	256.807
10			0.001	GW	0.001	GW	0.	0.		0.	256.805

Fig. 8.22 Water use plan scenario I (Case I)



Fortnight	Ag Demand	Supply Sour	Human Dem	Supply Sour	Animal Dem	Supply Sour	Evapo	Seepage	Rainfall	SW Balance	GW Balance
11	35.926	RF	0.001	GW	0.001	GW	0.	0.	235.318		113.698
12	29.778	RF	0.001	GW	0.001	GW	0.	0.	781.152		166.296
13	35.953	RF	0.001	GW	0.001	GW	0.	0.	227.444		181.534
14	36.937	RF	0.001	GW	0.001	GW	0.	0.	422.981		211.522
15	22.046	RF	0.001	GW	0.001	GW	0.	0.	218.775		227.97
16	19.463	RF	0.001	GW	0.001	GW	0.	0.	419.064		258.498
17	19.485	GW	0.001	GW	0.001	GW	0.	0.	0.		239.011
18	18.992	GW	0.001	GW	0.001	GW	0.	0.	0.	0.	220.017
19			0.001	GW	0.001	GW	0.	0.		0.	220.015
20			0.001	GW	0.001	GW	0.	0.		0.	220.013
21			0.001	GW	0.001	GW	0.	0.		0.	220.011
22			0.001	GW	0.001	GW	0.	0.		0.	220.009
23			0.001	GW	0.001	GW	0.	0.		0.	220.007
24			0.001	GW	0.001	GW	0.	0.		0.	220.005
1			0.001	GW	0.001	GW	0.	0.		0.	220.003
2			0.001	GW	0.001	GW	0.	0.		0.	220.001
3			0.001	GW	0.001	GW	0.	0.		0.	219.999
4			0.001	GW	0.001	GW	0.	0.		0.	219.997
5			0.001	GW	0.001	GW	0.	0.		0.	219.995
6			0.001	GW	0.001	GW	0.	0.		0.	219.993
7			0.001	GW	0.001	GW	0.	0.		0.	219.991
8			0.001	GW	0.001	GW	0.	0.		0.	219.989
9			0.001	GW	0.001	GW	0.	0.		0.	219.987
10			0.001	GW	0.001	GW	0.	0.		0.	219.985

Fig. 8.23 Water use plan scenario II (Case I)

8.2.8.3 Scenario III (Case I)

As seen in Fig. 8.21, this scenario is the combination of operation of Rainfall Infiltration module and Penman-Monteith module. User is supposed to use Rainfall Infiltration module to get the groundwater resources in the watershed. The ET must be estimated by the Penman-Monteith module.

As shown in Fig. 8.24, the annual human and animal water demand has been distributed equally in 24 fortnight periods. The human and animal water demand in each fortnight works out to be 0.001 ha-m for each demand period, as described earlier.

The agricultural demand as estimated in the Crop Water Requirement module is called here to display it fortnightly. Present cropping pattern in the Khadak Ohal watershed is rainfed, hence no water demand is displayed after the eighth row in the GUI of module. Agricultural water demand in the case of real physical system in the year 2002 varies from 16.114 ha-m to 49.768 ha-m. Maximum water demand is found in the first fortnight of June, minimum is found in the last fortnight of September.

The effective rainfall that can be utilized by crops is shown in the first six rows. Maximum rainfall (752.04 ha-m) is available from the second fortnight of June. The minimum rainfall was observed in the first fortnight of June, which is 195.919 ha-m. The ground water availability is increasing from 11th fortnight till 18th fortnight. At the starting fortnight groundwater availability is 113.698 ha-m, while at the end of 18th fortnight, 225.727 ha-m of groundwater is available for utilization. Last two fortnights during the monsoon period don't have any recharge.

As per allocation policy formulated (Section 5.11.3), the DSS suggests that all the human and animal water demand can be met out through the groundwater. As there is no surface water available for storage in the watershed, there will be no seepage and evaporation losses in absence of surface water storage. The agricultural water demand in the first six fortnights can be fulfilled from available rainfall. Thus, DSS has shown RF in the supply source against these demands. There is considerable agricultural water demand in the month of September, when there is no rainfall. In paucity of any surface water availability, DSS has allocated this demand to groundwater. The string GW is displayed against the supply source in these time periods. After fulfilling all the demand, there is still availability of considerable amount of groundwater (225.695 ha-m).

8.2.8.4 Scenario IV (Case I)

The combination of two choices available each for the estimation of groundwater and evapotranspiration, there are four maximum possible scenarios; which could be generated from the DSS. This is the last scenario that could be generated, with the combination of Water Table Fluctuation and Hargreaves-Samani module. The scenario generated is shown in Fig. 8.25. User is expected to work out the agricultural water demand using the Hargreaves–Samani module of ET estimation. The effective rainfall will be computed using the fortnightly rainfall and ET.

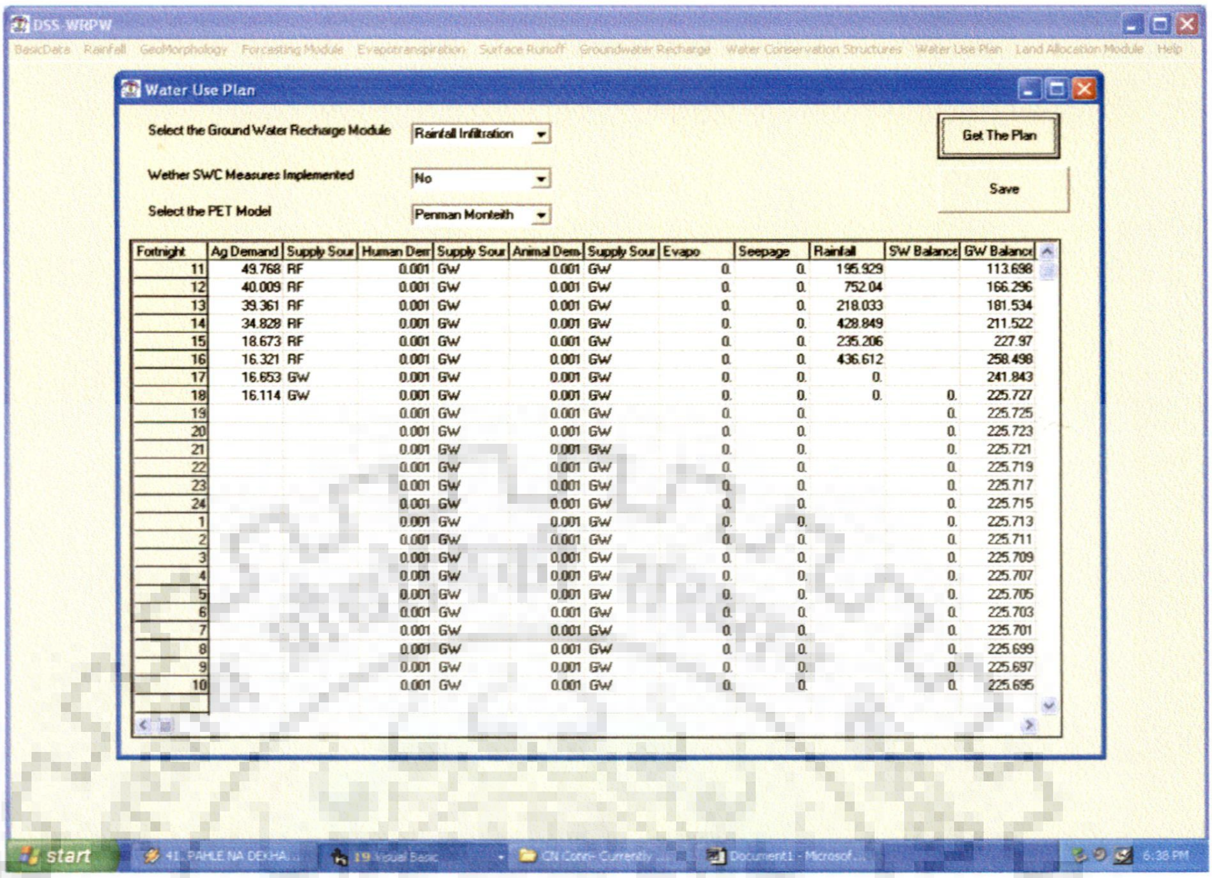
As human, animal population and their water demands are constant in this scenario, there is no change in fortnightly water demand in these two sectors. The GUI of module (Fig. 8.25) shows 0.001 ha-m in both the case in every fortnight period.

Agricultural water demand computed using the ET estimated Hargreaves-Samani is different than that of earlier scenario. This is because of the difference in the ET estimated by two methods. The maximum value of agricultural water demand (36.937 ha-m) is found at 14^{th} fortnight, while minimum value (18.992 ha-m) is found at 18^{th} fortnight.

In the water availability side the effective rainfall is maximum (738.783ha-m) in the 12^{th} fortnight, while it is minimum (168.085 ha-m) at 16^{th} fortnight. Whole of the September month did not produce any effective rainfall.

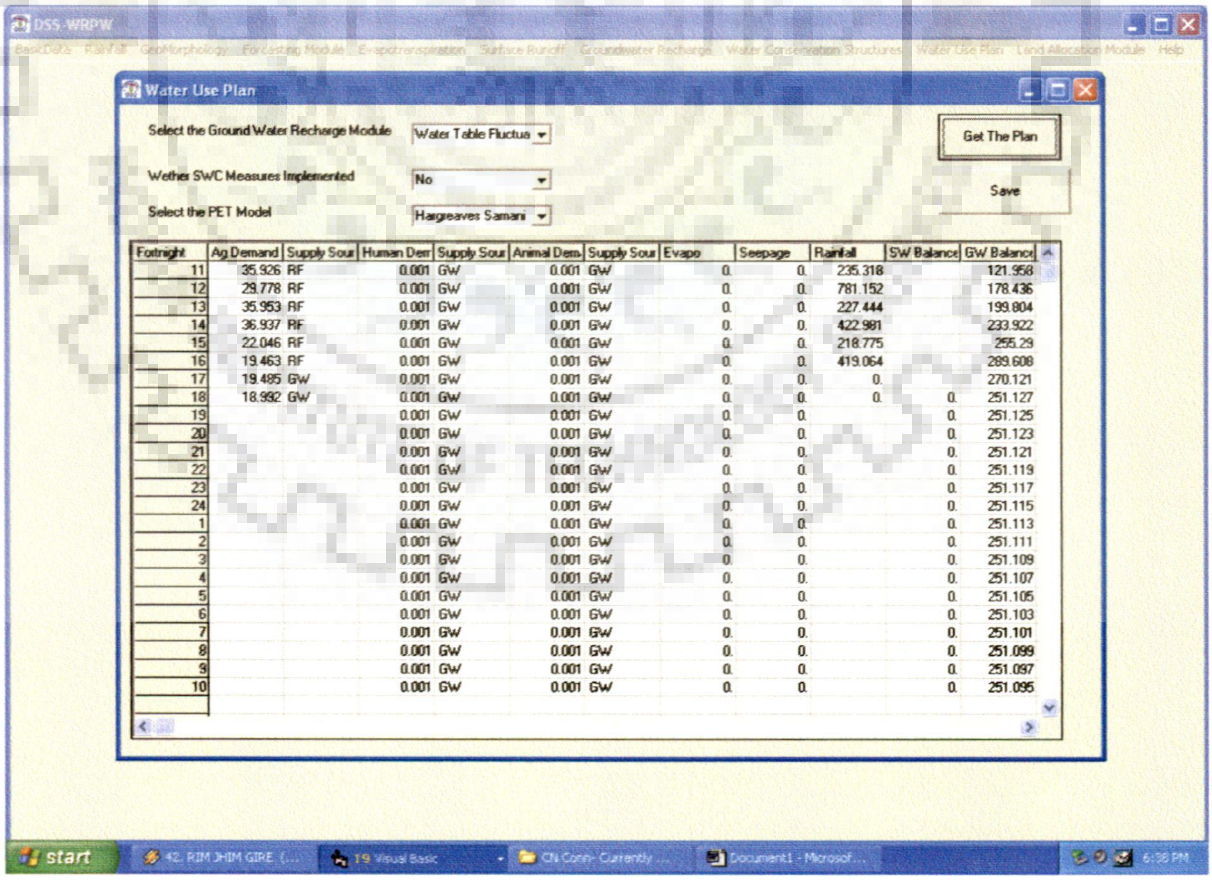
The groundwater resource in watershed can be seen increasing throughout the first six fortnights i.e. monsoon period. The incremental recharge from each fortnight is added to next row after fulfilling demand in the respective time interval. There is no recharge in the month of September due to proportional distribution of recharge. The available groundwater at the end of 18^{th} fortnight is 251.127 ha-m.

DSS suggests that all the human and animal water demand can be met out from the groundwater. As there is no surface water available for storage in the watershed, the seepage and evaporation losses shows zero values. The agricultural water demand in the first six fortnights can be fulfilled from available rainfall. Thus, DSS has shown RF in the supply source against these demands. There is considerable agricultural water demand in the month of September, in which there is no rainfall. In absence of any surface water availability, DSS has allocated this demand to groundwater. The string GW is written against the supply source in these time periods. The 251.095 ha-m of groundwater will be additional water available to utilize for additional demand generated if farmers in the watershed go for second crop in the year.



Fortnight	Ag Demand	Supply Sour	Human Dem	Supply Sour	Animal Dem	Supply Sour	Evapo	Seepage	Rainfall	SW Balance	GW Balance
11	49.768	RF	0.001	GW	0.001	GW	0.	0.	195.929		113.698
12	40.009	RF	0.001	GW	0.001	GW	0.	0.	752.04		166.296
13	39.361	RF	0.001	GW	0.001	GW	0.	0.	218.033		181.534
14	34.828	RF	0.001	GW	0.001	GW	0.	0.	428.849		211.522
15	18.673	RF	0.001	GW	0.001	GW	0.	0.	235.206		227.97
16	16.321	RF	0.001	GW	0.001	GW	0.	0.	436.612		258.498
17	16.653	GW	0.001	GW	0.001	GW	0.	0.	0.		241.843
18	16.114	GW	0.001	GW	0.001	GW	0.	0.	0.	0.	225.727
19			0.001	GW	0.001	GW	0.	0.		0.	225.725
20			0.001	GW	0.001	GW	0.	0.		0.	225.723
21			0.001	GW	0.001	GW	0.	0.		0.	225.721
22			0.001	GW	0.001	GW	0.	0.		0.	225.719
23			0.001	GW	0.001	GW	0.	0.		0.	225.717
24			0.001	GW	0.001	GW	0.	0.		0.	225.715
1			0.001	GW	0.001	GW	0.	0.		0.	225.713
2			0.001	GW	0.001	GW	0.	0.		0.	225.711
3			0.001	GW	0.001	GW	0.	0.		0.	225.709
4			0.001	GW	0.001	GW	0.	0.		0.	225.707
5			0.001	GW	0.001	GW	0.	0.		0.	225.705
6			0.001	GW	0.001	GW	0.	0.		0.	225.703
7			0.001	GW	0.001	GW	0.	0.		0.	225.701
8			0.001	GW	0.001	GW	0.	0.		0.	225.699
9			0.001	GW	0.001	GW	0.	0.		0.	225.697
10			0.001	GW	0.001	GW	0.	0.		0.	225.695

Fig. 8.24 Water use plan scenario III (Case I)



Fortnight	Ag Demand	Supply Sour	Human Dem	Supply Sour	Animal Dem	Supply Sour	Evapo	Seepage	Rainfall	SW Balance	GW Balance
11	35.926	RF	0.001	GW	0.001	GW	0.	0.	235.318		121.958
12	29.778	RF	0.001	GW	0.001	GW	0.	0.	781.152		178.436
13	35.953	RF	0.001	GW	0.001	GW	0.	0.	227.444		199.804
14	36.937	RF	0.001	GW	0.001	GW	0.	0.	422.981		233.922
15	22.046	RF	0.001	GW	0.001	GW	0.	0.	218.775		255.29
16	19.463	RF	0.001	GW	0.001	GW	0.	0.	419.064		289.608
17	19.485	GW	0.001	GW	0.001	GW	0.	0.	0.		270.121
18	18.992	GW	0.001	GW	0.001	GW	0.	0.	0.	0.	251.127
19			0.001	GW	0.001	GW	0.	0.		0.	251.125
20			0.001	GW	0.001	GW	0.	0.		0.	251.123
21			0.001	GW	0.001	GW	0.	0.		0.	251.121
22			0.001	GW	0.001	GW	0.	0.		0.	251.119
23			0.001	GW	0.001	GW	0.	0.		0.	251.117
24			0.001	GW	0.001	GW	0.	0.		0.	251.115
1			0.001	GW	0.001	GW	0.	0.		0.	251.113
2			0.001	GW	0.001	GW	0.	0.		0.	251.111
3			0.001	GW	0.001	GW	0.	0.		0.	251.109
4			0.001	GW	0.001	GW	0.	0.		0.	251.107
5			0.001	GW	0.001	GW	0.	0.		0.	251.105
6			0.001	GW	0.001	GW	0.	0.		0.	251.103
7			0.001	GW	0.001	GW	0.	0.		0.	251.101
8			0.001	GW	0.001	GW	0.	0.		0.	251.099
9			0.001	GW	0.001	GW	0.	0.		0.	251.097
10			0.001	GW	0.001	GW	0.	0.		0.	251.095

Fig. 8.25 Water use plan scenario IV (Case I)

8.2.9 Summary of Decision Scenarios

The DSS have been demonstrated in the first test case i.e. real physical system of the watershed, in which the existing conditions of year 2002-03 were taken into consideration. Four scenarios that would be available to the decision makers have been described in details in the previous section.

The inputs, (various model outputs) required to generate these scenarios have been authenticated, therefore the scenarios generated can be considered as more realistic. A scenario that will give maximum available water from groundwater after fulfilling all demands can be considered the most preferential scenario. All four scenarios that could be generated from the DSS have been summarized in Table 8.11. The scenario I (Penman-Monteith and Water Table Fluctuation Modules) which would result a balance of 256.805 ha-m of water after fulfilling all demands can be considered the most preferred scenario. The scenario II (combination of Hargreaves-Samani and Rainfall Infiltration Modules) would result in water balance of 219.985 ha-m which may be considered as the least preferred scenario. This would be helpful to decision makers to choose the combination of modules, while using the DSS in watershed planning process.

Table 8.11 Summary of all scenarios in test case I

Scenario	Groundwater available after allocation (ha-m)	Preference
I	256.805	I
II	219.985	IV
III	225.695	III
IV	251.095	II

8.3 Test Case II

The developed DSS has been run with another set of data to generate the future scenario. This comprises of a system which would provide results for the year 2011-12. The data input consists of 75% probable rainfall taken from the nearby place (Dahanu, Dist Thane, Maharashtra, Latitude 19.58^0 and Longitude 72.43^0) to the watershed. The climatic conditions are assumed to be average conditions. The demands have been estimated for the forecasted population.

The landuse in the watershed is kept unchanged, but the agricultural cropping pattern is optimized pattern depending upon the needs of population. The rest of the physiographic conditions are assumed to be constant throughout the period of simulation. The following discussions provide the findings generated by DSS for different models which are essential to run the developed DSS. The basic data module and the geomorphology module will be same for this test case as given for earlier case.

8.3.1 Rainfall Module

The analysis of rainfall data has been given much importance since the beginning of hydrologic science. Its analysis helps in planning of irrigation, storage and other activities such as agriculture. Ray et al., (1980) suggested that rainfall at 80% probability of exceedence be taken as minimum assured values, while 70% value was considered by Subudhi et al., (1996). Mathur et al., 1997 used rainfall at 75% probability for irrigation planning.

In the present study, 75% probability of exceedence was considered. The 75% probable daily rainfall with date and month is loaded in the *MSFlexGrid* (Fig. 8.26). This daily rainfall is totaled fortnightly to compute the effective rainfall during each fortnight. Table 8.12 gives the fortnightly rainfall from June to October. Total annual rainfall in this case is expected to be 1940.5 mm, out of which 1920.3 mm would fall during the June to September. There will be 98 events having rainfall more than 5mm per day. The average daily rainfall could be forecasted as 19.80 mm.

Table 8.12. Expected fortnightly rainfall in Khadak Ohal watershed in 2011.

Month	Fortnight	Rainfall, mm
June	I	296.3
	II	425.2
July	I	248.6
	II	452.0
August	I	204.1
	II	145.2
September	I	101.6
	II	47.3

8.3.2 Forecasting Module

The human population in Khadak Ohal watershed was 3637 in year 1981, which later increased to 5844 in year 2001. There were 1360 cows/bullocks, 870 sheep/goats and 105 buffalos in the year 1981. These data have been used to forecast the human and population for the year 2011. As seen from the screen shot of the module (Fig. 8.27), the population growth rate is estimated to be 0.02 %. This computed growth rate is based on the human population records of 1981 and 2001

For year 2011, the human population forecast come out to be 7405, while with same growth as of human population, animal forecast are as; (i) cows/bullocks 2770 (ii) sheep/goats 1772 and (iii) 214 buffalos. In the year of forecast, all the human and animals are expected to need 554800 lit of water and 1718656 kg of food grains. These requirements for the year 2011 can be seen in Fig. 8.27. The food requirement has been used in the need based optimal land allocation module, which is further used in computing the agricultural water requirement in the evapotranspiration module.

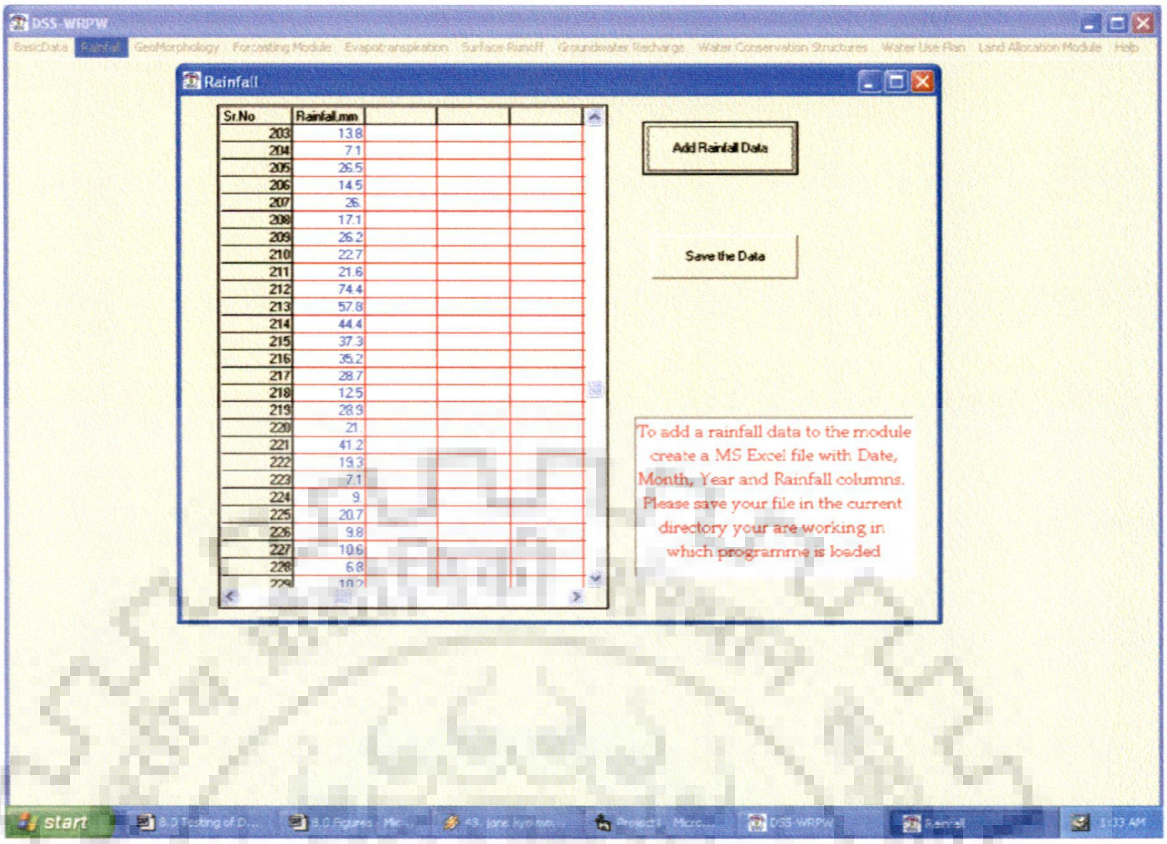


Fig. 8.26 Rainfall module in forecast condition

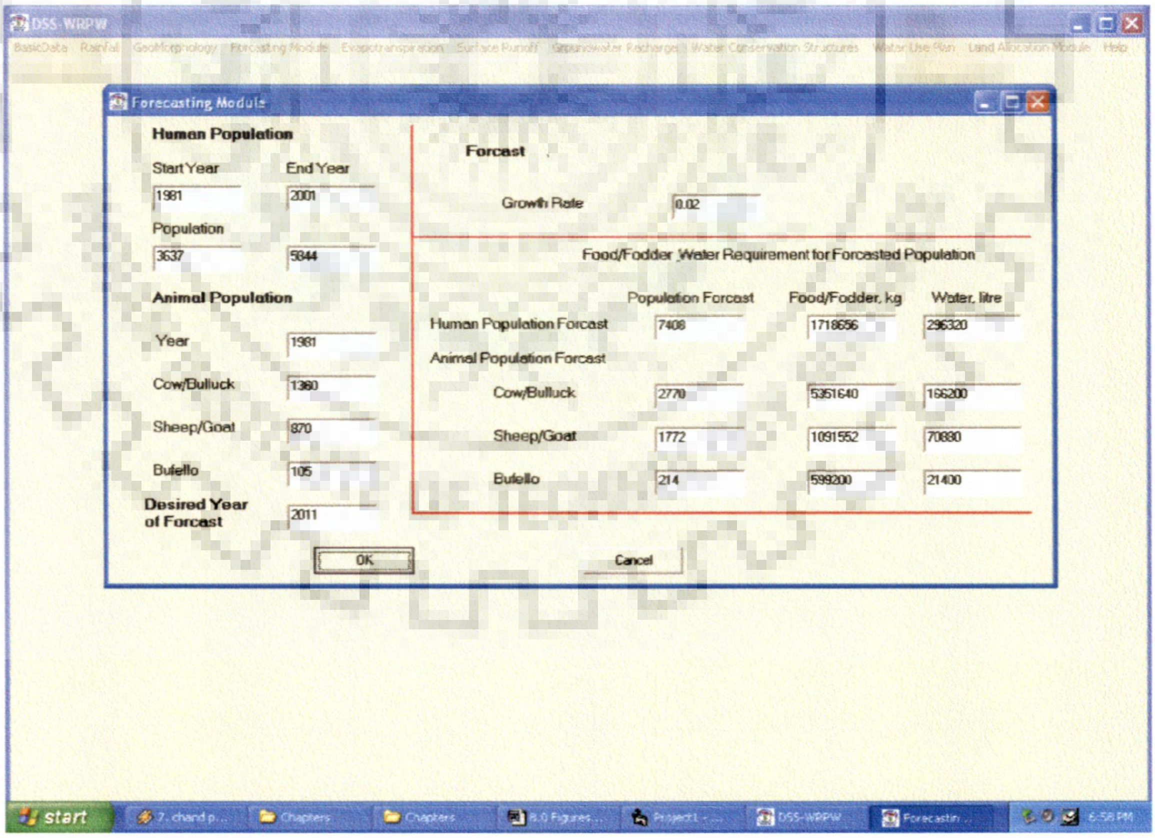


Fig. 8.27 Population and resources forecast in the year 2011

8.3.3 Land Allocation Module

The land allocation modules are designed and developed in DSS for the allocation of cropping land among different crops based on the food requirement of habitants. Two different sub-modules have been programmed in the DSS, each for *Kharif* and *Rabi* season. *Kharif* season in India is from June to September, while *Rabi* season is from October to March. User has to give the current levels of productivity of the crops as input to these modules. The standard dietary needs (Section 5.10.1) of people and productivity values of different crops have been used to get the optimized land allocations under different crops.

8.3.3.1 *Kharif* Season

This sub-module solves the linear optimization problem as formulated in Section 5.12.1 by simplex method. User has to give input of different crops and their productivity. The formulated optimization problem by simplex table is displayed in the upper portion of *MSFlexGrid* (Fig. 8.28). The upper limit for the total land allocation has been taken as existing cropping area in the watershed. This means that the overall land use pattern in the watershed will not change with the time. The Khadak Ohal watershed has an area of 380 ha under different crops. The constraints for the each crop have been decided from the food requirement under types of crop i.e. cereals, oilseeds, etc. The optimized solution thus obtained from the solution is shown in the *MSFlexGrid* (Fig. 8.28). The sub-module does six iterations to arrive at the optimized solution. The message "Optimal Solution Achieved" is popped up to the screen. The land allocation under different crops has been summarized in Table 8.13.

The DSS gives 27.27 ha area to the paddy crop, while 117.00 ha to the red gram. The groundnut may be grown on 75.24 ha area, likewise to other crops. These allocated areas of crops have further been used in the computation of crop water requirement. Allocation as shown in Table 8.13 shows a total of 338.71 ha under different crops. The remaining area out of 380 ha has been kept under vegetable crops, which is not considered in the computation of water requirement due to complexity involved in selecting vegetable types. The project authorities have supplied the anticipated productivity values which are considered in the present study.

8.3.3.2 *Rabi* Season

This is second sub-module in the land allocation module, which determines optimal land allocation for *Rabi* season. The same constraints of maximum cropping area and food grain requirements have been used in this sub-module. An additional constraint of irrigation requirement has been introduced in this sub module. However the maximum limit for total area constraint has been fixed at 80% of total cropping area in the watershed, which is 300 ha for the Khadak Ohal watershed. The details of optimization problem thus formulated have been given in Section 5.12.1. The sub-modules solves this linear optimization problem using simplex method. User has to provide the name of crops and their anticipated productivity values as input. The crops taken here are few representative crops in the particular group, which are suitable to be grown in the Khadak Ohal watershed. The simplex table formulated for this condition is displayed in the top most portion of *MSFlexGrid.* While running this sub-module, eleven iterations are required to solve the problem. The finally optimized solution is displayed in the *MSFlexGrid* (Fig. 8.29)

The DSS gives 154.78 ha area to wheat, 40.3 ha area to gram and 75.24 ha area to *Rabi* groundnut. Remaining area has been allocated to the vegetables, maize and sunflower. This allocation alongwith the productivity of crops has been given in Table 8.13. Out of these, the wheat, gram and *Rabi* groundnut have been used for further computation of crop water requirements.

Table 8.13 Optimized land allocation under different crops

Crop	Anticipated Productivity (kg/ha)	Optimal Area (ha)
Kharif Season		
Paddy(x1)	1100	27.27
Finger Millet(x2)	400	31.53
Common Millet(x3)	350	33.16
Red Gram(x4)	500	117.00
Black Gram(x5)	350	4.28
Horse Gram(x6)	250	50.23
Groundnut(x7)	450	75.24
	Total Area (*Kharif* Season)	338.71
Rabi Season		
Wheat (x9)	1200	154.78
Gram (x10)	600	40.30
Rabi Groundnut (x13)	450	75.24
	Total Area (*Rabi* Season)	270.32

8.3.4 Evapotranspiration Module

The DSS developed provides two options to user for estimation of PET. The Penman-Monteith sub-module may be used in case user has detailed climatological data available. Another sub-module i.e. Hargreaves-Samani may be used in case of non-availability of detailed climatological data.

8.3.4.1 Penman-Monteith Sub-module

The total annual PET by Penman-Monteith method during forecast period is found to be 1303.4 mm, with average daily PET for the same period 3.57 mm/ day. The maximum is expected on 26th April, which is 6.65 mm/day, while minimum of 2.01 mm/day is on 12th December. Table 8.14 gives the fortnightly values of PET for selected watershed. This sub-module in the run mode for this case has been shown in Fig. 8.30.

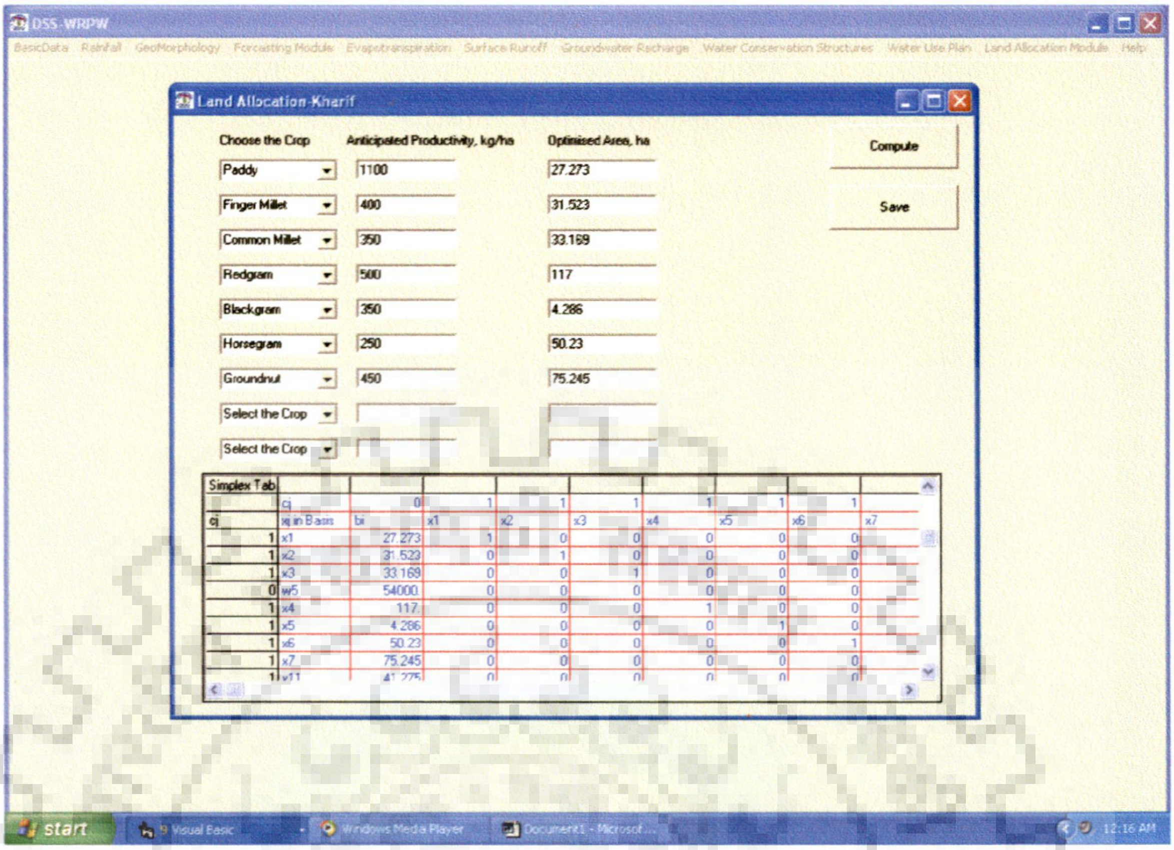


Fig. 8.28 Land allocation *Kharif*

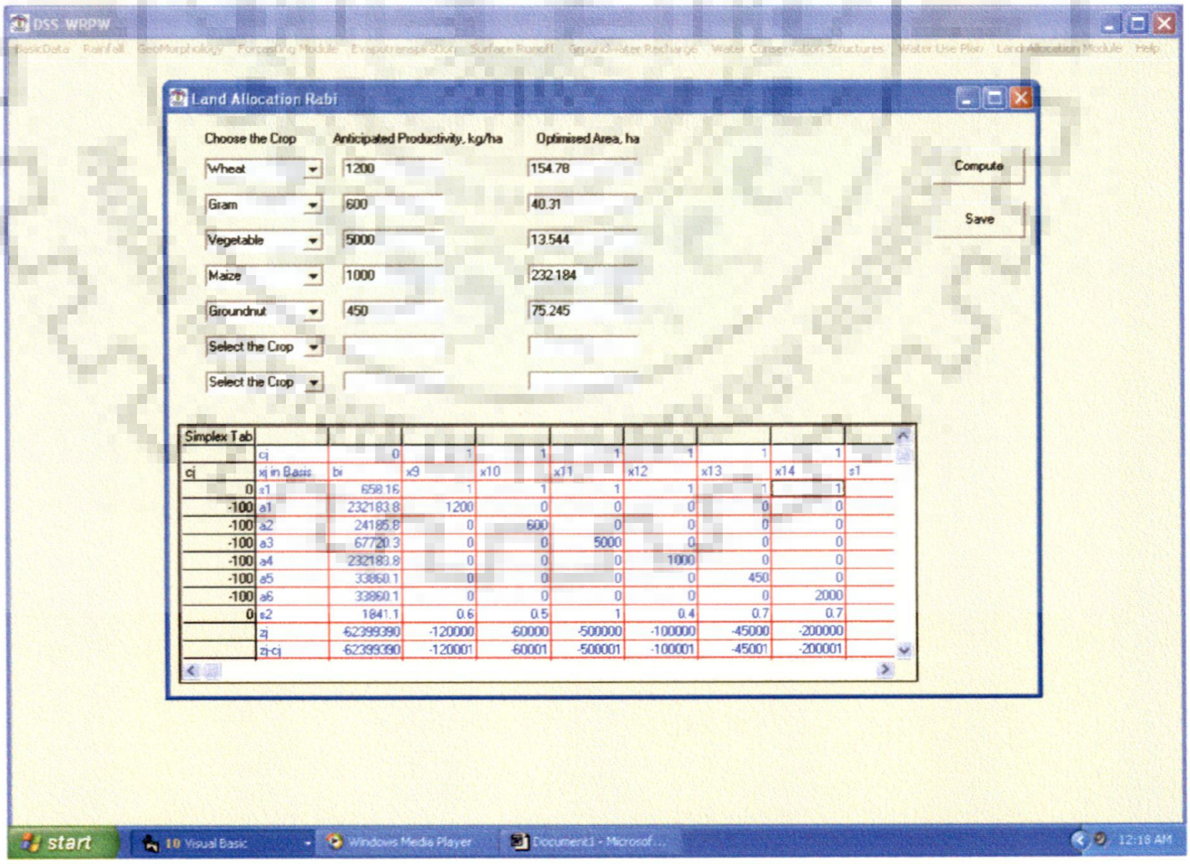


Fig. 8.29 Land allocation *Rabi*

8.3.4.2 Hargreaves –Samani Sub-module

Figure 8.31 shows the Hargreaves–Samani sub-module within the run mode with average climatic condition data display. The sub-module estimates the total annual PET of 1624.888 mm. The daily average PET for the considered year of 2011 is 4.451 mm mm/day. The maximum and minimum daily PET are forecasted on 19th December (6.537 mm) and 20th May (3.180 mm) respectively. The fortnightly values of the PET estimated by this method have been given in Table 8.14. The method is giving slight over- estimate in the PET as compared to the Penman-Monteith method, which may be because of the use of few parameters temperature, solar radiation and difference between minimum and maximum temperatures.

8.3.4.3 Crop Water Requirement Sub-module

Optimal cropping pattern for forecasted conditions have been taken in consideration for computing the crop water requirement (CWR) or agricultural demand. In the Khadak Ohal watershed, 27.27 ha area would be needed to grow paddy, 31.53 ha under finger millet, 33.16 ha under common millet, 117 ha under red gram, 4.28 ha under black gram, 50.23 ha under horse gram. In the oil seeds, it would need groundnut on 75.24 ha area. All these crops are to be grown during the monsoon or *Kharif* season. In the *Rabi* season, if irrigation facilities are introduced in near future, watershed need to grow wheat on 154.78 ha area, gram on 40.3 ha and *Rabi* groundnut on 75.24 ha.

The crop water requirement estimation by using the Penman-Monteith method is shown in Fig. 8.32, while Fig. 8.33 gives its values by using alternative method i.e. Hargreaves Samani method. These fortnightly values of irrigation water requirement (IWR) in ha-m have been given in Table 8.14. From this table, it may be seen that DSS generated irrigation water requirement values for both of the model operational scenarios i.e. using Penman-Monteith method and Hargreaves-Samani method have some difference in the estimates of irrigation water requirement. This difference is principally because of the difference in the PET values used in the two methods.

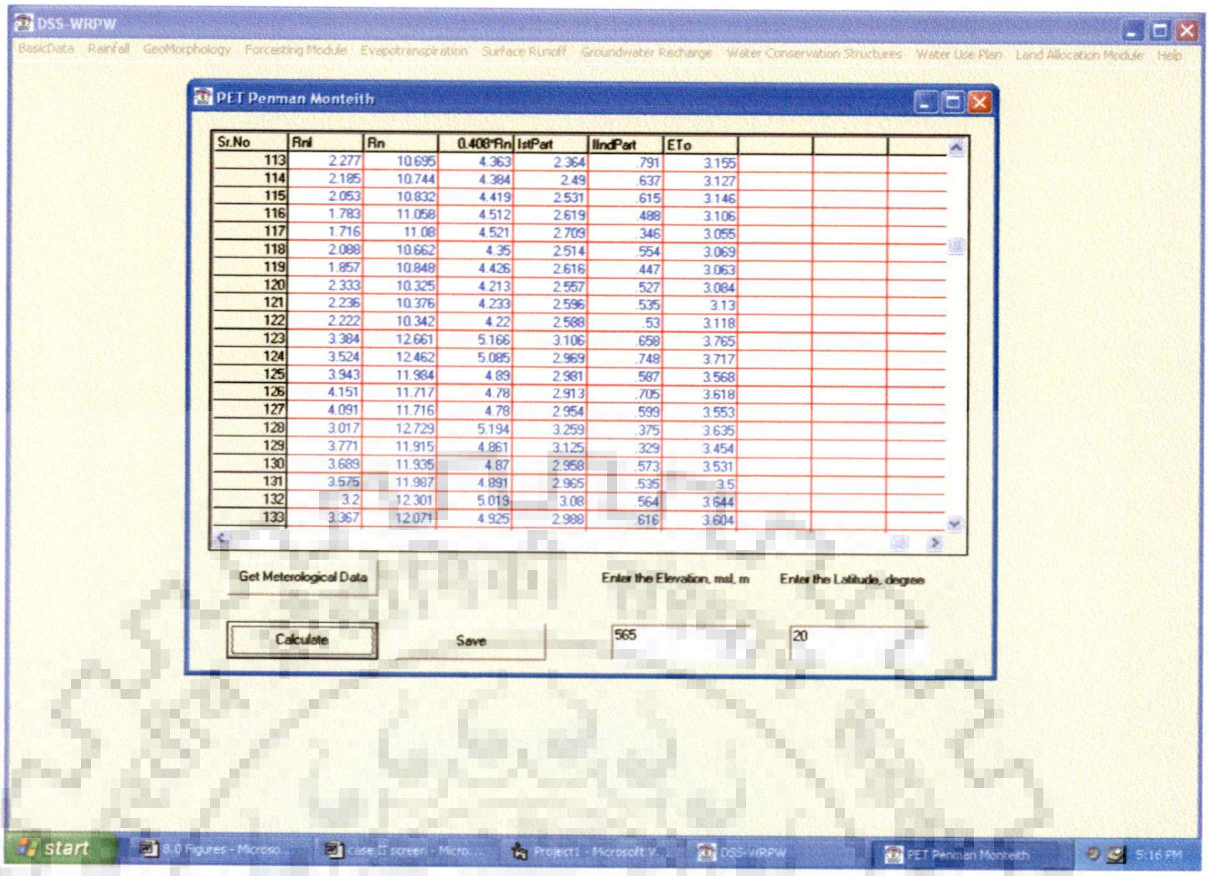


Fig. 8.30 PET estimation by Penman-Monteith sub-module

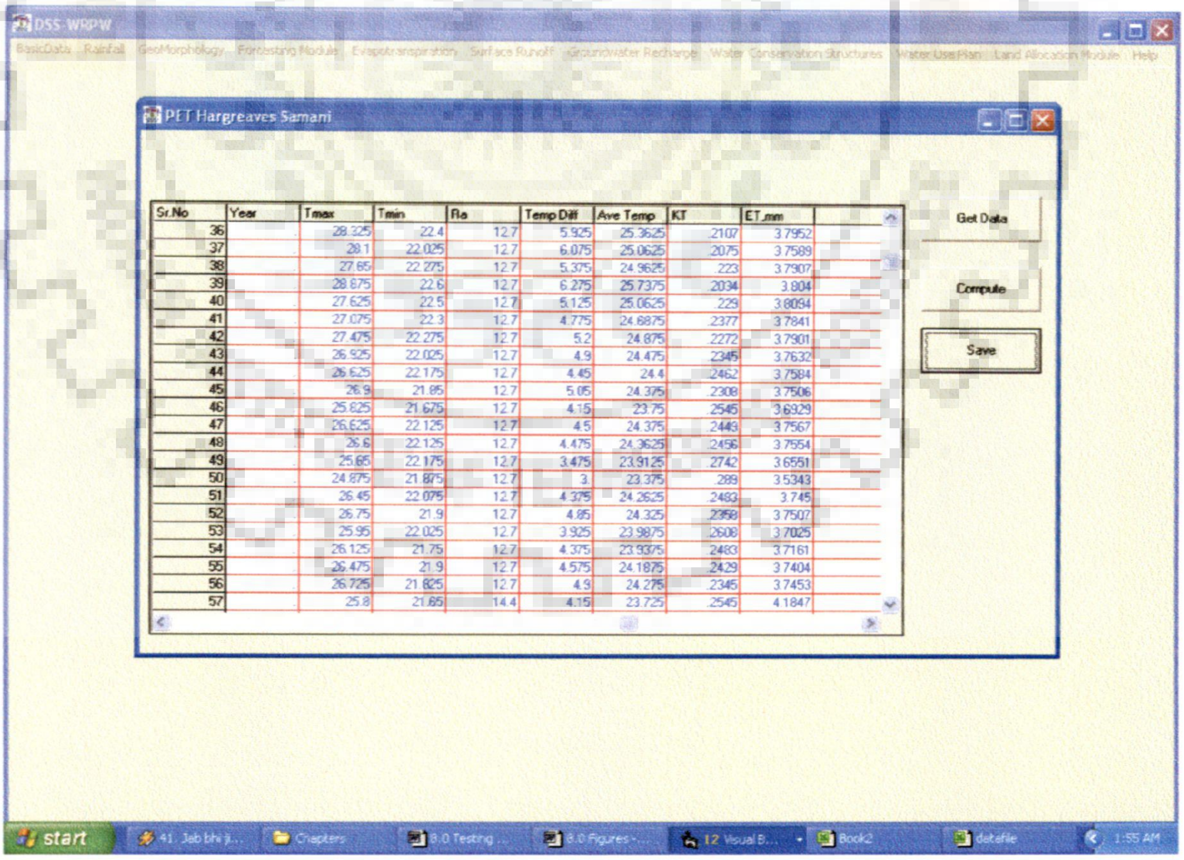


Fig. 8.31 PET estimation by Hargreaves-Samani sub-module

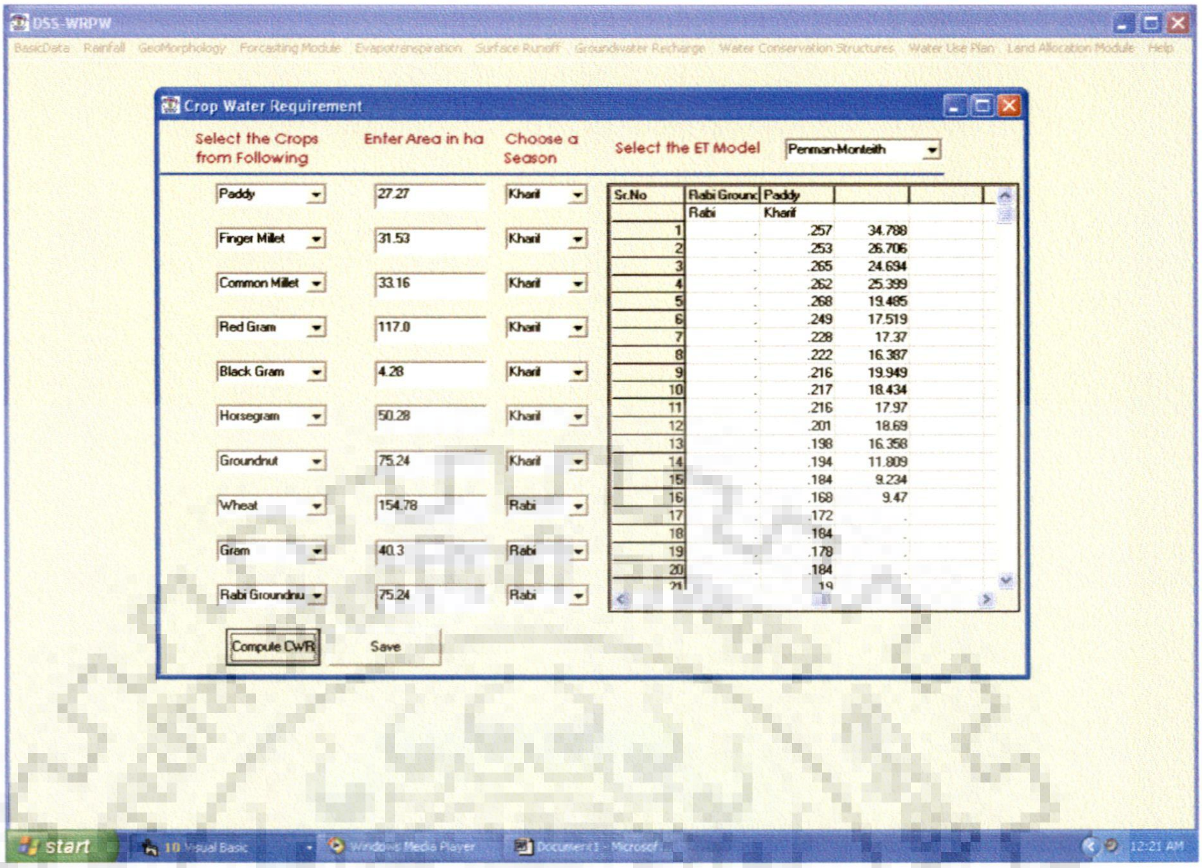


Fig. 8.32 CWR estimation by Penman-Monteith method

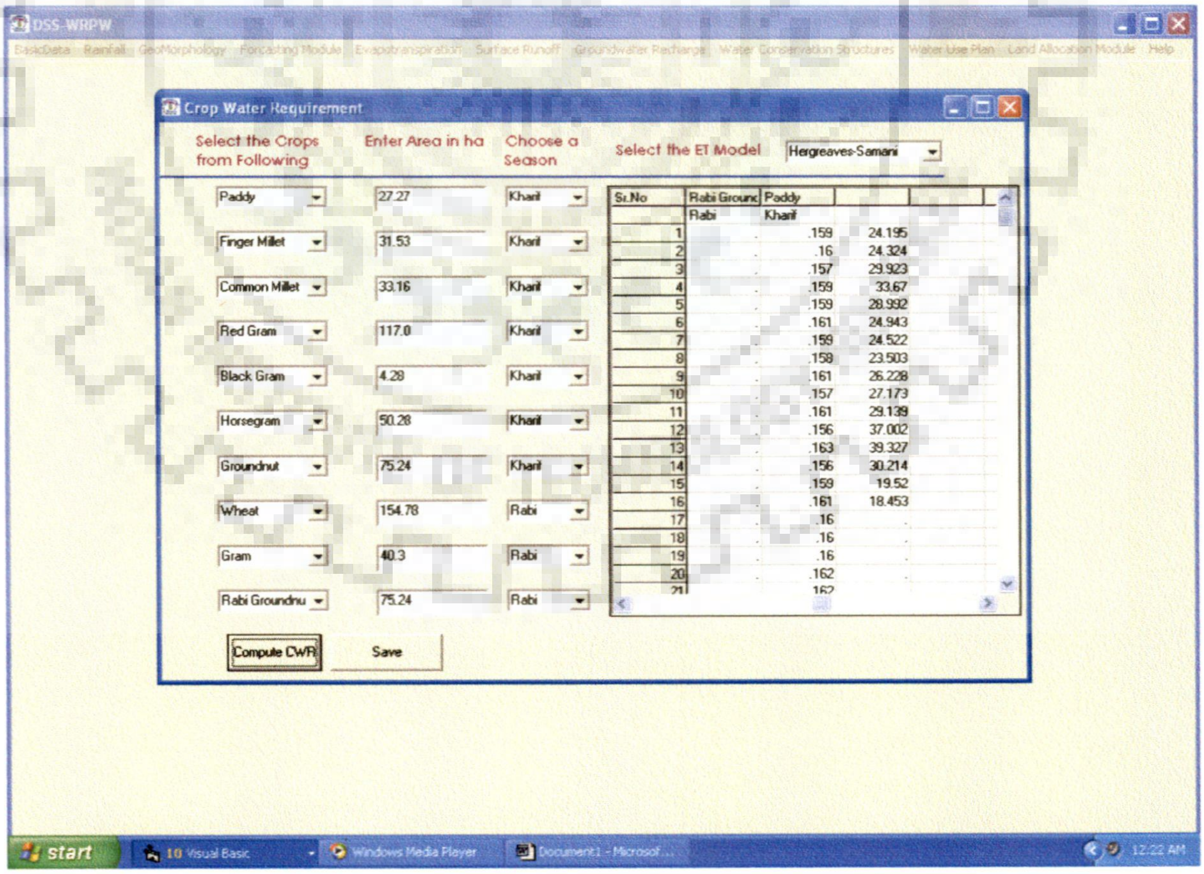


Fig. 8.33 CWR estimation by Hargreaves-Samani method

Table 8.14 Evapotranspiration and irrigation water requirement of all crops.

Month	Fortnight	Penman-Monteith		Hargreaves-Samani	
		PET (mm)	IWR (ha-m)	PET (mm)	IWR (ha-m)
June	I	71.843	34.789	49.964	24.195
	II	55.151	26.706	50.231	24.324
July	I	46.937	24.694	56.731	29.923
	II	43.471	25.399	57.696	33.67
August	I	41.293	19.485	61.441	28.992
	II	44.345	17.519	63.234	24.943
September	I	47.384	17.37	66.893	24.522
	II	46.375	16.387	66.670	23.503
October	I	45.837	19.949	69.386	26.228
	II	49.835	18.434	71.885	27.173
November	I	44.55	17.969	71.189	29.139
	II	38.711	18.689	75.322	37.002
December	I	36.462	16.358	87.656	39.327
	II	34.434	11.809	86.418	30.214
January	I	35.649	9.234	76.580	19.52
	II	13.819	9.469	76.631	18.453
February	I	45.057	-	74.663	-
	II	51.329	-	66.325	-
March	I	59.867	-	71.232	-
	II	68.096	-	76.692	-
April	I	76.767	-	63.113	-
	II	88.632	-	61.333	-
May	I	94.077	-	58.570	-
	II	125.348	-	61.549	-

8.3.5 Runoff Module

Both the modules (NRCS CN and CELTHYM) available in DSS for runoff estimation have been used in this test case. The same spatial data as used in earlier case have been used as input to the modules. The rainfall values at 75% probability of exceedence have been used, while PET values estimated by the average data are taken into consideration. The runoff values thus received after running these modules have been used in the computation of water harvesting potential.

8. 3.5.1 NRCS CN Interface

As applied in the Test Case I i.e. the real physical system, the interface based on the NRCS CN methodology (often called NRCS CN module) has performed at satisfactory level. The NRCS CN interface was run second time after changing the input rainfall data. It has been assumed that the land use pattern would not change during the forecast period, hence same GIS data or shape file as described in Table 8.6 has been used as input in the map layer of the module.

8. 3.5.1.1 Parameter Estimation

The sub-module named *NRCS CN* interface calls the required shape file to the GUI. Once a file is loaded in the map layer, user has to send all the attributes to the *MSFLexGrid* to compute the lumped CN value. For Khadak Ohal watershed, the input shape file can be seen in the screen shot of the module in the run mode (Fig. 8.11). The CN values at AMC II condition are assigned in the third column of *MSFLexGrid* by running the codes written to implement this sub routine. This event is loaded with click on the button *Compute*. The CN vales for Khadak Ohal watershed ranged from 61 to 91 for the AMC II condition, while the lumped value of CN at this AMC is 68 (Text box in Fig. 8.11).

8. 3.5.1.2 Runoff Computation

The lumped value of CN at AMC II is exported to next module in the same module of DSS with the click on the button *Contd.* Figure 8.34 gives the picture of runoff computation interface in the running mode. The rainfall data at 75% probability of exceedence is called to the *MSFLexGrid* in this sub-module. The AMC condition is assigned for each day by computing the 5-day preceeding rainfall. The Khadak Ohal watershed has most of the AMC III conditions during the peak monsoon period. The lumped value of 68 of CN at AMC II is converted to 83 in AMC III and 47 in AMC I. The last column in the *MSFLexGrid* in Fig. 8.34 gives the runoff produced from the rainfall of each day (in rows). The total runoff is computed and placed in the text box (at top of Fig. 8.34). The year 2011 may produce 283.544 mm of runoff out of 1940.5 mm rainfall from the Khadak Ohal watershed.

8. 3.5.2 CELTHYM Interface

In Test Case I, it was found that the performance of CELTHYM is good in those rainfall events, which are considerably high. The basic data required for CELTHYM interface include shape file describing the land use, soil database in the grid format besides rainfall and evapotranspiration data. The same shape file, as described in Table 8.7, has been used for running of the module for forecasted year. The same rainfall and climatological data as used in the earlier module, has been called as input.

8. 3.5.2.1 Data Input

The CETHYM interface provides a facility to open shape file through Windows common dialogue control, which displays the required GIS data in the *MapLayer*. As shown in Fig. 8.14, user has to open the file and sort out the attributes of the displayed GIS file to send to the parameter generation module. The test box below the open control in the GUI gives the number of data grids present in the spatial data. There are 1726 grids of 100 m X 100 m in Khadak Ohal watershed. Click on the control button, *Compute Runoff* lead to open another sub-module in the CELTHYM interface, which displays the input parameters required to simulate the runoff.

8. 3.5.2.3 Runoff Computation

For the monsoon period of year 2011, the CELTHYM model would yield the total runoff of 55.737 mm from a total rainfall of 1940.5 mm. This is around 2% of total rainfall; whereas NRCS CN interface estimated around 15% runoff from the Khadak Ohal watershed. The reasonable difference in the estimates of runoff between two methods is because of the inherited difference in the concept of two modules. This is due to some rainfall events, which although has relative small rainfall, has not been considered in CELTHYM after soil moisture balancing.

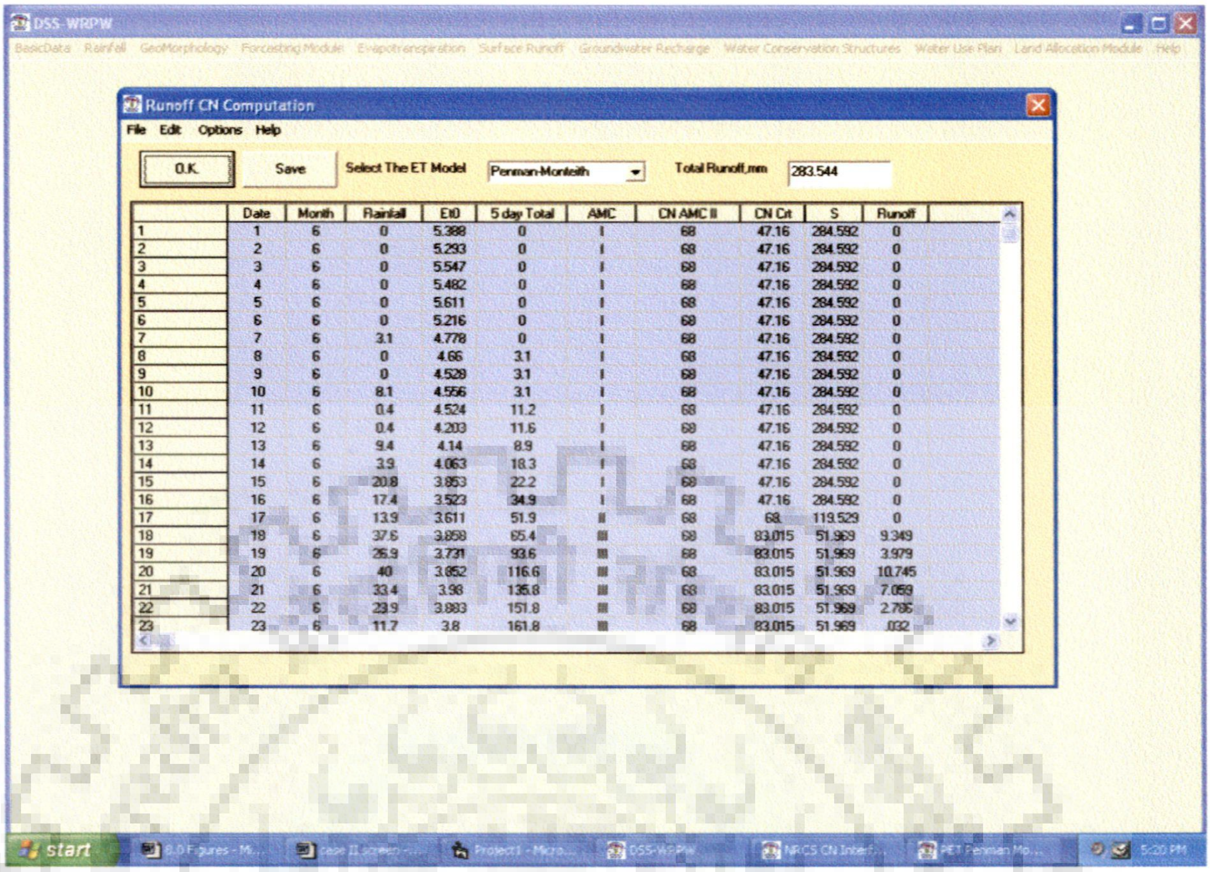


Fig. 8.34 Runoff estimation by NRCS CN method (Future System)

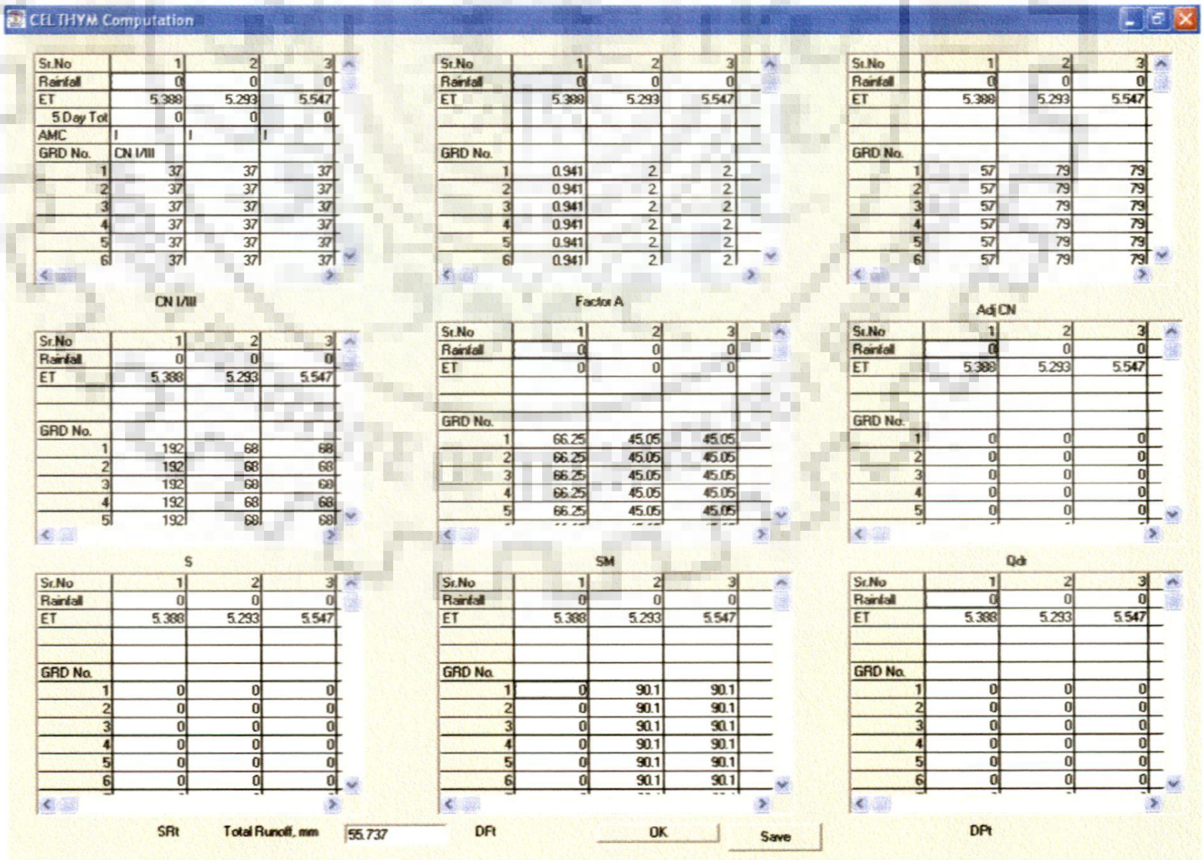


Fig. 8.35 Runoff estimation by CELTHYM method (Future System)

8.3.6 Groundwater Recharge Module

Application of both methods of groundwater recharge estimation (rainfall infiltration and water table fluctuation) have been demonstrated for Khadak Ohal watershed in Test Case I with two separate sub-modules developed. The estimates of the recharges by these two methods do not show any significant difference. But the prediction of water table fluctuation over a period of time is difficult, hence one module i.e. rainfall infiltration can be applied in this forecasted test case. The rainfall infiltration module uses the rainfall data to compute the recharge terms as a fraction of it, going to the aquifer. Computation of groundwater recharge using this sub-module has been described in the next sub-section. The spatial input data remains same as used in earlier test case.

8.3.6.1 Rainfall Infiltration Sub-module

The groundwater recharge available is a fraction of rainfall going to the aquifer. This fraction varies according to the geology of the watershed. The sub-module (Fig. 8.36) takes the input of shape file describing the type of geological formation in *MapLayer*. The type of geological formation is then exported to the text box. Another eight text boxes need to be entered the values of fortnightly effective rainfall. The estimated values of recharge for each fortnight are displayed in the text box opposite to these text boxes.

Khadak Ohal watershed consists of vesicular and joint basalt in its geological formation. This formation is found in consistent throughout the hilly region of Nashik District, hence there is no variation in the geological formation in the watershed. The effective rainfall computed for the first fortnight is 224.458 mm, while highest is found in the second fortnight of July. The groundwater recharge from this highest rainfall is 49.34 ha-m. Total recharge from the 1940.5

mm of rainfall in the watershed of 1726 ha area by this method is 183.91 ha-m. The fortnightly estimated groundwater recharge is given in Table 8.15.

Table 8.15 Fortnightly ground water recharge estimation (ha-m) by DSS.

Month	Fortnight	Recharge (ha-m)
June	I	27.11
	II	44.70
July	I	24.36
	II	49.34
August	I	19.66
	II	12.08
September	I	6.55
	II	0.11
Total (ha-m)		183.91

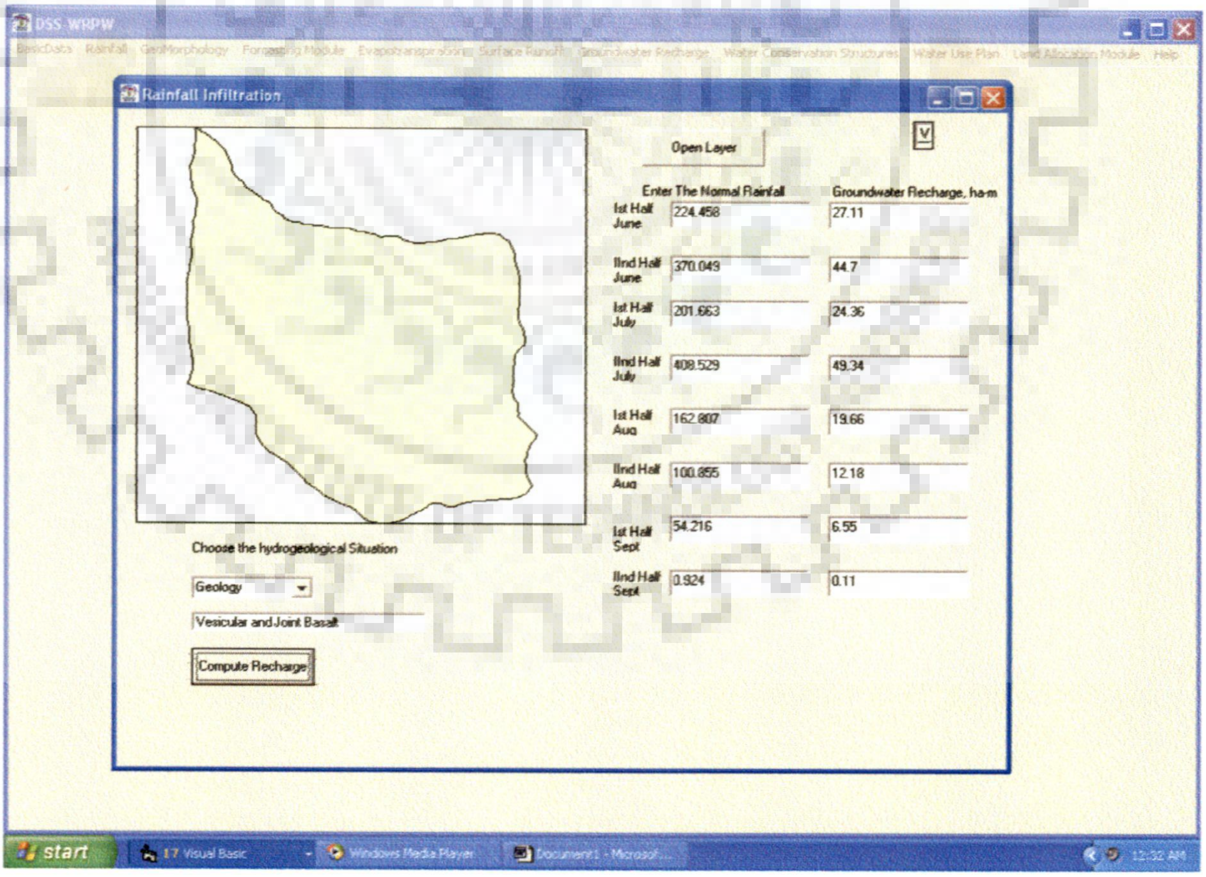


Fig. 8.36 Recharge estimation by rainfall infiltration method

8.3.7 Water Conservation Structures Module

Watershed management plans are assumed to be incomplete without provision of any soil and water conservation measures. These measures have certain impact in terms of increase in opportunity time of runoff, thereby increase in the water availability. These measures are mostly dependent on the topography and runoff generated from the water. In order to have an idea about the length of structures required to be constructed in the watershed, this module has been developed. This module has been divided into three parts viz; (i) Soil Water Conservation (SWC) structures, (ii) SWC structures design, (iii) Water Harvesting, and (WH) pond water balance.

As at present there is no structure to conserve water in the Khadak Ohal watershed, this module has not been applied in Test Case I, but in Test Case II. There may be some structures which would be constructed as a watershed management programme. Therefore application of this module in details has been described in the subsequent sections.

8.3.7.1 SWC Structures

This is a preliminary sub-module in this module, which takes GIS data regarding slope characteristics in the watershed. The sub-module is operating in the similar manner as that of other module and sub-modules those use *MapLayer*. This sub-module loaded with the shape file describing the slope of the Khadak Ohal watershed is shown in Fig. 8.37. The colour differentiation in the *MapLayer* gives the ranges of slope. The combo box in the sub-module is used to sort the attributes. This information of attributes is sent to the next sub-module. The number "1031" in the text box indicates the land parcels of different slope values. The button control *Bunds and Bench Terraces* opens the SWC structures design sub-module.

8.3.7.2 SWC Structures Design

There are many approaches of soil and water conservation, which includes agronomical and mechanical approaches. The agronomical approaches have been often reported to site specific, but the mechanical approach often uses some topographical parameters in the watershed. These may include number of types of bunds, terraces and waterways, spillways. Out of which, contour bunds, graded bund, and broad base terraces have been considered to demonstrate its use in the current DSS.

The sub-module is loaded with the slope and area data of all 1031 land parcels which are shown in Fig. 8.38. The sub-module is essentially an *MSFlexGrid*. Other interactive controls have been added to make it more useful. The first column in the *MSFlexGrid* shows the ID of land parcel, with its slope in second column. The area of these parcels is shown in the third column. Based on the slope values, the type of structure is decided in the fourth column, while the design parameters i.e. vertical and horizontal intervals are being shown in the fifth and sixth column respectively. The length of structure required is computed using area of individual land parcel, which summed according to type of structures to display in the text box of total length of structures. User has to give additional input of soil depth in the watershed, to design the terraces.

The sub-module suggests that Khadak Ohal watershed would need 211.7 km of contour bunds, 294.4 km of graded bunds and 363 km of bench terraces. The soil depth that has been used in the computation of terrace parameters is 1.5 m. The sub-module is also considering the impact of structures on the groundwater recharge. For this, the user has to provide the information on size of bunds and terraces, their percentage of construction. With the dimension as shown in the Fig. 8.38, this was used for further application. Scenario generation starts here itself with the percentage of structures completed.

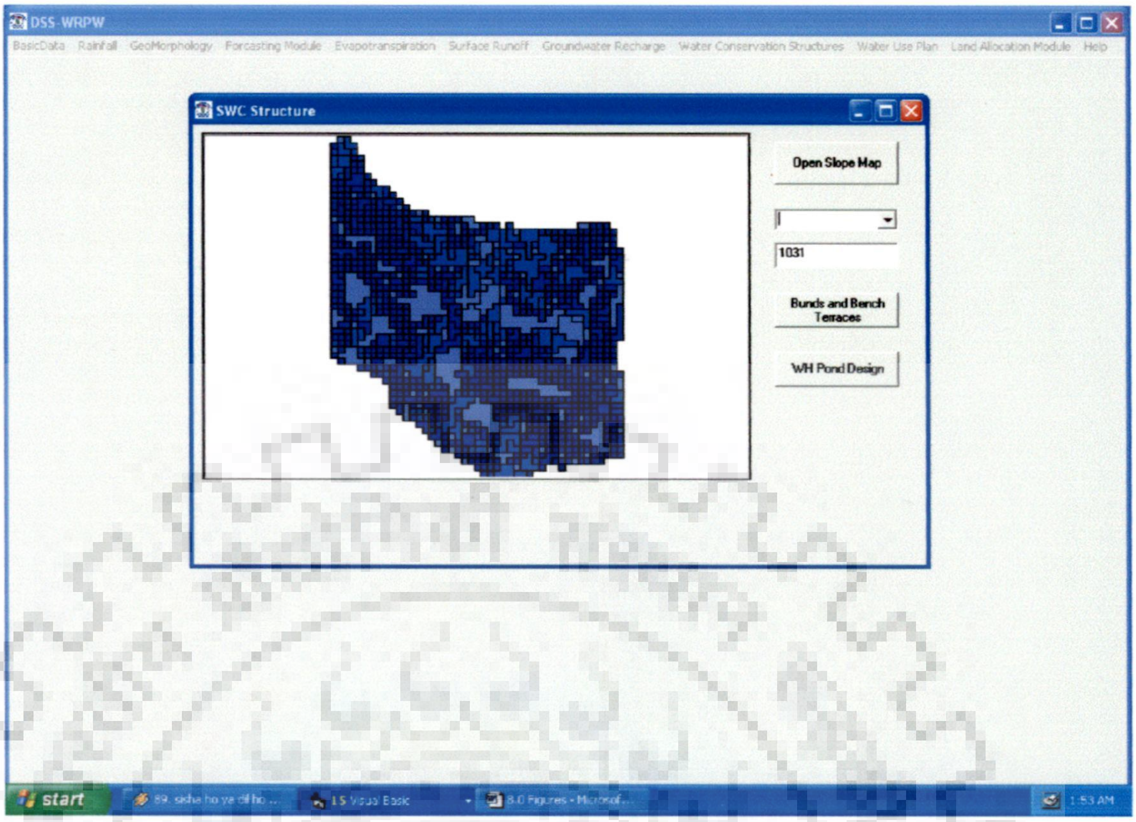


Fig. 8.37 Soil conservation structures module

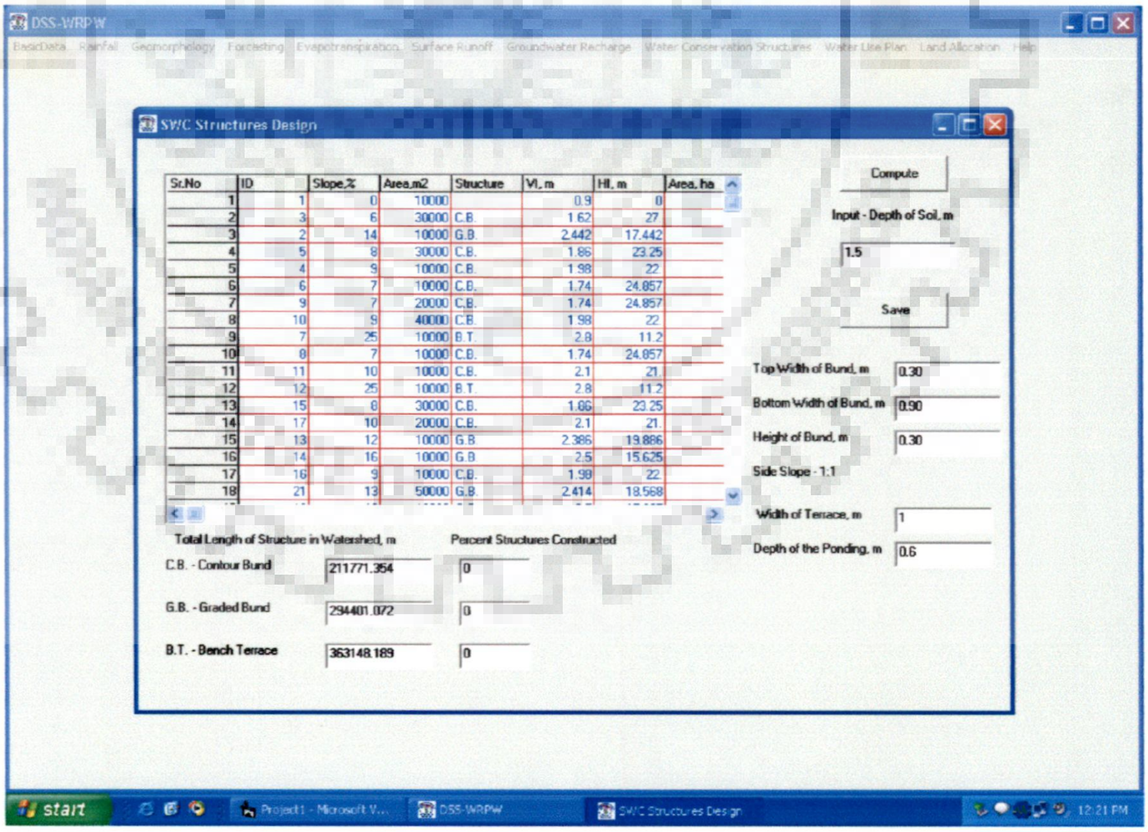


Fig. 8.38 Soil conservation structures design sub-module

8.3.7.3 WH Pond Water Balance

The water harvesting ponds are commonly used to store the excess water from the watershed. These ponds are also useful in recycling of water and augmentation of groundwater. The sub-module is interactive in many ways. To start the operation of this module, the user has to choose the option of "Yes/No" for existing water harvesting ponds. With option "Yes", user may enter details of the existing ponds in the watershed. The control button "Pond Water Balance" will give the pond water balance in the watershed. Before this user has to select the type of lining material, and if there is no lining then select underlying soil type.

With option "No", user has to go through all the controls in left hand side of sub-module to get the dimensions of the pond, their number required. User has to enter the number of ponds constructed in this option to get the scenario. For Khadak Ohal watershed, there is no existing pond. Hence the option "No" would make to user to go through all the options in the left hand side of the sub-module.

Based on the regional dimensions, the sub-module gives the total surface area of water harvesting ponds as 0.960 ha, with total storage capacity of individual pond as 3.540 ha-m. This would mean that 111 water harvesting ponds would be needed to store the runoff generated from the watershed during the year of forecast. With an assumption that all of these ponds are available for storage at this time, the simulations of water balance are carried out for different combinations of models.

For the selected region as west, runoff model NRCS CN, ET model Hargreaves-Samani and silty loam type of underlying soil and dependency level of 80%, DSS generates water balance of 3350.467 ha-m rainfall as shown in Fig 8.39. Out of this rainfall, 2958.093 ha-m would go in all the losses i.e. evaporation, abstraction, etc, while 392.374 ha-m of rainfall will be available for storage. The water available for application after seepage and evaporation losses would be around 349.667 ha-m. Similarly, other combination of runoff and evaporation models would result in differential amount of water available for application in the watershed. These combinations are shown in Figs. 8.40 to 8.42. The selection of combination from this sub-module starts another scenario generation mode in the DSS.

8.3.8 Scenario Generation

There can be a number of scenarios for final decision making in this test case i.e. future system of watershed. Scenario generation starts initially at crop water requirement estimation level, with the selection of PET model. At second instant, it can be at percentage structures constructed in the SWC structures design module. Number of operational variables in the WH pond water balance sub-module makes it possible to the user to generate various combinations depending upon the data availability. Finally with this pre-decided combination, more scenarios are possible in the final decision making agent i.e. water use planning module.

In the subsequent discussions, four representative scenarios have been discussed, in which there no bunds/terraces with completed water are harvesting ponds. The only groundwater recharge module that can be operated here is rainfall infiltration. With the combination of two runoff and two PET models four scenarios give the picture of watershed in future water use plan with extended cropping in *Rabi* season. These scenarios can be diagrammatically explained in Fig. 8.43.

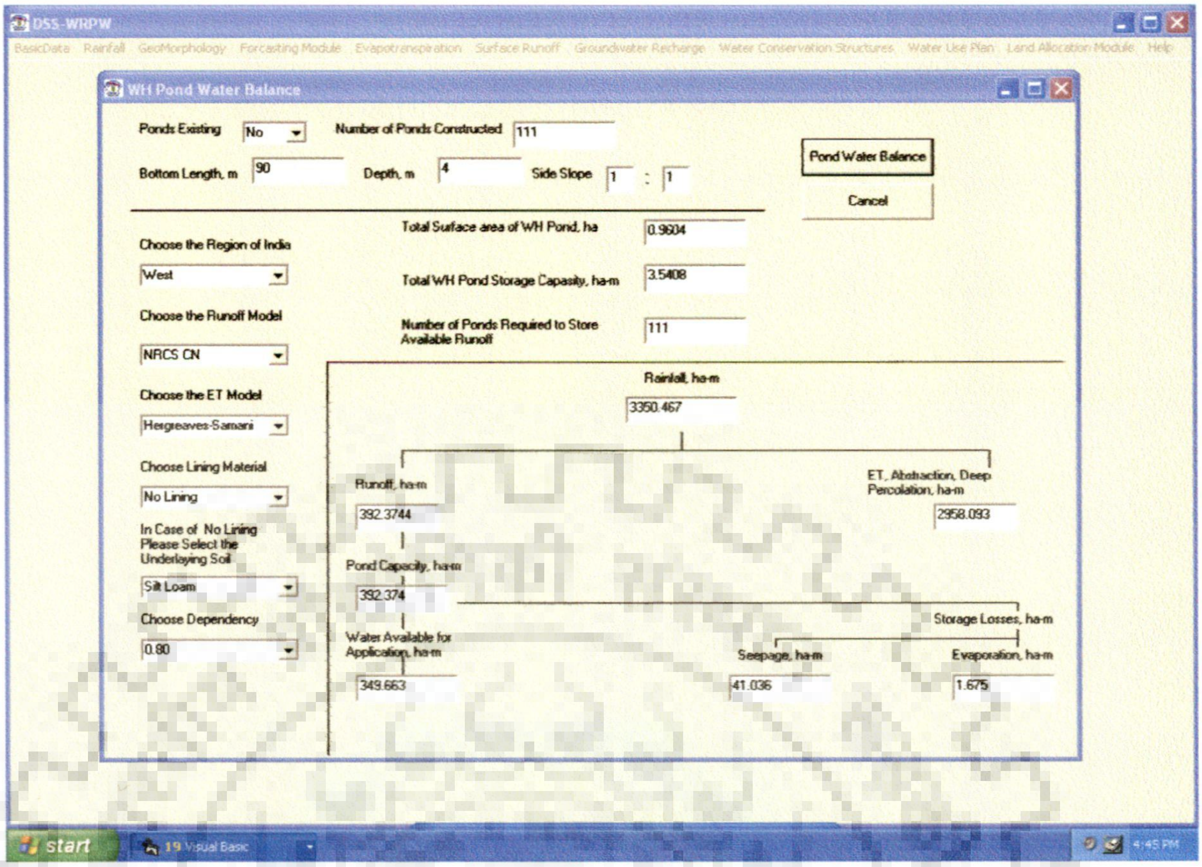


Fig. 8.39 WHP water balance design sub-module (CN + HS)

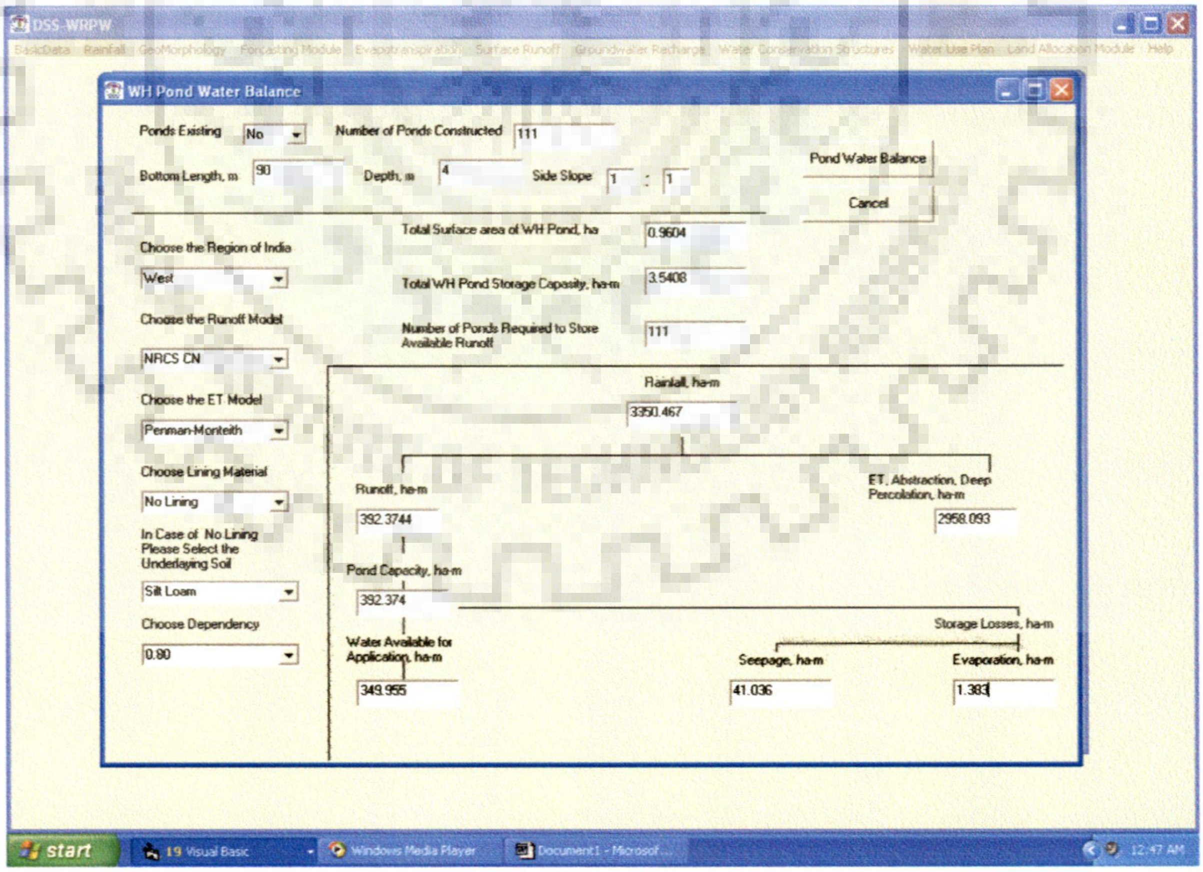


Fig. 8.40 WHP water balance design sub-module (CN +PM)

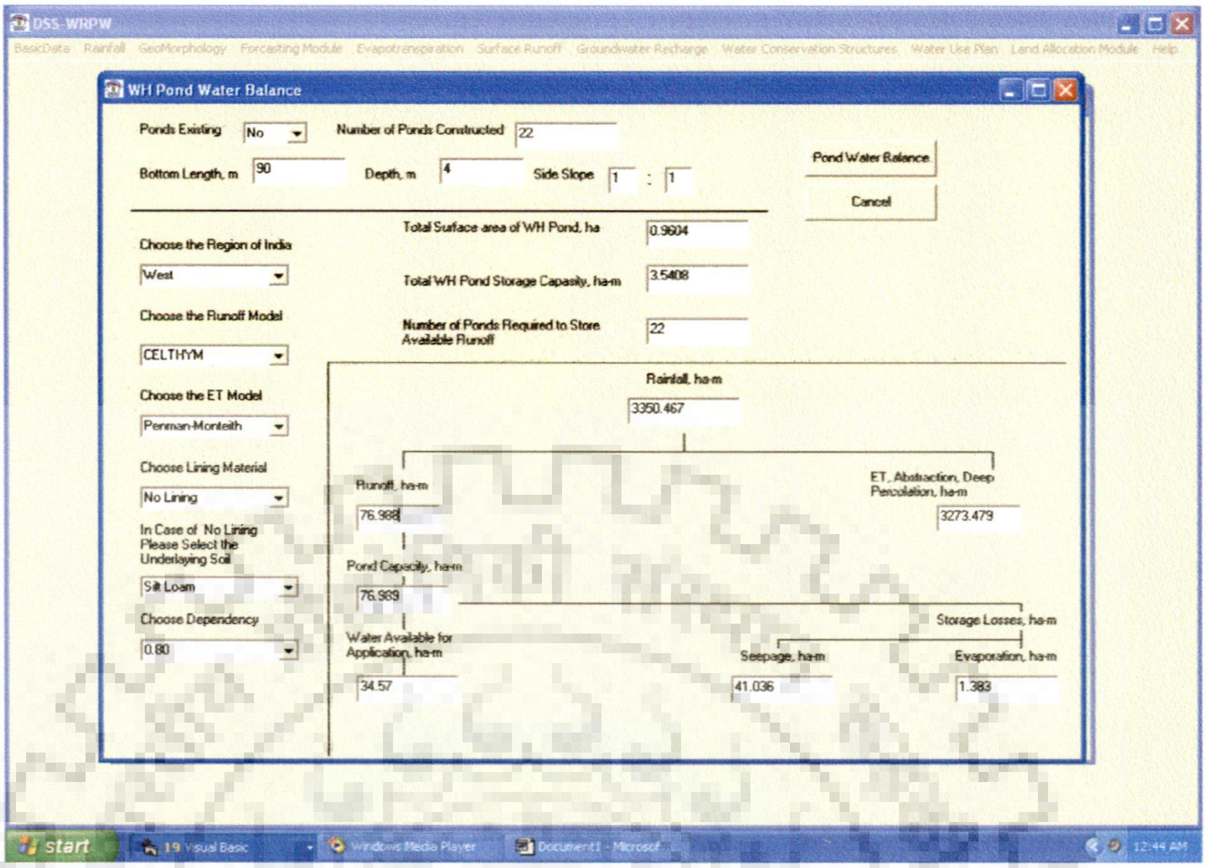


Fig. 8.41WHP water balance design sub-module (CELTHYM +PM)

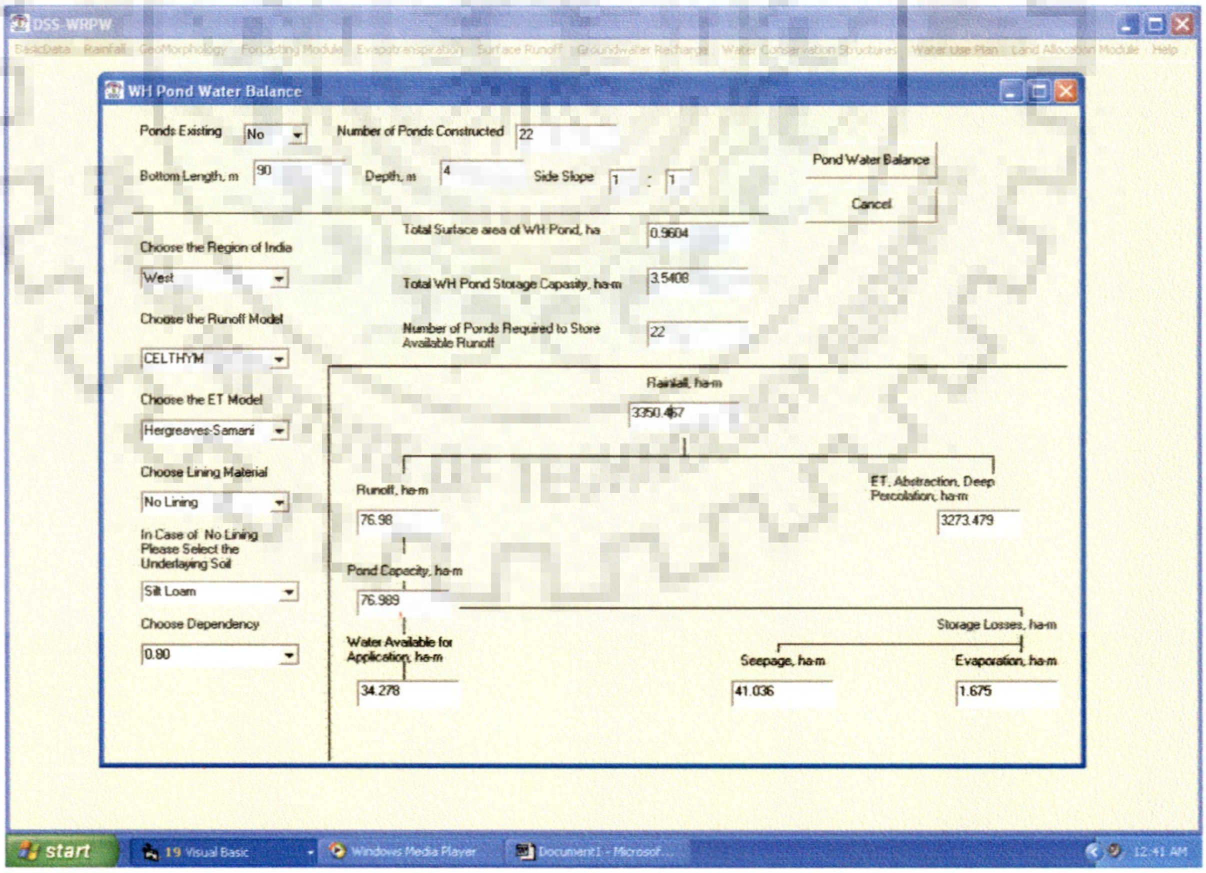


Fig. 8.42 WHP water balance design sub-module (CELTHYM +HS)

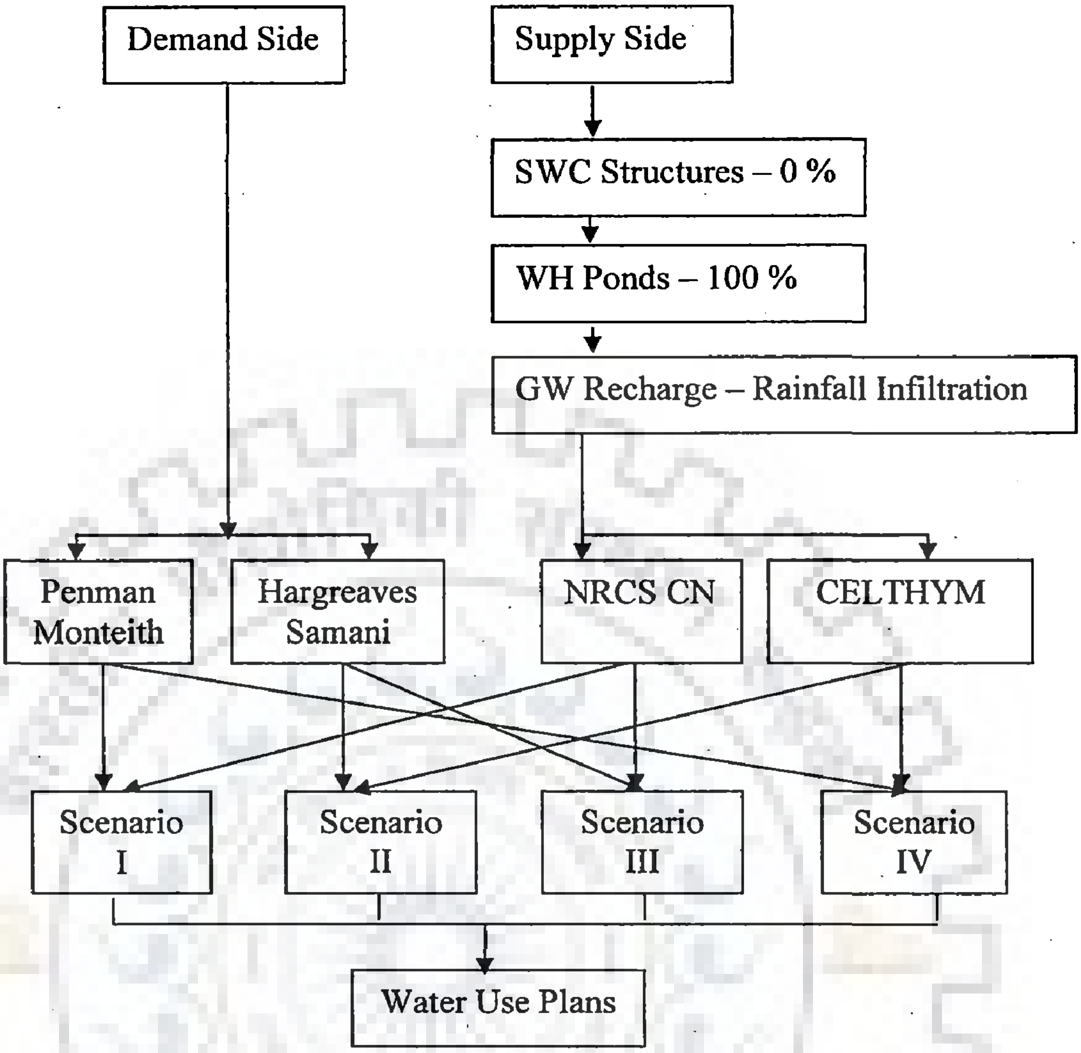


Fig. 8.43 Schematic of generated scenarios in Test Case II

8.3.8.1 Scenario I (Case II)

This is the first scenario that could be generated from the DSS using combination of models as shown in Fig. 8.43. Prior to generate this scenario, user has to run all the required modules. The scenario generated by this combination is shown in Fig. 8.44. As shown in Fig. 8.44, the annual human and animal water demand has been distributed equally in 24 fortnight periods in the rows numbered from 11 to 24 and 1 to 10 respectively. The 11th fortnight is the serial number of 1st fortnight of June, while 10th fortnight is serial number of last fortnight of May.

The human and animal water demand in each fortnight works out to be 0.001 ha-m for each demand sector.

The agricultural demand as estimated in the *Crop Water Requirement* module is called here and displayed it fortnightly. There would be crops in both the *Kharif* and *Rabi* seasons in the Khadak Ohal watershed, hence no water demand is displayed after the sixteenth row in the GUI of module. Agricultural water demand in the year 2011 varies from 9.234 ha-m to 34.788 ha-m. Maximum water demand is found at first fortnight of June, minimum is found at first fortnight of January.

On the water resources availability side, the effective rainfall that can be utilized by crops is shown in the first six rows. Maximum rainfall (705.366 ha-m) is available from the second fortnight of July. In the second fortnight of September, there would be negligible amount of rainfall in the watershed, hence the total available rainfall in the complete monsoon period is less than the annual average rainfall in the watershed. There would be 392.374 ha-m of surface water available at the near end of the monsoon period; this would be useful in meeting out the irrigation demand.

The groundwater resource in the watershed can be seen increasing throughout the first six fortnights i.e. monsoon period. The incremental recharge from each fortnight is added to next row after fulfilling demand in the respective time interval. There is no recharge in the second fortnight of September. The available groundwater at end of 18^{th} fortnight is 227.334 ha-m.

As per allocation policy formulated (Section 5.11.3), the DSS suggests that all the human and animal water demand can be met out from the groundwater. As surface water is available for storage in the watershed, the losses side of seepage and evaporation are shown as 2.414 ha-m and 0.081 ha-m respectively. The agricultural water demand in the first seven fortnights can be fulfilled from available rainfall. Thus, DSS has shown RF (Rainfall) in the supply source against these demands. There is a considerable agricultural water demand in the month of September, in which there is no rainfall. In presence of surface water availability, DSS has allocated this demand to surface water (SW). The string SW is written against the supply source in these time periods. After fulfilling all the demands, there is still availability of considerable amount of surface water (242.180 ha-m) and groundwater (277.302 ha-m). This suggests that the additional crops can be grown in summer with this amount of utilizable surface. The scenario generated here can be considered the best because of the popularity of these two models.

8.3.8.2 Scenario II (Case II)

This scenario is generated when user opts for the CELTHYM module for surface water estimation and Hargreaves-Samani module for evapotranspiration (ET) estimation. User is expected to get the crop water requirement and effective rainfall by using ET estimated by this method.

As human, animal population and their water demand are constant in this scenario, there is no change in fortnightly water demand for these two sectors. The GUI of module (Fig. 8.45) shows 0.001 ha-min every fortnight period.

Agricultural water demand using Hargreaves-Samani method is different than that of earlier scenario. This is because of the difference in the ET estimated by the two methods. The maximum agricultural water demand (39.327 ha-m) is found in the 22nd fortnight, while minimum (18.453 ha-m) is found at 2nd fortnight.

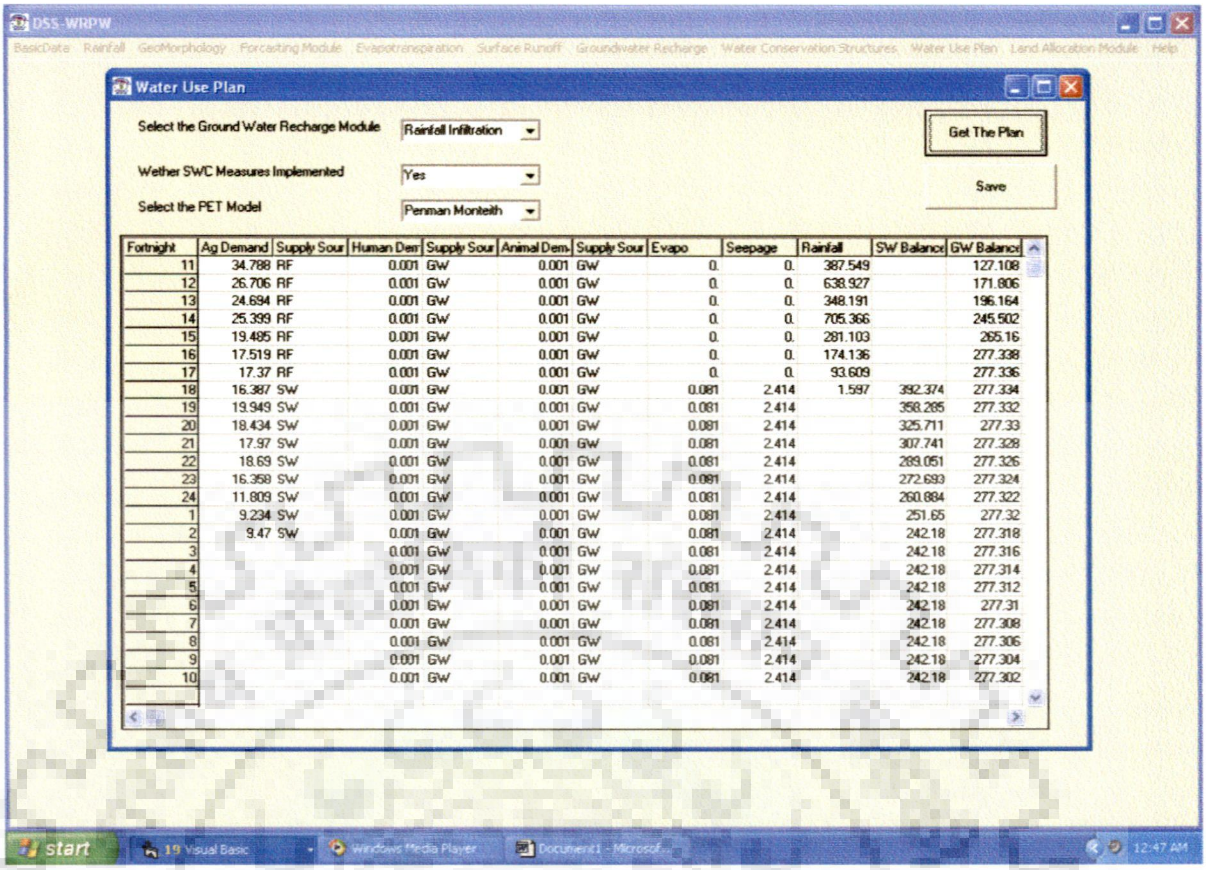
In the water availability side, the effective rainfall is maximum (680.804 ha-m) in the 14th fortnight, while it is minimum (59.925 ha-m) at 17th fortnight. Second fortnight of the September month did not produce any effective rainfall. The ground water availability increases from 11th fortnight till 18th fortnight. At the starting fortnight it is 127.108 ha-m, while at the end of 18th fortnight, 277.334 ha-m of groundwater is available for utilization. Last two fortnights during the monsoon period don't have any recharge. CELTHYM module would result in 76.989 ha-m of surface available for application after end of the monsoon.

Decision support generated from this scenario suggests that the groundwater may be used to fulfill human water demand. This is according to water allocation policy formulated in the development of DSS considering the water quality constraints. The animal water demand has been marked with supply source GW i.e. groundwater.

There is sufficient effective rainfall available in the watershed to meet out the water requirements of all crops during *Kharif* season, at least in first seven fortnights of monsoon. After balancing the demand and effective rainfall available, DSS has allocated the supply source rainfall (RF). In case of 18th and 19th fortnights there is no effective rainfall available that can be used by crops. In such case, the policy suggests that the demand may be balanced from the surface water to irrigate the crops. Thus the string SW is displayed against these demands (Fig. 8.45, Column 3, rows 8 & 9).

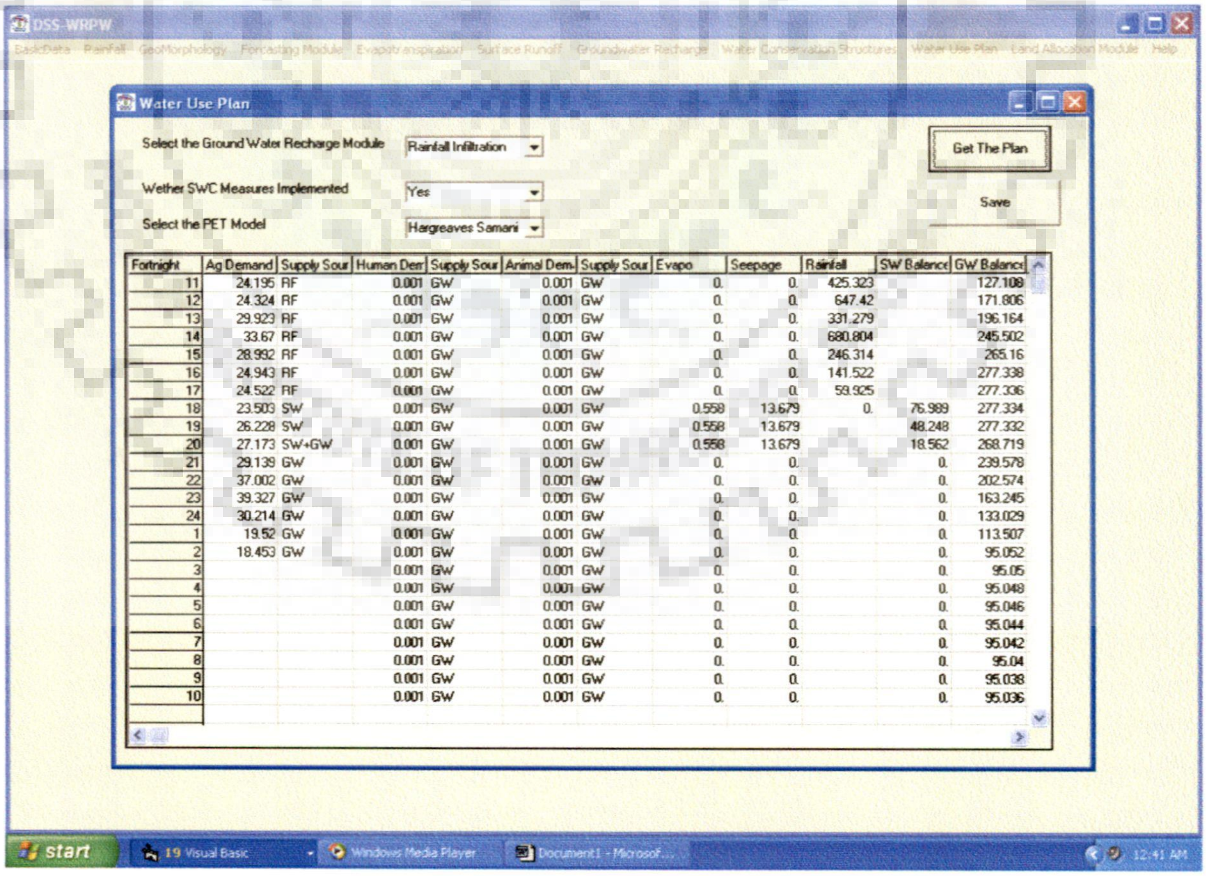
In case of 21st fortnight, agricultural demand can not be met from surface water, DSS suggest that the surface water may first be used and remaining may be balanced from groundwater, hence a string SW + GW is displayed in supply source column in the respective row.

After meeting out all the demands in the watershed, the groundwater balance is 95.036 ha-m. This is less than 100 ha-m, thus leading to the little undermining of groundwater.



Fortnight	Ag Demand	Supply Sour	Human Dem	Supply Sour	Animal Dem	Supply Sour	Evapo	Seepage	Rainfall	SW Balance	GW Balance
11	34.788	RF	0.001	GW	0.001	GW	0.	0.	387.549		127.108
12	26.706	RF	0.001	GW	0.001	GW	0.	0.	638.927		171.806
13	24.694	RF	0.001	GW	0.001	GW	0.	0.	348.191		196.164
14	25.399	RF	0.001	GW	0.001	GW	0.	0.	705.366		245.502
15	19.485	RF	0.001	GW	0.001	GW	0.	0.	281.103		265.16
16	17.519	RF	0.001	GW	0.001	GW	0.	0.	174.136		277.338
17	17.37	RF	0.001	GW	0.001	GW	0.	0.	93.609		277.336
18	16.387	SW	0.001	GW	0.001	GW	0.081	2.414	1.597	392.374	277.334
19	19.949	SW	0.001	GW	0.001	GW	0.081	2.414		358.285	277.332
20	18.434	SW	0.001	GW	0.001	GW	0.081	2.414		325.711	277.33
21	17.97	SW	0.001	GW	0.001	GW	0.081	2.414		307.741	277.328
22	18.69	SW	0.001	GW	0.001	GW	0.081	2.414		289.051	277.326
23	16.358	SW	0.001	GW	0.001	GW	0.081	2.414		272.693	277.324
24	11.809	SW	0.001	GW	0.001	GW	0.081	2.414		260.884	277.322
1	9.234	SW	0.001	GW	0.001	GW	0.081	2.414		251.65	277.32
2	9.47	SW	0.001	GW	0.001	GW	0.081	2.414		242.18	277.318
3			0.001	GW	0.001	GW	0.081	2.414		242.18	277.316
4			0.001	GW	0.001	GW	0.081	2.414		242.18	277.314
5			0.001	GW	0.001	GW	0.081	2.414		242.18	277.312
6			0.001	GW	0.001	GW	0.081	2.414		242.18	277.31
7			0.001	GW	0.001	GW	0.081	2.414		242.18	277.308
8			0.001	GW	0.001	GW	0.081	2.414		242.18	277.306
9			0.001	GW	0.001	GW	0.081	2.414		242.18	277.304
10			0.001	GW	0.001	GW	0.081	2.414		242.18	277.302

Fig 8.44 Scenario I (Case II)



Fortnight	Ag Demand	Supply Sour	Human Dem	Supply Sour	Animal Dem	Supply Sour	Evapo	Seepage	Rainfall	SW Balance	GW Balance
11	24.195	RF	0.001	GW	0.001	GW	0.	0.	425.323		127.108
12	24.324	RF	0.001	GW	0.001	GW	0.	0.	647.42		171.806
13	29.923	RF	0.001	GW	0.001	GW	0.	0.	331.279		196.164
14	33.67	RF	0.001	GW	0.001	GW	0.	0.	680.804		245.502
15	28.992	RF	0.001	GW	0.001	GW	0.	0.	246.314		265.16
16	24.943	RF	0.001	GW	0.001	GW	0.	0.	141.522		277.338
17	24.522	RF	0.001	GW	0.001	GW	0.	0.	59.925		277.336
18	23.503	SW	0.001	GW	0.001	GW	0.558	13.679	0.	76.989	277.334
19	26.228	SW	0.001	GW	0.001	GW	0.558	13.679		48.248	277.332
20	27.173	SW+GW	0.001	GW	0.001	GW	0.558	13.679		18.562	268.719
21	29.139	GW	0.001	GW	0.001	GW	0.	0.		0.	239.578
22	37.002	GW	0.001	GW	0.001	GW	0.	0.		0.	202.574
23	39.327	GW	0.001	GW	0.001	GW	0.	0.		0.	163.245
24	30.214	GW	0.001	GW	0.001	GW	0.	0.		0.	133.029
1	19.52	GW	0.001	GW	0.001	GW	0.	0.		0.	113.507
2	18.453	GW	0.001	GW	0.001	GW	0.	0.		0.	95.052
3			0.001	GW	0.001	GW	0.	0.		0.	95.05
4			0.001	GW	0.001	GW	0.	0.		0.	95.048
5			0.001	GW	0.001	GW	0.	0.		0.	95.046
6			0.001	GW	0.001	GW	0.	0.		0.	95.044
7			0.001	GW	0.001	GW	0.	0.		0.	95.042
8			0.001	GW	0.001	GW	0.	0.		0.	95.04
9			0.001	GW	0.001	GW	0.	0.		0.	95.038
10			0.001	GW	0.001	GW	0.	0.		0.	95.036

Fig 8.45 Scenario II (Case II)

8.3.8.3 Scenario III (Case II)

As seen in Fig. 8.46, this scenario is the combination of operation of NRCS CN module and Penman-Monteith module. User is supposed to use NRCS CN module to get the surface water resources in the watershed. The ET is estimated by the Penman-Monteith module.

As shown in the Fig 8.46, the annual human and animal water demand has been distributed equally in the 24 fortnight periods. The human and animal water demand in each fortnight works out to be 0.001 ha-m for each demand period, as described earlier.

The agricultural demand as estimated by Crop Water Requirement module is called here to display it fortnightly. Cropping pattern in the Khadak Ohal watershed is in both *Kharif* and *Rabi* seasons; hence no water demand is displayed after the sixteenth row in the GUI of module. Agricultural water demand in the case of forecasted system in the year 2011 varies from 18.453 ha-m to 39.327 ha-m. Maximum water demand is found in the first fortnight of June, whereas the minimum is found in the last fortnight of September.

The effective rainfall that can be utilized by crops as shown in the first seven rows. Maximum rainfall (680.804 ha-m) is available from the second fortnight of July. The minimum rainfall was observed in the first fortnight of September, which is 59.925 ha-m. The ground water availability increases from 11^{th} fortnight till 18^{th} fortnight. At the starting fortnight it is 127.108 ha-m, while at the end of 18^{th} fortnight, 227.334 ha-m of groundwater is available for utilization. Last fortnight during the monsoon period don't have any recharge.

As per allocation policy formulated (Section 5.11.3), the DSS suggests that all the human and animal water demand can be met out through the groundwater. As surface water is available for storage in the watershed, there will be seepage and evaporation losses 2.414 ha-m and 0.099 ha-m respectively from surface water storage. The agricultural water demand in the first seven fortnights can be fulfilled from available rainfall. Thus DSS has shown RF in the supply source against these demands. There is a considerable agricultural water demand in the second fortnight of the September, when there is no rainfall. DSS has allocated this demand to surface water. The string SW is displayed against the supply source in these time periods. After fulfilling all the demand, there is still availability of considerable amount of surface water (125.398 ha-m) and groundwater (277.302 ha-m).

8.3.8.4 Scenario IV (Case II)

This is the combination of two choices available each for the estimation of surface water and evapotranspiration. This is the last scenario that could be generated, with the combination of CELTHYM and Penman-Monteith module. The scenario generated is shown in Fig. 8.47. User is expected to work out the agricultural water demand using the Penman-Monteith module of ET estimation. The effective rainfall will be computed using the fortnightly rainfall and ET.
As human, animal population and their water demands are constant in this scenario, there is no change in fortnightly water demand in these two sectors. The GUI of module (Fig. 8.47) shows 0.001 ha-m for both of demand sectors in every fortnight period.

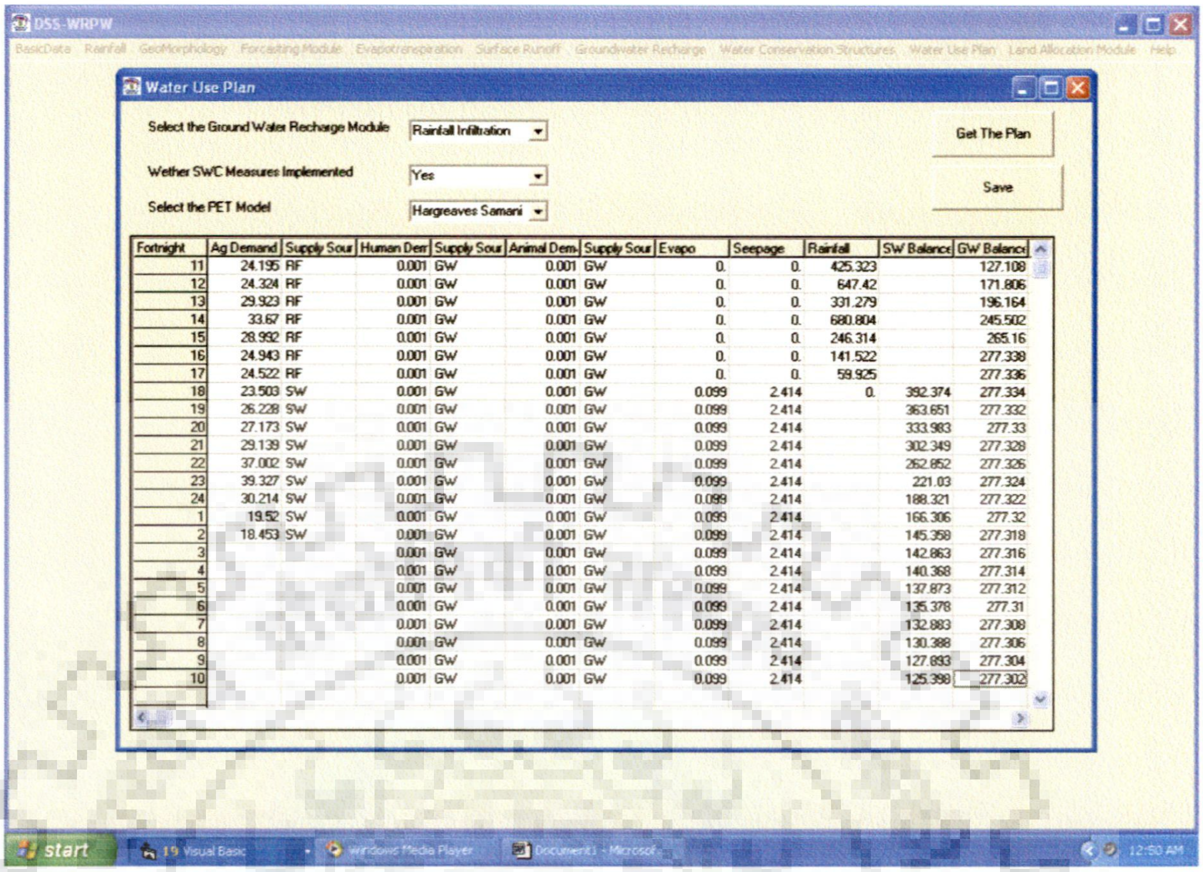
Agricultural water demand computed using the ET estimated Penman Monteith is different than that of earlier scenario. This is because of the difference in the ET estimated by the two methods. The maximum value of agricultural water demand (34.789 ha-m) is found at 1st fortnight, while minimum value (9.470 ha-m) is found at 2nd fortnight.

In the water availability side, the effective rainfall is maximum (705.3.66 ha-m) at 14th fortnight, while it is minimum (1.597 ha-m) at 18th fortnight. CELTHYM module would result in 76.989 ha-m of surface available for application after the end of the monsoon

The groundwater resource in watershed can be seen increasing throughout the first seven fortnights i.e. monsoon period. The incremental recharge from each fortnight is added to next row after fulfilling demand in the respective time interval. There is no recharge in the second fortnight of September due to proportional distribution of recharge. The available groundwater at end of 18th fortnight is 227.334ha-m.

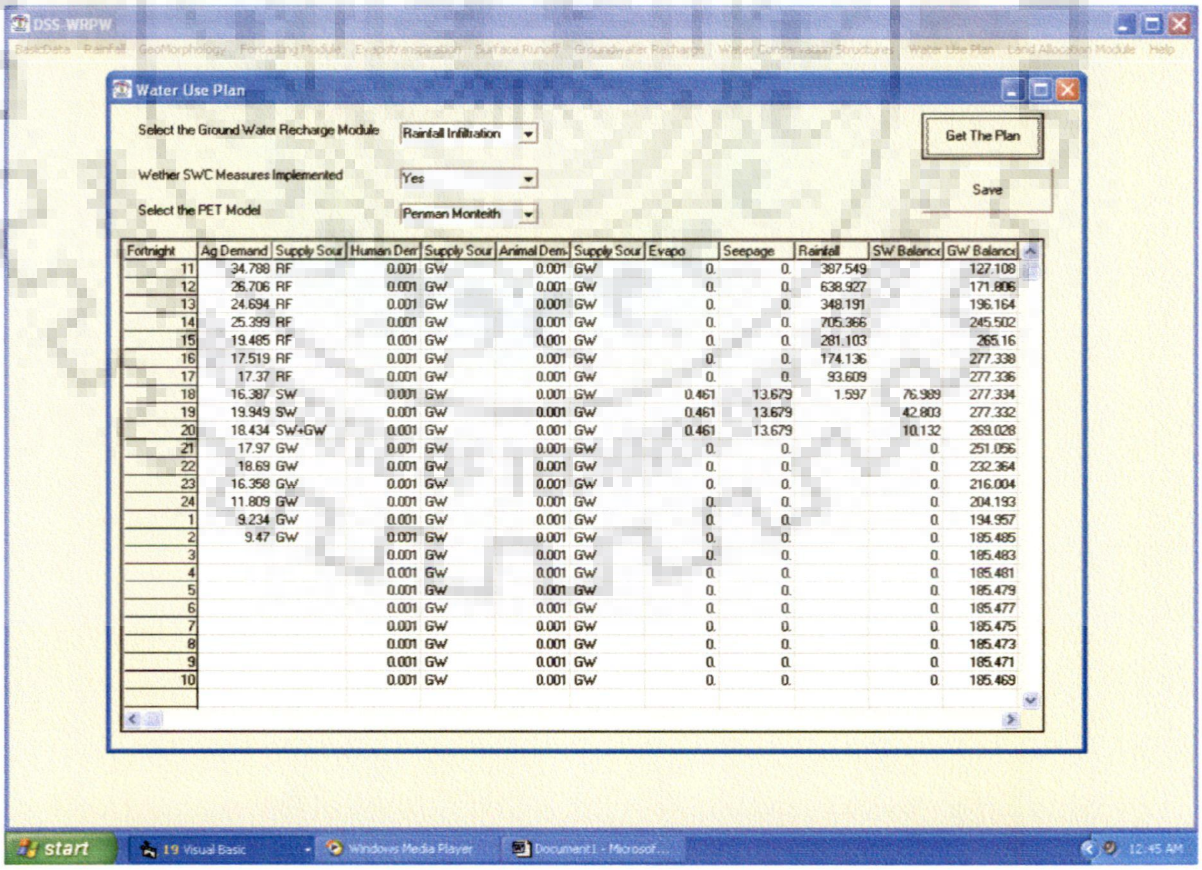
DSS suggests that all the human and animal water demand can be met out from the groundwater. As surface water is available for storage in the watershed, the seepage and evaporation losses shows 13.679 ha-m and 0.461 ha-m values respectively. The agricultural water demand in the first seven fortnights can be fulfilled from available rainfall. Thus DSS has shown RF in the supply source against these demands. There is considerable agricultural water demand in the month of September, in which there is no sufficient rainfall. With surface water available, DSS has allocated this demand to surface water. The string SW is written against the supply source in these time periods. In case of 20th fortnight, agricultural demand can not be met from surface water, the DSS suggests that the surface water may first be used and remaining may be balanced from groundwater, hence a string SW + GW is displayed in supply source column in the respective row.

The 185.469 ha-m of groundwater will be additional water available to utilize for additional demand generated if farmers in the watershed go for the third crop in a year.



Fortnight	Ag Demand	Supply Sour	Human Dem	Supply Sour	Animal Dem	Supply Sour	Evapo	Seepage	Rainfall	SW Balance	GW Balance
11	24.195	RF	0.001	GW	0.001	GW	0.	0.	425.323		127.108
12	24.324	RF	0.001	GW	0.001	GW	0.	0.	647.42		171.806
13	29.923	RF	0.001	GW	0.001	GW	0.	0.	331.279		196.164
14	33.67	RF	0.001	GW	0.001	GW	0.	0.	680.804		245.502
15	28.992	RF	0.001	GW	0.001	GW	0.	0.	246.314		265.16
16	24.943	RF	0.001	GW	0.001	GW	0.	0.	141.522		277.338
17	24.522	RF	0.001	GW	0.001	GW	0.	0.	59.925		277.336
18	23.503	SW	0.001	GW	0.001	GW	0.099	2.414	0.	392.374	277.334
19	26.228	SW	0.001	GW	0.001	GW	0.099	2.414		363.651	277.332
20	27.173	SW	0.001	GW	0.001	GW	0.099	2.414		333.983	277.33
21	29.139	SW	0.001	GW	0.001	GW	0.099	2.414		302.349	277.328
22	37.002	SW	0.001	GW	0.001	GW	0.099	2.414		262.852	277.326
23	39.327	SW	0.001	GW	0.001	GW	0.099	2.414		221.03	277.324
24	30.214	SW	0.001	GW	0.001	GW	0.099	2.414		188.321	277.322
1	19.52	SW	0.001	GW	0.001	GW	0.099	2.414		166.306	277.32
2	18.453	SW	0.001	GW	0.001	GW	0.099	2.414		145.358	277.318
3			0.001	GW	0.001	GW	0.099	2.414		142.863	277.316
4			0.001	GW	0.001	GW	0.099	2.414		140.368	277.314
5			0.001	GW	0.001	GW	0.099	2.414		137.873	277.312
6			0.001	GW	0.001	GW	0.099	2.414		135.378	277.31
7			0.001	GW	0.001	GW	0.099	2.414		132.883	277.308
8			0.001	GW	0.001	GW	0.099	2.414		130.388	277.306
9			0.001	GW	0.001	GW	0.099	2.414		127.893	277.304
10			0.001	GW	0.001	GW	0.099	2.414		125.398	277.302

Fig 8.46 Scenario III (Case II)



Fortnight	Ag Demand	Supply Sour	Human Dem	Supply Sour	Animal Dem	Supply Sour	Evapo	Seepage	Rainfall	SW Balance	GW Balance
11	34.788	RF	0.001	GW	0.001	GW	0.	0.	387.549		127.108
12	26.706	RF	0.001	GW	0.001	GW	0.	0.	638.927		171.806
13	24.694	RF	0.001	GW	0.001	GW	0.	0.	348.191		196.164
14	25.399	RF	0.001	GW	0.001	GW	0.	0.	705.366		245.502
15	19.485	RF	0.001	GW	0.001	GW	0.	0.	281.103		265.16
16	17.519	RF	0.001	GW	0.001	GW	0.	0.	174.136		277.338
17	17.37	RF	0.001	GW	0.001	GW	0.	0.	93.609		277.336
18	16.387	SW	0.001	GW	0.001	GW	0.461	13.679	1.597	76.989	277.334
19	19.949	SW	0.001	GW	0.001	GW	0.461	13.679		42.803	277.332
20	18.434	SW+GW	0.001	GW	0.001	GW	0.461	13.679		10.132	269.028
21	17.97	GW	0.001	GW	0.001	GW	0.	0.		0	251.056
22	18.69	GW	0.001	GW	0.001	GW	0.	0.		0	232.364
23	16.358	GW	0.001	GW	0.001	GW	0.	0.		0	216.004
24	11.809	GW	0.001	GW	0.001	GW	0.	0.		0	204.193
1	9.234	GW	0.001	GW	0.001	GW	0.	0.		0	194.957
2	9.47	GW	0.001	GW	0.001	GW	0.	0.		0	185.485
3			0.001	GW	0.001	GW	0.	0.		0	185.483
4			0.001	GW	0.001	GW	0.	0.		0	185.481
5			0.001	GW	0.001	GW	0.	0.		0	185.479
6			0.001	GW	0.001	GW	0.	0.		0	185.477
7			0.001	GW	0.001	GW	0.	0.		0	185.475
8			0.001	GW	0.001	GW	0.	0.		0	185.473
9			0.001	GW	0.001	GW	0.	0.		0	185.471
10			0.001	GW	0.001	GW	0.	0.		0	185.469

Fig 8.47 Scenario IV (Case II)

8.3.9 Summary of Decision Scenarios

The DSS has been demonstrated in the first test case i.e. real physical system and second test case i.e. forecasted system of the watershed, in which the future conditions of year 2011 have been taken into consideration. Four scenarios that will be available to the decision makers have been described in details in the previous section.

A scenario that will give maximum available water from both the sources after fulfilling all demands can be considered the most preferential scenario. All the four scenarios that could be generated from the DSS have been summarized in Table 8.16. The scenario I would result in the balance of 519.482 ha-m of water after fulfilling all demands which can be considered the most preferred scenario. The scenario III would give water balance of 402.700 ha-m and 185.469 ha-m in the scenario IV. The scenario II giving a water balance of 95.036 ha-m may be considered as the least preferred scenario. This will be helpful to decision maker to choose the combination of modules, while using the DSS in the planning process.

Table 8.16 Summary of all scenarios in test case II (Future System)

Scenario	Surface water available after allocation(ha-m)	Groundwater available after allocation (ha-m)	Preference
I	242.180	277.302	I
II	0	95.036	IV
III	125.398	277.302	II
IV	0	185.469	III

8.4 Concluding Remarks

The DSS for water resources planning within watershed area has been demonstrated in this chapter with two test cases, as discussed in the prelude. The results obtained from running of different modules have been discussed for both the test cases. Different scenarios of water use planning have been discussed for both the cases.

In case of test case I, a combination of Water Table Fluctuation and Penman-Monteith modules may be useful in application, while NRCS CN and Penman-Monteith combination may be used in future system. For actual application to the current year, it may be concluded that user may run the DSS by September end. By this time, the rainfall data would also be available. The combination of NRCS CN, Water Table Fluctuation and Penman-Monteith module is expected to generate more realistic scenarios.

CHAPTER 9

CONCLUSIONS

Watershed management is one of the promising approaches for management of water resources in arid and semi-arid Indian ecosystems. Decision-making for water resources planning in watershed is a complex process. Keeping this in view a study was undertaken for the development and demonstration of DSS for water resources planning in watershed. This was done with the help of hydrological models and methods by developing computer programs.

In accordance to the research objective, the essential characteristics of a DSS, as appropriate for water resources planning on watershed basis are first identified. A comprehensive search on models and methods of various components of watershed hydrology was done keeping in view their data needs and type of output generated. The NRCS CN and CELTHYM models have been used in the surface water assessment, while Rational method has been used for storm runoff estimation. For groundwater recharge assessment GEC norms of 1997 have been implemented in the DSS. The bunds and terraces have been used in the soil and water conservation structures module. The dugout type water harvesting ponds have been considered for retention of surface runoff in the watershed. To facilitate the developement of a compressive and more rational DSS, various alternatives of development architectures (system framework) were reviewed.

Computer program has been written in the Visual Basic (Over 10,000 lines) to develop 10 modules and their 26 graphical user interfaces to from DSS. To incorporate the spatial component in the DSS, ActiveX control MapObjects@ was used in programming. A separate module or an interface was developed for each of the identified components of DSS. These interfaces or modules were integrated to the common GUI. The developed software platform is a prototype of the **Decision Support System** for **Water Resources Planning** in **Watershed**, which has been abbreviated and called as **DSS-WRPW**. The DSS-WRPW has spatial data input capabilities for management, storing and attribution of information about spatial data, which integrates hydrological models and methods in a standalone software platform incorporating GIS. The spatial data in the form of ESRI shape files has been used as input to the various modules or interfaces of the DSS. Thus, developed DSS may also be termed as the Spatial DSS or SDSS.

Based on the investigations and demonstration of DSS in the Khadak Ohal watershed the salient features of the study and conclusions drawn are given below:

1. The study fulfills its objectives for the development of DSS for water resources planning in watershed water demands. The DSS developed in the study is user friendly and capable of handling both the spatial and non-spatial data as input. An overview of developed DSS in the pictorial form has been given Fig. 9.1.
2. A methodology for ordering of streams (Strahler's configuration) has been developed and implemented in the GUI, which takes the vector format of spatial data as input. On the basis of this, geomorphological parameters of the watershed have been extracted. The GUI has generated maximum order of stream as 5 with total number of 467 streams. The total length of the stream has been found to be 106.269 km. The bifurcation ratio for selected watershed is found to be in the range of 0.833 to 3.333, while stream length ratio in the range of 0.648 to 1.581. The GUI has yielded the watershed compactness value as 1.32 and basin circularity as 0.57. The stream frequency and drainage density is found to be 25.83/km^2 and 6.51/km respectively. The length of overland flow and constant of channel maintenance is 0.08 km and 0.16 /km^2. These parameters are useful in the characterization of watersheds.

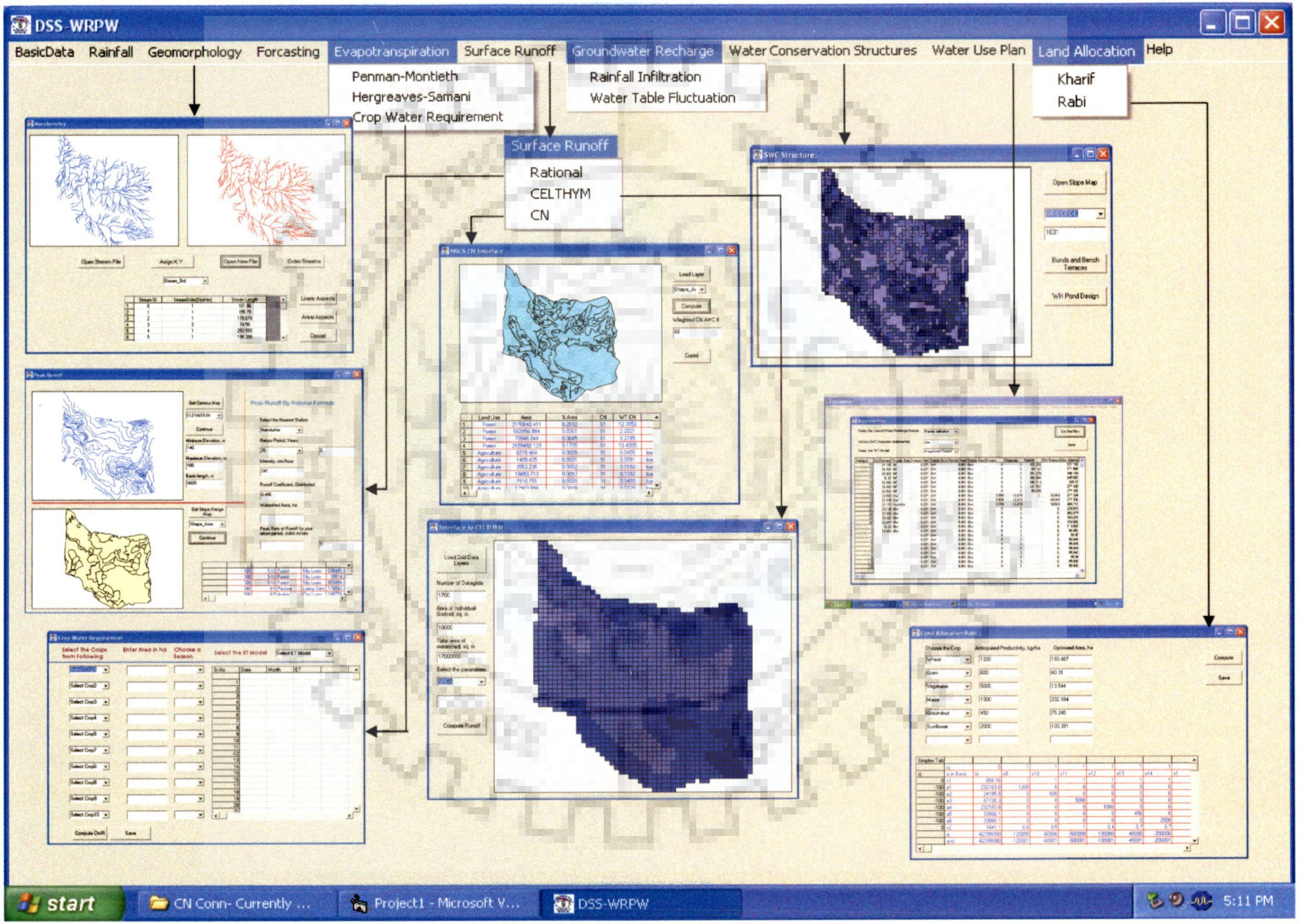


Fig. 9.1 An overview of module and sub-module components of developed DSS

3. Water resources assessment (Surface & Groundwater) models have been implemented in GUIs to demonstrate their application. There are two modules in each part i.e. surface (NRCS CN and CELTHYM) and ground water (Rainfall Infiltration and Water Table Fluctuation), which have different input data needs. The application of GUI for assessment of surface water to the selected watershed has been found to be reliable for three years data i.e. 2001 to 2003. The R^2 value computed for observed and computed daily runoff is in the range of 0.7 to 0.95 in case of NRCS CN, while it is 0.53 to 0.92 in case of CELTHYM.

   The rainfall infiltration module of groundwater assessment has yielded the recharge value of 158.51 ha-m in the first test case, while it is found to be 183.91 ha-m in the second test case. The water table fluctuation module gives the recharge estimate of 196.10 ha-m in the first test case. The estimates provided by these modules are in the acceptable limits.

4. An interactive module has been developed for the habitant population forecasting. The module gives water and food/fodder demand for the year of forecast. Two other modules have been developed to estimate the potential evapotranspiration in the watershed, based on the data input, i.e. one, which needed detailed climatic data (Penman-Montieth) and other requiring minimum input data (Hargreaves-Samani). The module for estimating agricultural water demand has been also developed and demonstrated.

5. A decision module has been developed for suggesting the water conservation structures, which gives the length of representative conservation structures selected in the study. A separate module has been developed to give water balance and design of water harvesting ponds under different module operational scenarios. The DSS-WRPW suggests the need of 211.771 length km of contour bunds, 294.401 km length of graded bunds and 363.149 km length of bench terraces. However, its structural design will be based on the actual site conditions.

6. A policy for operational planning (fortnightly) of water resources has been formulated and implemented through integration of all GUIs and modules in a separate decision making module. The working of this module has been demonstrated with different scenarios in the existing and future conditions.
7. A prototype DSS has been demonstrated for Khadak Ohal watershed through different scenarios generated in the existing and future test cases. In the first test case i.e. real physical system of watershed, first scenario, produced the maximum water surplus of 300.855 ha-m after fulfilling all the water demand. In this test case, it is assumed that there is no water harvesting and *Rabi* crops available. In the test case two i.e. future system of watershed (with water harvesting and *Rabi* crops) first scenario produced a water surplus of 560.675 ha-m after meeting all water demands in the watershed. Based on these scenarios, it is suggested that for more realistic results, the user may run the DSS-WRPW at September end. The combination of NRCS CN, Water Table fluctuation and Penman-Monteith module is expected to generate more realistic scenarios.
8. The study integrated spatial technologies, hydrological models and water resources decision policies in the form of platform independent software, which does not require any costly GIS package, conventionally used worldwide.

The following suggestions for further research and refining of the DSS components/interface are identified during the course of the present study:

1. The developed DSS can also be tested to other geographical area having similar characteristics; therefore attempts are required for application of this DSS in cooperation with implementing agencies.

2. The possibilities of integration of spatial data to the DSS presented in this research were limited to some GIS vector shape files; they can be further extended by adding raster data types. The study provided a semi-integration of hydrological models and spatial database and therefore the output generated by the models was limited to tabular format. Software could be improved by producing these outputs in the spatial format using Visual Basic with MapObjects.
3. The developed DSS suggests the length of contour bunds, graded bunds and bench terraces; more structures with their spatial positioning in the watershed can be also included. The geomorphology module may be extended in the runoff assessment using geomorphological approach.

Potential use of GIS and DSS in water resources planning and watershed management is yet to be appreciated by planners and managers in the developing countries. The developed DSS in the form of user friendly software (named DSS-WRPW) expected to be useful for various government and non government agencies involved in watershed management. The software can also be employed for domestic and agricultural water resources planning in the rural areas. It is hoped that with the reduced cost of hardware and software and availability of digital database with National Spatial Data Infrastructure (NSDI) in India, the DSS would form an essential tool for water resources planning exercises.

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