Application of *CPSP* model to Tapi River Basin

Final Project Report

National Institute of Hydrology
Roorkee - 247667

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CHAPTER - 1
INTRODUCTION

1.1 General

Extensive discussions and consultation among several international organizations and experts led to the preparation of World Water Vision. This was presented during the World Water Forum held at The Hague, The Netherlands during the year 2002. This vision document had projected large increases in global water withdrawals and storage of water for expansion of irrigation, the projected increase was quite substantial for the developing countries. However, there was no unanimity on the general conclusions and as a follow up, the International Commission on Irrigation and Drainage (ICID) initiated a project entitled “Country Policy Support Program (CPSP)”.

CPSP envisages a more detailed assessment of the water situation in a few representative river basins for conditions as in the past, as at present, and likely in future, discussions on these assessments through consultations at the respective basin and national levels, and the use of these findings in a review of the national policies related to water resources. The CPSP specifically envisages addressing future water scenario for food & rural development, water for people as also water for nature, in the attempt to consider the needs of the three sectors in an integrated manner in the broader context of Integrated Water Resources Development and Management (IWRDM) for sustainable water use.

The current form of Indian component of the CPSP is based on the study of the comparatively wet east coast Brahmani River flowing into the Bay of Bengal and the relatively dry west coast Sabarmati River flowing into the Arabian Sea. A preliminary assessment of the water availability and water use conditions of these basins was made and formed the basis of the basin level consultations during January 2003 at Bhubaneswar & Ahmedabad. Subsequently, the preliminary studies were presented in 3rd WWF in March 2003 in the ICID Session at Kyoto, Japan. Efforts for improvements in the approach used in the preliminary basin assessments as well as collection of more detailed sub-basinwise and seasonal data for refining assessments have continued.

A workshop was held at NIH, Roorkee, on Dec. 12, 2003 in which the results of the application of the CPSP hydrological model for Sabarmati and Brahmani basins were presented. It was felt that some additional studies have to be undertaken to assess the water situation in other river basins of the country. On the request of ICID, NIH has agreed to apply the existing CPSP model for two other river basins in India, Tapi and Pennar.

1.2 Scope of the Work

As regards the application of CPSP model to the Tapi basin, the scope of the work included analysis of past, present and future alternate water resource developmental scenarios. It has been envisaged that mostly secondary data would be used in the present work.

Computation of land parcels is one of the most exhaustive inputs for the *CPSP* model. Preparation of land parcels from the raw data was a tedious and time-consuming procedure. In addition to the envisaged scope of work, NIH has developed a user-friendly spreadsheet based program to generate land parcels from the raw data. The program makes it very easy to prepare land parcels. This module is a noteworthy contribution of NIH to the *CPSP* modeling system.

1.3 Organisation of the Report

The second chapter describes the spreadsheet based program developed at NIH for preparation of land parcels using the crop and land use data. The description of the Tapi basin is presented in Chapter - 3. The preparation of input data of the Tapi basin for the CPSP model is presented in Chapter – 4. Chapter -5 contains the calibration and validation results, values of different parameters, and the detailed results of different scenarios that were simulated for the basin. The results have also been summarized in the form of a summary table. The conclusions of the study are presented in Chapter – 6.

1.4 Acknowledgements

In the beginning, it was envisaged to use mostly the secondary data. However, with the progress of work, it was realized that the results from secondary data will be quite far from the reality. Therefore, extensive efforts were made to collect the data as realistically as possible. We would like to thank the concerned officers of the Central Water Commission and the State Government Departments for providing the data of the Tapi basin. Shri K. A. D. Sinha, helped in obtaining the crop data for the study basins. Shri Sanjay Belsare was very helpful in providing the land use and crop data for the Maharashtra part of Tapi basin and officers from Gujarat provided similar data for Gujarat portion. Thanks are also due to Shri S. K. Sharma, CGWB for providing ground water data of the two basins.

We had detailed discussions on various aspects of this study and about the CPSP Model with officers of ICID, namely Shri M. Gopalkrishnan, Secretary General, ICID & Dr. S. A. Kulkarni, Director, ICID. The application of a detailed and a sophisticated model such as the CPSP Model would not have been possible without the guidance of Shri A. D. Mohile and Shri L. N. Gupta who have developed this model and have applied it to other basins.

Thanks are also due to the scientists of NIH, Sh. A. K. Lohani, Sc. “E1” and Dr. R. Jha, Sc. “E1” for their association, continuous discussion, and feedback for this study. The staff of the Water Resources Systems Division of NIH is also thankfully acknowledged who have helped in data collection, entry, and processing.

* * *

CHAPTER - 2
MODULE FOR COMPUTATION OF LAND-PARCELS FOR *CPSP* MODEL

2.1 Introduction

The *CPSP* model divides the entire sub-basin in around 20 land parcels. Water balance for each land parcel depends on its characteristics, such as the land use/crop type, irrigated/rain-fed conditions, period of year during which crop remains on the land, crop water requirements etc. Computation of land parcels constitutes one of the most exhaustive inputs for the *CPSP* model. Preparation of land parcels from the raw data is a tedious procedure and is time consuming. NIH has developed a module to generate land parcels from the raw data. This is a very user-friendly spreadsheet based program which makes it very easy to prepare land parcels. This module is a noteworthy contribution of NIH to the *CPSP* modeling system.

For determining different land parcels for a sub-basin in a year, the land use data, cropping pattern details, crop-wise irrigated areas and the source-wise (surface water or groundwater) irrigated areas are needed for all the districts that lie within each sub-basin of a study basin. Such data are obtained from the Statistical Yearbooks prepared by the Directorate of Economics and Statistics (D.E.S.) of different States. Knowing the percent area of each district lying within different sub-basins of the basin, the land use data are proportionately reduced to obtain the values for the portion of the district falling within each sub-basin.

In the following section, the module that computes various land-parcels of the *CPSP* model is described. The module has been divided in various worksheets: General_Details, Land-Use_Parcels, Crop_Parcels, Waterspread_Parcel, and Final_Land_Parcels. Each worksheet has three different types of data cells: a) pink cells (for entry of mandatory data), b) green cells (for entry of desirable data which is not mandatory but helps in applying various checks), and c) blue cells (for computation only). Working procedure of each sheet is described in the following:

2.2 General_Details Worksheet

This worksheet is provided to enter the general details of the basin, such as the basin name, year for which land-parcels are being computed, basin area, number of sub-basins, names and areas of different sub-basins, number of districts that cover the basin, names and areas of different districts, and the percentage areas of different districts that lie within each sub-basin. For the purpose of computations in MS-Excel, each district is allocated a numeric identifier. Based on the number of districts that cover the entire basin, numeric identifiers are specified by the module and the user is required to enter the names and areas (optional) of different districts corresponding to various numeric identifiers.

After specifying the names of various districts in the basin against numeric identifiers, the user is required to specify the numeric identifiers of different districts (in increasing order of magnitude) that lie within each sub-basin and their percentage areas within the sub-basin. After the numeric identifiers of different districts falling within a sub-basin are specified, the corresponding names of districts are picked up by the program and invoked in the adjacent column. Based on the total area of each district and its percentage area within a sub-basin, the module calculates the area of each district that lies within a sub-basin. The program also computes the sum of areas of all districts that lie within the sub-basin and matches the same with the specified area of sub-basin. If the difference between the two exceeds 0.1% of the specified sub-basin area, a warning is issued to check the areas. The program also checks the sum of various sub-basin areas with the specified area of total basin.

2.3 Land-Use_Parcels Worksheet

Four land use parcels have been specified in the *CPSP* model: a) forest and miscellaneous trees, b) permanent pastures, c) land not available for cultivation, waste and fallow land, and d) land under reservoirs. This worksheet computes the first three land-use parcels for different sub-basins. The sheet contains form for the entry of district-wise data of land-use in the basin. Various land-use data that are considered by the program include forest area, barren and uncultivable land, land put to non-agricultural use, cultivable waste land, permanent pastures, land under miscellaneous crops and trees, fallow land, net sown area, area sown more than once, gross sown area, net irrigated area, and gross irrigated area. Forest area and land under miscellaneous trees together constitute the first parcel while the sum of barren and uncultivable land, land put to non-agricultural use, cultivable waste land, and fallow land constitute the third land parcel.

In this worksheet, the names and numeric identifiers of different districts that lie within the basin and within each sub-basin are automatically picked up from the General_Details worksheet and displayed in relevant cells. The user is only required to enter the district-wise values of different land-use areas (as specified in the Para above). The program proportionately reduces the district-wise values for each sub-basin (depending on the districts which form part of the sub-basin and their percentage areas as specified in the General_Details worksheet) and computes the three land-use parcels for each sub-basin.

The program also checks the sum of different land-use areas of a district with the reported area of the district (specified in the General_Details worksheet). If the difference between the two exceeds 0.1% of the district area, the program issues a warning so that the user can check various areas for a district. After checking the total area and different land-uses areas of warned districts, if the user feels that the areas specified in the module are correct, then the program distributes the difference between calculated and reported district area among various land use areas in proportion to their contribution to the total district area such that the total computed district area matches with the reported district area. The modified values of different land-use areas are used for deriving various land-use parcels.

2.4 Crop_Parcels Worksheet

The *CPSP* model uses a number of crop parcels. These are: a) rainfed Kharif paddy only, b) rainfed perennial, c) rainfed two seasonal, d) rainfed Kharif followed by Rabi, e) rainfed other Kharif only, f) rainfed other Kharif followed by irrigated

Rabi, g) irrigated Kharif paddy only, h) irrigated perennial, i) irrigated two seasonal, j) irrigated other Kharif followed by irrigated Rabi, k) fallow in Kharif and irrigated Rabi, l) irrigated other Kharif only, m) irrigated Rabi and Hot Weather (HW), n) fallow in Kharif, irrigated Rabi and irrigated HW, o) fallow in Kharif, irrigated Rabi and irrigated HW paddy, and p) irrigated Kharif, fallow in Rabi, irrigated HW.

From the Statistical Yearbooks of D.E.S., district-wise cropping pattern data, irrigated areas of different crops, source of irrigation, net irrigated area, gross irrigated area, net sown area, and area sown more than once can be obtained. Using these data, a number of logical expressions have been developed to classify the crop areas and irrigated areas into various crop parcels as required by the *CPSP* model. As for Land-Use_Parcels worksheet, the names and numeric identifiers of different districts that lie in the basin and within each sub-basin are picked up from the General_Details worksheet and specified in relevant cells. The user is required to provide three types of information: a) type of crop [whether single-season (represented by 11), two-seasonal-Kharif-Rabi (represented by 21), two-seasonal-Rabi-Hot-weather (represented by 22), or perennial (represented by 31)], b) district-wise acreage for different crops, and c) district-wise irrigated area of different crops. Corresponding to a number of crops specified in the D.E.S. records, columns have been specified and the user can enter the acreage of a crop in the relevant column. Further, to differentiate between a single crop being sown in different seasons (Kharif, Rabi, and Hot-weather), three columns have been reserved for each crop and different acreage of a single-season crop in different seasons can be specified in different columns. It needs to be mentioned here that if a crop is two-seasonal or perennial, its acreage needs to be specified only once (preferably in the column of starting season of the crop). The identifier of the type of crop (11, 21, 22, or 31) should also be specified in the same column in the relevant row. Similar to the acreage, the irrigated areas of different crops in different seasons need to be specified by the user.

As in case of Land-Use_Parcels worksheet, the program checks the sum of different crop areas of a district with the gross sown area of the district (specified in the Land-Use_Parcels worksheet). Similarly for the irrigated crop areas, the program checks the sum of irrigated areas of different crops of a district with the gross irrigated area of the district (specified in the Land-Use_Parcels worksheet). If the difference between the reported and computed values exceeds 0.1% of the district area, the program issues a warning so that the user can check various crop areas and irrigated areas for a district. After checking various areas of warned districts, if the user feels that the areas specified in the module are correct, then the program distributes the difference between calculated and reported areas among various areas (crop areas and irrigated areas as the case may be) in proportion to their contribution to the gross sown area and gross irrigated area such that the computed areas match with the reported area for each district. The modified values of different crop areas and irrigated areas are used for deriving various crop parcels.

After finalizing the district-wise crop areas and irrigated areas, the module proportionately reduces the district-wise values for each sub-basin (depending on the districts which form part of the sub-basin and their percentage areas as specified in the General_Details worksheet) and computes the total areas and irrigated areas of different crops for each sub-basin. Then, based on the types of different crops, various crop areas are classified and accumulated under the following categories: paddy crops, two-seasonal (K-R) crops, two-seasonal (R-H) crops, perennial crops, other Rabi crops, other Kharif crops, and Hot-weather crops. Similarly, irrigated areas of individual crops are also accumulated separately in these classes. After classifying various crops in specified major classes, different land parcels are prepared by utilizing the information of area sown more than once (ASMO) and area irrigated more than once (AIMO) in each sub-basin (obtained from Land-Use_Parcels worksheet). The steps for estimation of crop parcels are specified below:

i) *Rainfed Kharif Paddy Only (P5):* It is greater of the (total Kharif paddy – irrigated Kharif paddy) and zero.

ii) *Rainfed Two-seasonal (P6):* It is greater of the (total two-seasonal crop – irrigated two-seasonal crop) and zero.

iii) *Rainfed Perennial (P7):* It is greater of the (total perennial crop – irrigated perennial crop) and zero.

iv) *Irrigated Kharif Paddy Only (P11):* It is equal to the irrigated area of Kharif paddy.

v) *Irrigated Two-seasonal K-R (P13):* It is equal to the irrigated area of two-seasonal K-R crops.

vi) *Irrigated Two-seasonal R-H (P14):* It is equal to the irrigated area of two-seasonal R-H crops.

vii) *Irrigated Perennial (P12):* It is equal to the irrigated area of perennial crops.

viii) Fallow in Kharif, Irrigated Rabi, and Irrigated HW Paddy (P17): For its calculation, the values of ASMO and AIMO are utilized. If AIMO (gross irrigated area – net irrigated area) is less than ASMO, then *P17* parcel is the minimum of irrigated Rabi crops, irrigated HW paddy, or the AIMO. If AIMO is greater than ASMO, then this parcel is minimum of the irrigated Rabi crops, irrigated HW paddy, or the ASMO.

ix) Fallow in Kharif, Irrigated Rabi, and Irrigated HW (P16): For its calculation again, the ASMO and AIMO are utilized. If AIMO is less than ASMO, then *P16* parcel is the minimum of (irrigated Rabi crops-P17), irrigated HW crops, or the (AIMO-P17). If AIMO is greater than ASMO, then this parcel is minimum of the (irrigated Rabi crops – P17), irrigated HW crops, or the (ASMO – P17).

x) Irrigated Other Kharif and Irrigated Rabi (P15): For its calculation again, the ASMO and the AIMO are utilized. If AIMO is less than ASMO, then *P15* parcel is the minimum of irrigated other Kharif crops, (irrigated Rabi crops – P16 – P17), or the (AIMO - P16 - P17). If AIMO is greater than ASMO, then this parcel is minimum of irrigated other Kharif crops, (irrigated Rabi crops – P16 – P17), or the (ASMO – P16 – P17).

xi) Irrigated Other Kharif, Fallow Rabi, and Irrigated HW (P20): For its calculation again, the ASMO and the AIMO are utilized. If AIMO is less than ASMO, then *P20* parcel is the minimum of (irrigated other Kharif crops – P15), (irrigated HW crops – P16), or the (AIMO – P15 - P16 - P17). If

AIMO is greater than ASMO, then this parcel is minimum of (irrigated other Kharif crops – P15), (irrigated HW crops – P16), or the (ASMO – P15 - P16 – P17).

xii) *Rainfed Other Kharif followed by Rainfed Rabi (P8):* It is the minimum of rainfed other Kharif crop area, or rainfed Rabi crop area, or (ASMO-P15-P16-P17-P20).

xiii) *Rainfed Other Kharif and Irrigated Rabi (P10):* If the rainfed other Kharif crop area is not exhausted (after being accounted for under parcel P8), the irrigated Rabi area is still left (after being accounted for under parcel P15, P16, and P17), and the ASMO is also not exhausted (after being accounted for under parcels P8, P15, P16, P17, P20), then the area under parcel *P10* is minimum of the (rainfed other Kharif area – P8), (irrigated Rabi area – P15 – P16 – P17), and the (ASMO - P8 - P15 – P16 – P17 – P20).

xiv) *Rainfed Other Kharif only (P9):* If some rainfed other Kharif crop area is still left (after being accounted for under parcels P8 and P10), then the area under this parcel is the area of (rainfed other Kharif crops – P8 – P10).

xv) *Irrigated Rabi only (P18):* If the irrigated Rabi crop area is still left (after being accounted for under parcels P10, P15, P16, and P17), then the area under *P18* is the area of (irrigated Rabi crops – P10 – P15 – P16 – P17).

xvi) *Irrigated Other Kharif Only (P19):* If the irrigated other Kharif area is still left (after being accounted for under parcel P15 and P20), then the area under *P19* is the area of (irrigated other Kharif crops – P15 – P20).

xvii) *Fallow in Kharif and Rainfed Rabi (P21):* This is a new parcel added to the existing list of 20 parcels. The need for this parcel arose from the unaccounted large amount of rainfed Rabi crop area that could not be covered under any of the standard land parcels. It is evaluated as the (rainfed Rabi crop area – P8).

These logical expressions have been programmed in MS-Excel as formulae. The sum of all parcels from P5 to P21 gives the net sown area (NSA) while the sum of net sown area with the area of all those cells having double cropping gives the gross sown area (GSA). Similarly, the sum of all irrigated crop parcels (P11 to P20) gives the net irrigated area (NIA) while the sum of net irrigated area with the area of all those cells having double irrigated cropping (P15, P16, P17, P20) gives the gross irrigated area (GIA).

2.5 Waterspread_Parcel Worksheet

In the CPSP model, land-parcel (*P4*) represents the water spread area of all the water bodies lying within a sub-basin. In this worksheet, the user is required to enter the name, capacity (optional) and water spread area of each reservoir lying within a sub-basin. The program computes the total water spread area of all the water bodies under a sub-basin and this information is picked up by the Final_Land_Parcels worksheet.

2.6 Final_Land_Parcels Worksheet

In this worksheet, various land and crop parcels computed in different worksheets are picked up and displayed against their name and sub-basin. Since the waterspread area of different water bodies in a district is covered under the "land not available for cultivation, waste and fallow land", the waterspread area in a sub-basin [Parcel (*P4*), picked from Waterspread_Parcel worksheet] is subtracted from the "land not available for cultivation, waste and fallow land" [Parcel (*P3*) picked up from the Land-Use_Parcels worksheet] and the reduced *P3* is represented as parcel *P3*. The sum of all the land-parcels under a sub-basin is compared with the reported sub-basin area. Any discrepancy between the two is settled by adjusting the areas of different crop parcels (*P5* to *P21*) in proportion to their areas in the sub-basin.

For the purpose of checking the accuracy of computations, this worksheet also provides a comparison of computed and reported net sown area, gross sown area, net irrigated area and gross irrigated area for all the sub-basins of the basin.

* * *

CHAPTER – 3
DESCRIPTION OF TAPI BASIN

3.1 The Tapi River Basin

The Tapi River is the second largest west flowing river of India with its catchment area lying in the States of Madhya Pradesh, Maharashtra and Gujarat States. The river originates in the highlands of the Satpura hills near Multai town in Betul district of Madhya Pradesh at an elevation of 752 m above mean sea level (MSL) and finds its outlet in the Arabian Sea after traversing a total length of 724 km. For first 282 km, the river flows in Madhya Pradesh, for the next 228 km, it flows in Maharashtra and for the remaining 214 km, it flows in Gujarat.

The Tapi basin is the northern-most basin of the Deccan Plateau and lies between East Longitude 72^o 38' to 78^o 17' and North Latitude 20^o 05' to 22^o 00'. The Satpura range forms its northern boundary, Mahadeo hills form its eastern boundary and the Ajanta and Satmala hills form its southern extremity. Bounded on the three sides by the hill ranges, the Tapi River along with its tributaries flows over the plains of Vidarbha, Khandesh, and Gujarat. The total catchment area of Tapi basin up to its confluence with Arabian Sea is 65,145 sq. km whereas its catchment area up to Ukai dam is 62,225 sq. km. Nearly 80% of the basin lies in State of Maharashtra. The state-wise distribution of the basin area is presented in Table – 3.1. An Index map of the Tapi basin is presented in Figure – 3.1. The map also shows the locations of existing, on-going and planned projects, and various gauging sites in the basin. District boundaries under different states are shown in Figure – 3.2.

Table - 3.1
State-wise distribution of the catchment area of Tapi basin

State	Geographical area falling in Tapi Basin (Sq. km)	Percent of total basin area
Madhya Pradesh	9804	15.00
Maharashtra	51504	79.10
Gujarat	3837	05.90
Total	65145	100.00

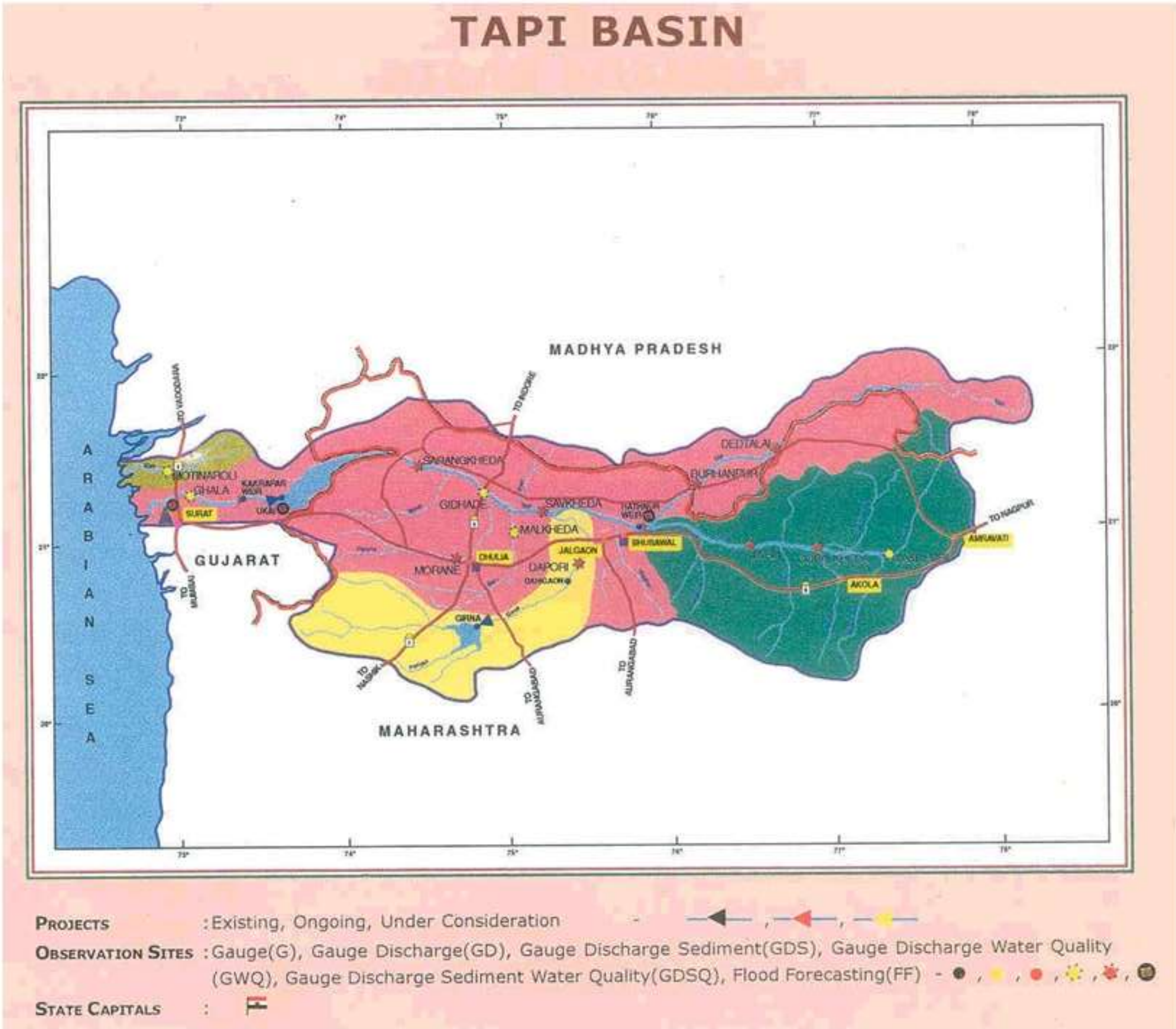


Figure – 3.1 Index map of Tapi River Basin

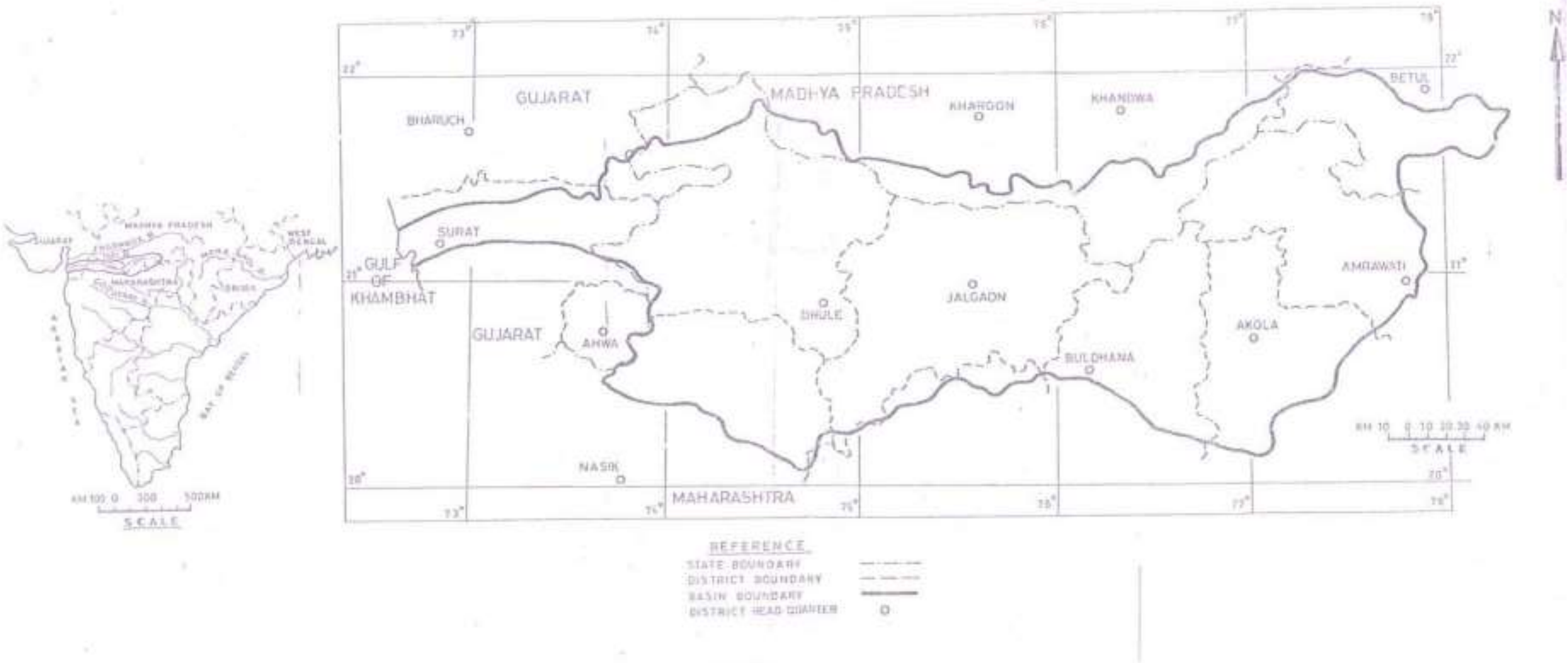


Figure – 3.2 Boundaries of different districts in Tapi basin

3.2 Main Tributaries of Tapi River

The Tapi River receives several tributaries on both the banks. There are 14 major tributaries having a length more than 50 km. On the right bank, 4 tributaries, namely Vaki, Aner, Arunawati, and Gomai have their origin in Satpura ranges and flow generally in South-West direction. They are comparatively of shorter length and individually drain small areas as they descend down the steep slopes of the Satpuras. On the left bank, 10 important tributaries, namely Nesu, Amravati, Buray, Panjhara, Bori, Girna, Waghur, Purna, Mona, and Sipna drain into the main Tapi River. The left bank tributaries rise in Gawaligarh hills, Ajanta hills, the Western Ghats, and the Satmalas. These rivers are of comparatively longer length with fairly large individual drainage areas. The Purna and the Girna rivers together account for nearly 45% of the total catchment area of the Tapi basin. Major tributaries of the Tapi basin are shown in Figure – 3.3. A brief description of some major tributaries is given below.

a) Purna River

The Purna River is the largest tributary of the Tapi River rising in the Betul district in Gawaligarh hills of the Satpura range. It is the main artery for a large network of rivers and streams draining Akola, Amrawati and Buldhana districts of Maharashtra. The river has perennial flow. Its total length is 274 km. It joins Tapi north-west of Edalabad town. The Purna River drains an area of 18,580 sq. km.

b) Waghur River

The Waghur River rises in Ajanta hills at an elevation of 751 m and flows in a northern direction for 96 km before joining the Tapi River north-west of Bhusawal town. Waghur drains an area of 2525 sq. km.

c) Girna River

The Girna River rises in Western Ghats at an elevation of 900 m and drains the Nasik and Jalgaon districts of Maharashtra. It joins the Tapi River near Nanded after traversing a distance of 265 km in the Maharashtra State and drains an area of 10249 sq km, which is nearly 16% of total area of Tapi Basin.

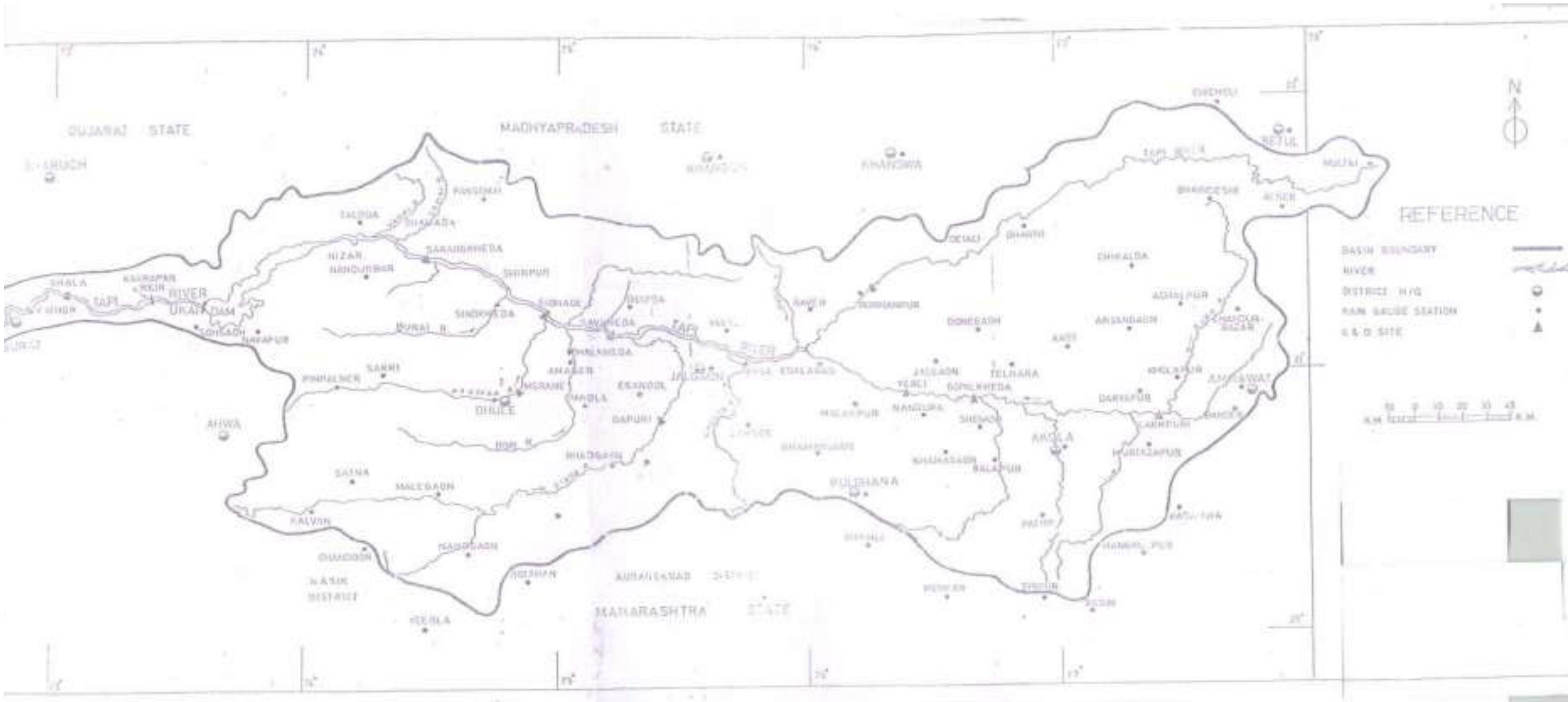


Figure – 3.3 Major rivers and hydro-meteorological stations in Tapi Basin

d) Bori River

The Bori River rises at an elevation of 600 m, flows first in easterly direction and then north direction to join Tapi River east of Botwad. It has a length of 130 km and drains an area of 2429 sq. km.

e) Panjhra River

The Panjhra River rises near Pimpalner from the Western Ghats at an elevation of about 600 m. It joins the Tapi River south of Talner. Its length is 138 km and it drains an area of 2849 sq. km.

f) Burai River

The Burai River rises in Satmala hills at an elevation of about 600 m. It has a total length of 87 km and drains an area of 1,127 sq. km.

g) Aner River

The Aner River is the largest north bank tributary of Tapi River with a length of 94 km. It rises in the Satpura hills at an altitude of about 600 m and drains an area of 1,399 sq. km before joining the Tapi River south of Hol.

h) Arunawati River

The Arunawati River rises at an elevation of 450 m in Satpura hills, flows for 53 km to join Tapi River east of village Virdal. River drains a total area of 798 sq. km.

i) Gomai River

The Gomai River rises at an elevation of 600 m in Satpura hills, flows in a south–westerly direction for about 58 km to join the Tapi River near village Prakasha. Its catchment area is 1311 sq. km.

3.3 Topography, Physiography and Geology of Tapi Basin

The Tapi basin is bounded on the north by the Satpura range, on the east by the Mahadeo hills, and on the south by the Ajanta and Satmala ranges. The basin has elongated shape with a maximum length of 587 km from east to west and a maximum width of 210 km from north to south.

The Tapi basin has two well-defined physical regions, viz. the hilly regions and the plains. The hilly regions cover the Satpura, the Satmala, the Mahadeo, the Ajanta and the Gawaligarh hills and are well forested. The plains cover the Khandesh plains which are broad and fertile areas suitable for cultivation.

The basin in Madhya Pradesh is mostly covered with Deccan trap lava flows. Other formations found in the basin are alluvium, lower Gondwana, Cuddapah system, Bijawar series, and Granite Gneiss. Most of the area of Tapi basin falling within Maharashtra State is full of cuts & valleys. Lands on the right side of the river lying on southern slopes of Satpura hills consist of black soils. The soil cover is deep and rock is found at greater depths. Lands on the left side of the river on northern slopes of Sahyadri consist mainly of dykes & red murrum soil and are rocky in most part.

3.4 Rainfall and Climate of Tapi Basin

The annual average rainfall in the Tapi basin is 830 mm and it is in medium rainfall zone. The south-west monsoon sets in by the middle of June and withdraws by mid-October. About 90% of the total rainfall is received during the monsoon months, of which 50% is received during July and August. There are 70 raingauge stations in and around the basin up to Ukai dam.

The climate of the basin is characterized by hot dry summer and winter. Owing to topographical characteristics, the climate is variable. In winter, the minimum temperature varies from 10°C to 14.5°C. May is the hottest month with temperature varying from 38°C to 48°C. The Purna sub-catchment of the Tapi basin is one of the hottest regions of India. Eight IMD observatories at Betul, Amrawati, Akola, Khandwa, Buldhana, Jalgaon, Malegaon and Surat are located in and around the basin.

3.5 Soils and Land Use in Tapi Basin

The soils in the Tapi basin can be broadly classified into 3 groups, viz. 1) coarse shallow soils, 2) medium black soils, and 3) deep black soils. The area covered by these three groups of soils in the basin is given in Table – 3.2.

Table – 3.2
Soil-wise Break-up of the Catchment Area of Tapi Basin

S. No.	Type of soil	Districts covered
1.	Coarse shallow soil	Betul, Khandwa, Khargaon, Amrawati, Akola, Buldhana, Jalgaon, Dhule, Aurangabad and Nasik.
2.	Medium black soil	Khandwa, Amrawati, Akola, Buldhana, Jalgaon, Dhule and Nasik.
3.	Deep black soil	Amrawati, Akola, Buldhana, Jalgaon, Dhule, Nasik, Surat and Bharuch.

Coarse shallow soils have developed primarily from the basaltic Deccan traps and have depth generally between 25 cm to 50 cm and seldom more. Their texture from surface to sub-surface varies from silt-loam to clay. Medium black soils have developed from Deccan traps and cover the largest area of the basin. Their depth is generally between 50 cm to 1 m. Deep black soils are found along the Purna River and in the middle & lower reaches of Tapi River. These soils have originated primarily from decomposition of trap rocks of hilly ranges and their depth varies from 1 to 6 m.

The major land use of the basin in the year 1995-96 is presented in Table – 3.3. The values of different land use categories are derived by proportionately reducing the district-wise statistics in the ratio of the percentage area of different districts falling within the Tapi basin. It is seen from the statistics that major part of the land use is covered by the forests (> 20%) and the cultivated area (around 60%). The important crops grown in the basin are cotton, jowar, bajra, oilseeds, wheat, paddy, tuar, black gram, fodder crops, vegetable, fruit, and sugarcane. The Tapi basin, as observed from the NOAA satellite, is presented in Figure – 3.4.

3.6 Population, Agriculture and Animal Husbandry

The population of Tapi basin, as per the 1991 census, is 12.576 million of

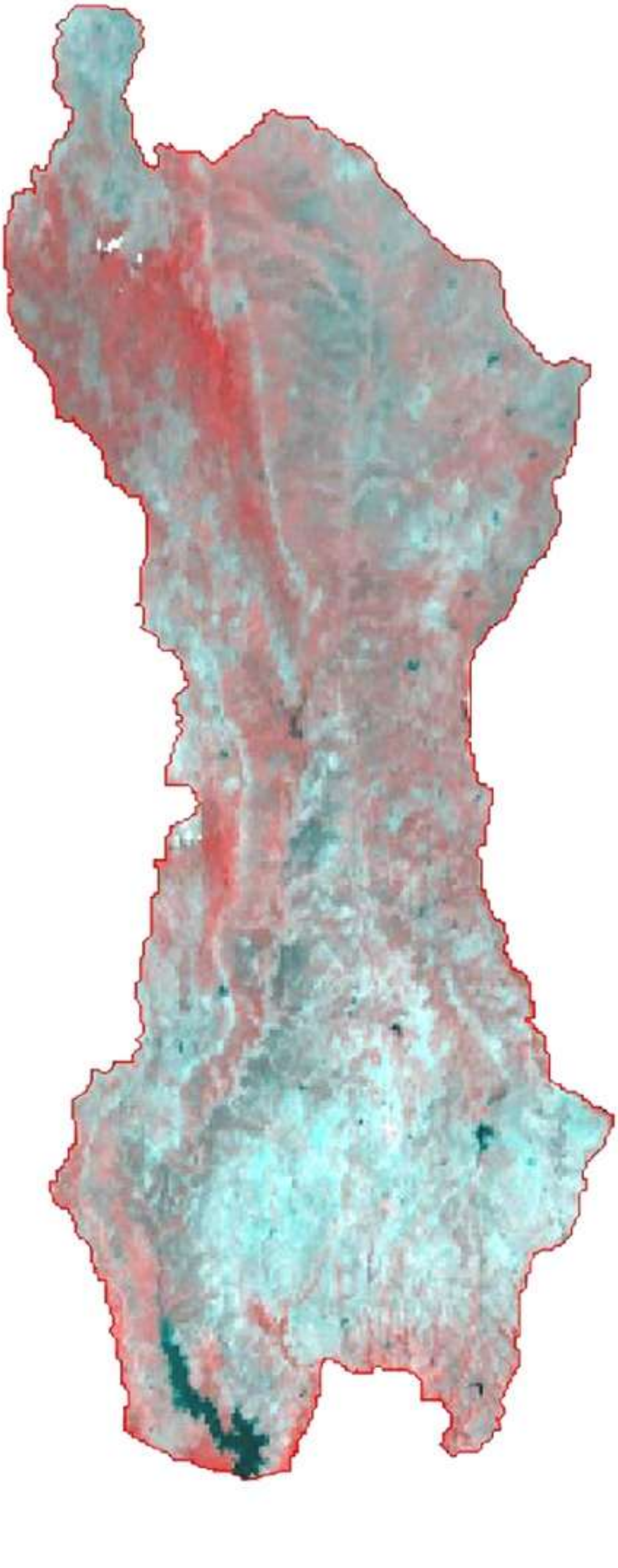


Figure – 3.4 A view of Tapi basin up to Ukai dam from NOAA Satellite

Table – 3.3
Major land uses in Tapi basin in the year 1995-96

Land use category	Area (sq. km)
Forest area	14788.72
Barren/Uncultivable area	2737.97
Non-agricultural area	2002.84
Cultivable waste land	719.21
Permanent pasture	2312.33
Miscellaneous crops/trees	118.43
Fallow land	1781.46
Net sown area	37765.07
Area sown more than once	8304.50
Gross sown area	46069.57
Net irrigated area	4335.02
Gross irrigated area	5741.84

which, the rural population is 9.132 million and the urban population is 3.444 million [NWDA Report (WB-194), 2002]. The basin population in the NWDA report was derived from the district-wise population census of year 1991 on proportionate area basis. In the report, 1991 population has been projected for the years 2020 and 2030 by adopting medium variant growth rates (1.10% and 0.92% respectively) provided in the U.N. publication "World Population Prospects – 1994 (revised)". The density of population in the year 1991 in Madhya Pradesh, Maharashtra and Gujarat is 128 per sq. km, 250 per sq. km, and 204 per sq. km respectively. In the NWDA report, the livestock population of the basin (7.0 million) is also estimated on proportionate area basis from the district-wise data of year 1992. For the year 2050, the projected livestock population has been worked out by assuming growth rate of 1%. In the present study, the projected livestock population for the year 2025 was assumed to lie mid-way between the populations for the year 1992 and 2050.

3.7 Water Resources Development in Tapi Basin

The utilizable water from Tapi River at Ukai dam has been estimated by Central Water Commission (CWC) to be 14500×10^6 m^3. According to the agreements among different states constituting the Tapi basin, the upstream utilization by riparian States of Maharashtra and Madhya Pradesh will be 5420×10^6 m^3 and 1980×10^6 m^3

respectively. The balance quantity of $7100*10^6$ m^3 can be utilized by Gujarat. As per the preliminary investigations carried out by the Government of Gujarat, the water requirements for irrigation uses from the Ukai reservoir are about $4546*10^6$ m^3 respectively. The surplus quantity of water available at Ukai reservoir has been estimated to be $1554*10^6$ m^3.

There is no import of water to the Tapi basin. However, water is exported from the Lower Tapi basin (from Ukai dam and Kakrapar weir). In the proposed Par-Tapi-Narmada interlinking scheme, it is planned to transfer $1554*10^6$ m^3 from the Ukai dam for meeting the demands in water deficit areas in North Gujarat. For the future scenario (2025), such export of water from Lower Tapi basin has been considered.

There are 12 G&D sites maintained by CWC in Tapi basin, viz. Dedtalai, Burhanpur, Lakhpuri, Gopalkheda, Yerli, Dapuri, Savkheda, Malkheda, Morane, Gidhade & Sarangkheda located upstream of the Ukai dam and Ghala G&D site located downstream of the Ukai dam. The Kathor G & D site is located downstream of the Ghala G & D site and is maintained by the Government of Gujarat.

There are 5 major, 27 medium and 364 minor existing irrigation projects in the basin with annual irrigation of 3,57,959 ha utilizing $2717*10^6$ m^3 of water. Most of these projects are located in Maharashtra portion only. Construction of 3 major, 24 medium and 123 minor projects is going on in the basin while 3 major, 4 medium and 197 minor projects are proposed to be constructed in future in the Tapi basin. Hathnur dam, Kakrapar weir, Ukai dam, Girna dam, and Dahigaon weir are some of the important hydraulic structures in the Tapi basin. Important existing major and medium hydraulic structures along with their capacities are presented in Table - 3.4. Information about these projects have been drawn from the Hydrological Year Book of the Tapi Basin (1998-99), published by the CWC. Information about the on-going major, medium and minor projects is obtained from the Annexure – 6.4 of the NWDA (2002) report. A district-wise list of on-going projects in the Tapi basin along with their design utilisation is presented in Table – 3.5.

Table – 3.4
Major/Medium existing projects in Tapi basin

Name of project	River	Status	Gross storage (10^6 m^3)	Live storage (10^6 m^3)	Utilisation
Upper Tapi Basin (up to Hathnur Dam)					
Sonkhedi Tank	Local Nala	Medium	5.45	4.59	Irrigation
Chandora	Tapi	Medium	18.2	16.48	Irrigation
Kate Purna	Kate Purna	Major	97.67	86.35	Irrigation/Domestic
Nal ganga	Nal ganga	Major	76.2	69.32	Irrigation/Domestic
Uma	Uma	Medium	14	11.68	Irrigation/Domestic
Nirguna	Nirguna	Medium	32.29	28.85	Irrigation/Domestic
Morna	Morna	Medium	44.74	41.46	Irrigation/Domestic
Gyan ganga	Gyan ganga	Medium	36.26	33.93	Irrigation/Domestic
Mos	Mos	Medium	17.5	15.14	Irrigation/Domestic
Paltag	Vishv ganga	Medium	9.09	7.51	Irrigation/Domestic
Man	Man	Medium	39.76	36.83	Irrigation/Domestic
Thoran	Tributary of Purna	Medium	8.48	7.9	Irrigation/Domestic
Hathnur	Tapi	Medium	388	255	Irrigation
Total			**787.64**	**615.04**	
Middle Tapi Basin (up to Gidhade Gauging Site)					
Girna	Girna	Medium	608.45	523.55	Irrigation
Dahigaon	Girna	Medium	-	-	Irrigation
Manyad	Manyad	Medium	53.95	40.27	Irrigation
Bori	Bori	Medium	40.3	25.15	Irrigation
Suki	Suki	Medium	50.16	39.85	Irrigation
Abhora	Boked Nalla	Medium	7.44	6.02	Irrigation
Boker Bari	Boker Bari Nalla	Medium	7.09	6.54	Irrigation
Agnawati	Agnawati	Medium	3.74	2.76	Irrigation
Titur	Titur	Medium	-	-	Irrigation
Tondapur	Khadki Nalla	Medium	4.63	4.64	Irrigation/Domestic
Aner	Aner	Medium	103.23	56.38	Irrigation
Karwand	Arunawati	Medium	33.84	31.15	Irrigation
Panjhra	Panjhra	Medium	43.41	35.63	Irrigation
Malangaon	Kan	Medium	13.02	11.35	Irrigation
Kanholi	Kanholi	Medium	11.79	8.45	Irrigation
Burai	Burai	Medium	21.33	14.21	Irrigation
Arunawati	Arunawati	Medium	27.78	14.97	Irrigation
Rangawali	Rangawali	Medium	15.02	12.89	Irrigation
Nagasakya	Panzar	Medium	15.62	11.24	Irrigation
Haran bari	Mausam	Medium	34.78	27	Irrigation
Total			**1095.58**	**872.05**	
Lower Tapi Basin					
Ukai	Tapi	Major	8510	7092	Irrigation & Power
Kakrapar	Tapi	Major	51.51	36.57	Irrigation/Domestic
Lakhigav	Dhakani	Medium	38.8	37.41	Irrigation
Ver	Ver	Medium	4.9	4.61	Irrigation
Total			**8605.21**	**7170.59**	

Table – 3.5
Major/Medium/Minor on-going projects in Tapi basin

Name of project	District	CCA (Ha)	Design irrigation (Ha)	Design utilization (10^6 m^3)
Maharashtra State (Major projects)				
Wan	Akola	22525	19177	84.4
Waghur	Jalgaon	29748	23580	307.0
Punand	Nasik	17841	10850	46.0
Maharashtra State (Medium projects)				
Chandrabhaga	Amrawati	7013	6732	51.54
Purna	Amrawati	7843	9815	48.99
Torna	Buldhana	1831	1428	7.36
Utawali	Buldhana	4650	5394	28.89
Bahula	Jalgaon	5487	4654	16.0
Gul	Jalgaon	3220	2630	16.0
Anjani	Jalgaon	3567	3670	16.0
Hiwara	Jalgaon	2923	2566	10.0
Mor	Jalgaon	3113	2160	8.0
Mangrul	Jalgaon	2404	2446	6.0
Lower Panzara	Dhule	9980	6810	99.0
Sulwade	Dhule	7560	7560	75.05
Wadi Shewadi	Dhule	7851	7180	35.0
Amrawati	Dhule	4005	3870	26.0
Sonwad	Dhule	3302	3450	22.0
Jamkhedi	Dhule	6270	4130	19.0
Shivan	Dhule	3547	2670	26.0
Dehali	Dhule	3706	3480	25.0
Prakasha	Dhule	9840	8860	82.98
Nagan	Dhule	3427	3000	27.0
Dara	Dhule	3523	3450	17.0
Kordi	Dhule	4032	3660	17.0
Sarangkheda	Dhule	9742	8768	79.01
Maharashtra State (Minor projects)				
5 Nos.	Amrawati	2123	1429	9.11
16 Nos.	Akola	9192	8037	49.32
42 Nos.	Jalgaon	14538	12880	102.0
50 Nos.	Dhule	23463	18879	124.3
4 Nos.	Nasik	1770	1348	7.0
Madhya Pradesh (Major projects)				
Nil	-			-
Madhya Pradesh (Medium projects)				
Nil	-			-
Madhya Pradesh (Minor projects)				
6 Nos.	Khandwa	-	1576	7.7
Total				**1495.75**

* * *

CHAPTER – 4

PREPARATION OF *CPSP* INPUT FOR TAPI BASIN

4.1 General

The Tapi basin up to the sea was divided in three sub-basins: Upper Tapi Basin up to Hathnur [confluence of Purna river with the main Tapi river (29430 sq. km)], Middle Tapi Basin from Hathnur up to the Gidhade gauging site (25320 sq. km), and Lower Tapi Basin from the Gidhade gauging site up to the sea (10395 sq. km). The CPSP model requires detailed input with respect to different land parcels in different sub-basins, hydrological variables, such as rainfall and evapo-transpiration at monthly time step, population details, storage filling and depletion details in various storage structures, proportion of surface and groundwater irrigation in the basin, and specification of various model parameters and constants.

Before beginning this study, it was planned to use secondary data for the CPSP model. However, during the course of this study, extensive efforts were made by NIH to collect detailed data from the concerned departments so that the analysis could be made as realistic as possible. The preparation of input details for the model for various years is described in the following.

4.2 Selection of Period of Analysis

Before acquiring the actual data for various years, it was required to identify the period of analysis for calibration and validation of the CPSP model and for analyzing various scenarios using the validated model parameters. Monthly flows (in 10^6 m^3) at a number of gauging sites (Burhanpur, Yerly, Savkheda, Malkheda, Morane, Dapuri, and Sarangkheda) were available from the NWDA Technical Study No. WB-194, October 2002 (Preliminary Water Balance Study of Tapi Basin up to Ukai Dam) for the period from 1979 onwards.

The flows at different gauging stations in different years are shown in Table – 4.1. These flows were analyzed and the years corresponding to dry, wet, and average

Table – 4.1

Flows (in 10^6 m^3) at different gauging stations in different years for determining average year

Gauging Station	Flow in Different Years																	Average Flow	Years Close to Average Flow			
	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995		I	II	III	IV
Burhanpur	4636	4644	5240	1816	5402	3885	1554	3765	1208	6553	3957	10588	2637	2889	6579	10301	3633	4664	1979-80	1980-81	1981-82	**1989-90**
Yerly	4703	1754	2341	647	3937	1073	1235	2641	723	7250	1813	4880	763	1730	1084	1963	1102	2332	1981-82	1986-87	**1989-90**	-
Savkheda	10162	6928	8932	2716	10090	6236	3046	7436	2293	15218	7198	14627	3671	4895	6863	13199	4379	7523	1986-87	**1989-90**	-	-
Malkheda	200	205	48	19	161	43	20	5	84	178	94	74	63	91	8	78	17	82	1987-88	**1989-90**	-	-
Morane	181	119	109	75	212	76	44	12	70	366	158	106	77	45	68	290	27	120	1980-81	1981-82	**1989-90**	-
Dapuri	473	522	243	133	703	149	71	84	204	817	608	691	404	653	236	736	55	399	1979-80	1980-81	1991-92	-
Sarangkheda	11989	8831	9907	3340	13742	3985	3469	6828	2738	16741	8204	16262	4219	5624	7844	14584	4180	8248	1993-94	**1989-90**	-	-
Average Year Identified – 1989-90																						

conditions were identified. The year 1987-88 was found to be the driest year during the period of available record while the years 1988-89 and 1990-91 were found to be the wet years. For all the gauging sites, the year 1989-90 was found to represent the average flow conditions. Based on these observations, the calibration of the model was carried out for the average year, i.e. 1989-90 and validation was carried out for two years 1988-89 and 1990-91. To analyze the past conditions in the basin, one year in the decade of 1960s was chosen for analysis while to analyze the present conditions, the data availability for one of the most recent years was investigated from various departments. Looking at the data availability, the year 1995-96 was chosen for analysis of present conditions. For various years selected for analysis, hydrological data, land use data, cropping pattern, source-wise irrigation done, and the storage filling/depletion details were required.

4.3 Rainfall Data

The application of CPSP model requires observed rainfall data at various stations for the analysis period (1987-88 to 1990-91). The same were obtained from the Executive Engineer, Tapi Division, C.W.C., Surat through the Office of the Chief Engineer, Narmada and Tapi Basin Organisation (NTBO), Vadodara, Gujarat.

To find the sub-basin-wise long-term average monthly rainfall, long-term average monthly rainfall of stations within the three sub-basins were considered and the arithmetic average rainfall was worked out. The rainfall stations considered for the purpose are mentioned below and their average monthly rainfall is presented in Table – 4.2.

For Upper Tapi Basin: Betul, Burhanpur, Dharni, Buldhana, Akola, and Amravati.
For Middle Tapi Basin: Jalgaon, Pimpalner, Amalner, and Malegaon.
For Lower Tapi Basin: Navapur, Shirpur, Taloda, and Songadh.

The annual rainfall for the upper, middle, and lower Tapi basins for the year 1989-90 (average year considered in this study) comes out to be 997.3 mm, 827.6 mm, and 1052.13 mm while the long-term average annual rainfall for these three sub-

Table – 4.2

Long-term average monthly rainfall (mm) in three sub-basins of Tapi basin

Stations	June	July	August	September	October	November	December	January	February	March	April	May
Upper Tapi Basin												
Betul	150.9	353.0	331.5	199.4	49.5	23.4	11.2	13.5	14.3	17.4	8.0	10.5
Burhanpur	153.3	226.4	210.4	166.0	57.7	19.2	10.8	6.5	4.5	5.0	1.9	10.7
Dharni	165.6	372.0	341.2	206.6	38.2	18.5	6.7	5.8	5.1	5.0	2.4	6.8
Buldhana	168.0	220.9	186.4	150.5	50.0	23.6	10.1	8.2	6.1	5.6	6.5	13.1
Akola	120.5	185.1	137.8	129.9	49.7	26.2	6.7	5.6	2.6	5.3	7.5	14.4
Amravati	140.7	233.3	189.2	153.0	42.3	18.1	13.0	11.1	12.6	11.3	8.1	11.6
Ave_Monthly	149.8	265.1	232.8	167.6	47.9	21.5	9.8	8.5	7.5	8.3	5.7	11.2
Middle Tapi Basin												
Jalgaon	123.6	189.5	158.2	142.8	48.1	17.2	8.4	7.8	6.8	4.4	3.1	9.2
Pimpalner	101.6	171.9	114.7	114.2	38.4	20.6	9.3	3.3	2.3	3.8	2.3	11.2
Amalner	126.6	189.6	152.1	119.2	41.8	18.0	5.2	4.7	3.1	3.8	2.1	6.9
Malegaon	104.3	112.1	88.5	131.7	43.7	23.4	6.9	3.7	2.3	2.1	3.2	18.5
Ave_Monthly	114.0	165.8	128.4	127.0	43.0	19.8	7.5	4.9	3.6	3.5	2.7	11.5
Lower Tapi Basin												
Navapur	154.2	415.3	302.4	177.8	42.2	13.0	5.6	3.3	1.1	1.0	1.7	5.2
Shirpur	117.2	205.8	146.9	114.8	33.6	12.7	3.7	3.9	1.4	2.8	1.7	7.6
Taloda	126.5	276.0	197.5	142.2	28.6	12.5	3.1	3.6	1.0	0.9	1.1	9.2
Songadh	216.0	636.6	449.4	228.7	44.0	6.0	4.0	2.5	1.5	1.0	1.5	1.0
Ave_Monthly	153.5	383.4	274.1	165.9	37.1	11.1	4.1	3.3	1.3	1.4	1.5	5.8

basins is calculated as 935.55 mm, 631.55 mm, and 1042.33 mm respectively. This shows close correspondence of long-term average rainfall with that of year 1989-90.

To find the actual average monthly rainfall for the period from 1987-88 to 1990-91, actual rainfall of the following stations within three sub-basins were considered and arithmetic average values were worked out. The actual average rainfall in different years in the three sub-basins is given in Table – 4.3.

For Upper Tapi Basin: Yerly, Amravati, Chikaldara, Lakhpuri, Burhanpur, Dedtalai, & Hathnur.

For Middle Tapi Basin: Bhusawal, Malkheda, Dahigaon, Dapori, Savkheda, Gidhade, & Sarangkheda.

For Lower Tapi Basin: Ukai dam, Sarangkheda, and Gidhade.

For the year 1987, the rainfall data of Amravati and Chikaldara stations in the Upper Tapi Basin were not available and average rainfall was worked out using the five other rainfall stations only.

4.4 Reference Evapo-transpiration

For finding the monthly reference evapo-transpiration in the three sub-basins, meteorological data of Akola (for Upper Tapi Basin), Jalgaon (for Middle Tapi Basin), and Surat (for Lower Tapi Basin) were used. Meteorological data included monthly minimum and maximum temperatures, average relative humidity, cloud cover, and wind speed. Average monthly values for the three stations were obtained from the NWDA (2002) report. Cloud cover values (in Oktas) were converted to the radiation term using the guidelines given in FAO-24 (1977). Reference monthly evapo-transpiration was calculated using the Penman-Monteith method with the CROPWAT 4 WINDOWS software. The data and the evapo-transpiration estimates for the three sub-basins are given in Table – 4.4.

Reference monthly evapo-transpiration values were assumed to be the same for all the years of analysis.

Table – 4.3

Monthly rainfall (mm) in three sub-basins of Tapi basin in different years

Month	Upper Tapi Basin				Middle Tapi Basin				Lower Tapi Basin			
	1987-88	1988-89	1989-90	1990-91	1987-88	1988-89	1989-90	1990-91	1987-88	1988-89	1989-90	1990-91
June	147.0	146.3	250.7	208.20	131.2	86.8	276.2	85.04	66.1	140.8	369.4	122.2
July	87.0	448.3	203.7	323.56	112.8	298.2	176.7	138.39	174.3	451.3	376.8	183.2
August	247.7	328.5	355.6	540.94	268.9	86.3	248.6	340.89	163.0	108.8	190.2	294.8
September	17.7	264.6	91.7	91.97	6.3	247.5	56.5	126.03	20.3	234.2	58.1	162.5
October	42.2	167.6	7.7	107.01	24.2	45.5	6.9	104.24	1.0	38.9	13.2	54.5
November	37.5	5.8	0.0	0.51	33.9	3.3	0.0	1.90	12.2	7.7	0.0	2.9
December	12.6	0.1	7.8	5.60	27.3	1.2	0.5	7.51	16.5	0.0	0.0	0.0
January	0.0	0.0	8.0	0.00	0.0	0.0	1.7	0.00	0.0	0.0	3.7	0.0
February	0.2	0.0	3.1	0.00	0.0	0.0	1.5	0.00	0.0	0.0	3.5	0.0
March	0.0	49.0	0.6	49.03	0.0	36.5	0.0	36.49	0.0	25.7	0.0	25.7
April	2.3	0.0	0.4	0.04	3.7	0.0	0.0	0.00	5.3	0.0	0.0	0.0
May	1.9	7.1	68.1	7.07	0.5	9.3	58.9	37.84	1.2	2.1	37.2	68.7

Table – 4.4

Evapo-transpiration estimation in three sub-basins of Tapi basin

Month	Max_temp	Min_temp	Max._Hum	Min_Hum	Av_Hum	Wind_Km/d	Cloud_Oktas	n/N	N	n	PET_PM (mm/d)	PET_PM (mm/m)
	For Upper Tapi Basin Using Akola Station Data (Altitude - 290 m, Latitude - 20.66 N, Longitude - 77 E)											
January	33	8.5	55	28	41.5	110.4	1.7	0.78	10.9	8.50	3.93	121.83
February	36.9	10.4	42	21	31.5	124.8	1.3	0.82	11.45	9.39	5.12	143.36
March	40.6	13.8	35	18	26.5	146.4	1.4	0.81	12	9.72	6.55	203.05
April	43.7	20.1	32	17	24.5	172.8	1.8	0.77	12.6	9.70	7.94	238.2
May	45.1	23	39	18	28.5	295.2	2.2	0.73	13.1	9.56	10.58	327.98
June	42.4	22.3	67	43	55	333.6	4.9	0.46	13.4	6.16	8.71	261.3
July	36.5	22	81	66	73.5	278.4	6.4	0.27	13.3	3.59	5.42	168.02
August	34.3	21.8	84	68	76	266.4	6.6	0.23	12.8	2.94	4.65	144.15
September	35.7	20.9	80	60	70	208.8	5.0	0.45	12.3	5.54	5.18	155.4
October	36.2	15.2	65	40	52.5	112.8	2.7	0.68	11.7	7.96	4.74	146.94
November	33.8	11.6	57	34	45.5	91.2	2.1	0.74	11.2	8.29	3.76	112.8
December	32.4	9	58	33	45.5	88.8	1.8	0.73	10.9	7.96	3.33	103.23
	For Middle Tapi Basin Using Jalgaon Station Data (Altitude - 220 m, Latitude - 21 N, Longitude - 75.56 E)											
January	33.5	6.7	58	28	43	110.4	1.7	0.78	10.9	8.50	3.95	122.45
February	37.6	8.2	43	19	31	124.8	1.2	0.83	11.45	9.50	5.18	145.04
March	41.7	12	36	15	25.5	146.4	1.3	0.82	12	9.84	6.67	206.77
April	45	18.7	36	14	25	172.8	1.6	0.79	12.6	9.95	8.12	243.6
May	45.8	23.5	54	19	36.5	295.2	1.5	0.8	13.1	10.48	10.64	329.84
June	42.9	22.5	73	44	58.5	333.6	4.6	0.49	13.4	6.57	8.73	261.9
July	37.7	22.4	85	65	75	278.4	6.6	0.23	13.3	3.06	5.43	168.33
August	34.8	21.7	88	72	80	266.4	6.8	0.19	12.8	2.43	4.41	136.71
September	36	20.2	85	60	72.5	208.8	5.4	0.41	12.3	5.04	5.05	151.5
October	36.9	13.4	68	37	52.5	112.8	2.5	0.7	11.7	8.19	4.82	149.42
November	35	10.5	59	32	45.5	91.2	2.1	0.74	11.2	8.29	3.82	114.6
December	32.9	7.6	62	34	48	88.8	1.9	0.76	10.9	8.28	3.36	104.16
	For Lower Tapi Basin Using Surat Station Data (Altitude - 20 m, Latitude - 21.16 N, Longitude - 72.80 E)											
January	35.5	10.3	65	39	52	165.6	1.0	0.85	10.9	9.27	5.02	155.62
February	38.1	11.5	62	33	47.5	170.4	0.8	1	11.45	11.45	6.1	170.8
March	41	15.7	64	32	48	180	1.2	0.83	12	9.96	7.09	219.79
April	42.4	20.3	66	38	52	199.2	1.4	0.89	12.6	11.21	8.16	244.8
May	41.9	23.5	68	55	61.5	285.6	2.7	0.68	13.1	8.91	8.35	258.85
June	37.4	23.4	79	70	74.5	324	5.6	0.39	13.4	5.23	6.12	183.6
July	34.4	23.3	88	79	83.5	302.4	6.9	0.19	13.3	2.53	4.27	132.37
August	33.2	23.2	89	79	84	264	7.1	0.15	12.8	1.92	3.75	116.25
September	36.4	22.5	86	70	78	189.6	5.1	0.44	12.3	5.41	4.79	143.7
October	38.7	19.4	72	49	60.5	148.8	2.0	0.75	11.7	8.78	5.51	170.81
November	37.7	15.5	61	43	52	158.4	1.4	0.81	11.2	9.07	5.16	154.8
December	35.9	12.1	65	43	54	172.8	1.3	0.82	10.9	8.94	4.87	150.97

4.5 Determination of Land Parcels

The CPSP model divides the entire sub-basin in around 20 land parcels. Water balance for each land parcel depends on its characteristics, such as the land use/crop type, irrigated/rainfed conditions, period of year during which crop remains on the land, crop water requirements etc. This is one of the most exhaustive inputs of model. Land-use parcels for various years were prepared by using the land parcels module developed during this study. The module has been described in detail in Chapter-2.

For determining different land parcels in different years, the land use data, cropping pattern details, crop-wise irrigated areas in different years and the source-wise irrigated areas were obtained from the Statistical Yearbooks prepared by the Directorate of Economics and Statistics (D.E.S.) of the States of M.P., Maharashtra, and Gujarat. From the D.E.S. of the State of M.P., required details were available for the years 1960-61, 1991-92, and for the period from 1996-97 to 2000-01. From the D.E.S. of the State of Maharashtra, required details were available for the years 1969-70, 1987-88, 1988-89, 1989-90, 1990-91, and 1995-96. From the D.E.S. of the State of Gujarat, required details were available for the years 1967-68, 1987-88, 1988-89, 1989-90, and 1998-99. From NWDA report, the land use data of the various districts falling within the Tapi Basin were available for the period from 1991-92 to 1995-96.

Looking at the data availability for different years in different states, various assumptions were made. For the decade of 1960, data of M.P., Maharashtra, and Gujarat States were available for the years 1960-61, 1969-70 and 1967-68 respectively. These data were assumed to represent the conditions in the year 1965-66 (lying mid-way in the decade), which was used to analyze the *PAST* conditions in the Tapi Basin. Looking at the data availability for the recent year in different states, the year 1995-96 was assumed to represent the *PRESENT* conditions. Since the land use data, cropping pattern, and source-wise irrigation data of M.P. State for the years 1987-88, 1988-89, 1989-90, and 1990-91 were not available, corresponding data for the year 1991-92 were assumed to represent the conditions for these years for the M.P. districts covering a part of the Tapi basin. Similarly, the irrigated areas of different crops for the Maharashtra State for the years 1987-88 and 1988-89 were not available and the same were assumed from the available corresponding records of other years. The years 1988-89 and 1990-91 represent wet years with annual rainfall or flow far exceeding the average annual values. For Gujarat State, the land use and crop details were available for the year 1988-89 and the same were used for the year 1990-91 also.

Various land use details were available for different districts. Knowing the percent area of each district lying within different sub-basins of the Tapi basin, the land use values for the portion of the district falling within the sub-basin were obtained by proportionately reducing the district-wise values. Percentage area of different districts falling within various sub-basins is presented in Table – 4.5.

Table – 4.5
Area (%) of different districts within three sub-basins

District	State	Total geographical area (Sq. km)	Area within sub-basin (sq. km)	Percent area
Upper Tapi Sub-basin				
Akola	Maharashtra	10560.00	6712.99	63.57
Buldhana	Maharashtra	9671.00	6033.74	62.39
Amravati	Maharashtra	12217.00	7944.72	65.03
Jalgaon	Maharashtra	11639.00	619.19	5.32
Betul	M.P.	10078.00	4122.91	40.91
Khandwa	M.P.	11183.57	3997.01	35.74
Middle Tapi Sub-basin				
Jalgaon	Maharashtra	-	10643.87	91.45
Aurangabad	Maharashtra	10077.00	980.49	9.73
Nasik	Maharashtra	15634.00	6184.81	39.56
Dhule	Maharashtra	14380.00	6410.60	44.58
Khargaon	M.P.	13485.03	1100.38	8.16
Lower Tapi Sub-basin				
Dhule	Maharashtra	-	5028.69	34.97
Khargaon	M.P.	-	736.28	5.46
Surat	Gujarat	7762.00	3675.31	47.35
Bharuch	Gujarat	7803.00	955.09	12.24

For different hydraulic structures in the Tapi basin, storage capacities were available but their areas of submergence were not available. Knowing the submergence area of the Ukai reservoir at FRL and the corresponding capacity, total submergence areas of structures within each sub-basin were estimated from their total capacities. Assuming that a storage in a headwater region would have comparatively lesser spread area due to topographic effects, the areas derived above were reduced by 50% for the Upper Tapi Basin and 25% for the Middle Tapi Basin.

From the crop statistics available for the different years of record, crop parcels were evaluated and the corresponding NCA, GCA, NIA, and GIA were worked out. The comparison of the net and gross cropped and irrigated areas obtained from the analysis and as reported in the reports of D.E.S. has been made. It is seen that most of the values match to a considerable extent. For all the years of analysis for which land use data were available, land parcels for three sub-basins were derived and the same are presented in Table - 4.6 to 4.8. The comparison of calculated and reported values of different areas like net sown area, gross sown area, net irrigated area, and gross irrigated area for different sub-basins is presented in Table – 4.9.

4.5.1 Development of land Parcels for Future (2025) Scenario

To analyze future scenario in the basin corresponding to year 2025, probable future land parcels have been made. It is assumed that forest area will remain almost the same (except for increased forest scenario when increase in 10% of forest area is assumed at the expense of barren land). Similarly, the permanent pasture area is also assumed to remain same. Due to greater stress on land for supporting population, the waste and fallow land will decrease. The land area under the reservoirs will increase with the completion of on-going projects. For the crop parcels, it is assumed that with the completion of on-going projects and creation of irrigation infrastructure, the irrigated area will increase with corresponding reduction in rainfed crops. Looking at the trends of different parcels for past few years, rainfed and irrigated areas of parcels have been assumed. For example, in Upper Tapi Basin, where net irrigated area (NIA) was around 2.25 % of the net sown area (NSA) in the year 1965 and 8 % in the year 1995-96, the same is assumed to increase to 11.5 % in year 2025. Similarly for the middle basin, the proportion of NIA is assumed to increase from 9.4 % in 1965 and 14.8 % in 1995 to 20.2 % in the year 2025. Similarly for the lower basin, the proportion of NIA is assumed to increase from 10.3 % in 1965 and 28.6 % in 1995 to 32.2 % in the year 2025. Under future scenario of increase in irrigation efficiency, NIA is assumed to be 15%, 22.4% and 35% of the NCA for upper, middle and lower sub-basins respectively. Land parcels for future scenario are given in Table - 4.6 to 4.8.

Table – 4.6

Land parcels (sq. km) for Upper Tapi Basin in Different Years & Scenarios

Name of Land Parcel	Parcel Identity	Parcel areas (sq. km) in different scenarios									
		1965-66	1987-88	1988-89	1989-90	1990-91	1995-96	2025			
								BAU	Increase in forest	BAU + Interlink	Increase in Irr. η
Forest & Misc. Trees	P1	6809.88	6901.62	6809.88	6904.51	6915.05	6738.28	6900.00	7300.00	6900.00	6900.00
Permanent Pastures	P2	2055.69	1466.36	2055.69	1461.57	1468.10	1246.59	1250.00	1250.00	1250.00	1250.00
Land not available for cult., Waste, & Fallow	P3	3085.70	3229.81	3073.68	3257.79	3178.27	3231.26	2800.00	2400.00	2800.00	2800.00
Land under Reservoirs	P4	15.75	27.77	27.77	27.77	27.77	27.77	40.00	40.00	40.00	40.00
Rainfed Kharif Paddy only	P5	324.19	386.95	365.64	405.82	275.00	265.00	250.00	250.00	250.00	225.00
Rainfed Two Seasonal (Kharif+Rabi)	P6	6674.95	6222.95	5889.44	6355.10	6275.00	6150.00	6000.00	6000.00	6000.00	5800.00
Rainfed Perennial	P7	53.69	0.00	149.51	0.00	0.00	0.00	50.00	50.00	50.00	40.00
Rainfed Other Kharif Followed by Rabi	P8	432.88	823.16	433.23	859.73	1500.00	1900.00	1900.00	1900.00	1900.00	1800.00
Rainfed Other Kharif only	P9	7716.92	8997.26	9313.57	8911.68	8600.00	8416.10	8000.00	8000.00	8000.00	7700.00
Rainfed other Kharif + Irrigated Rabi + Fallow	P10	0.00	638.77	0.00	656.03	750.00	800.00	650.00	650.00	650.00	700.00
Irrigated Kharif Paddy only	P11	4.90	21.99	3.51	8.77	4.65	15.00	25.00	25.00	25.00	25.00
Irrigated Perennial	P12	157.08	423.74	93.20	301.19	171.16	160.00	500.00	500.00	500.00	630.00
Irrigated Two Seasonal (Kharif+Rabi)	P13	20.95	105.74	29.81	122.28	90.00	120.00	250.00	250.00	250.00	375.00
Irrigated Two-Seasonal (Rabi+HW)	P14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Irrigated other Kharif + Irrigated Rabi + Fallow	P15	8.93	151.73	12.04	137.03	150.00	310.00	350.00	350.00	350.00	550.00
Fallow in Kharif + Irrigated Rabi + Irrigated HW	P16	10.82	32.16	7.73	20.71	25.00	50.00	40.00	40.00	40.00	50.00
Fallow in Kharif + Irrigated Rabi + Irrigated HW Paddy	P17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Irrigated Rabi only	P18	149.24	0.00	211.92	0.00	0.00	0.00	250.00	250.00	250.00	350.00
Irrigated other Kharif only	P19	43.42	0.00	37.44	0.00	0.00	0.00	50.00	50.00	50.00	70.00
Irrigated other Kharif + fallow Rabi + Irrigated HW	P20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fallow Kharif + Rainfed Rabi	P21	1865.01	0.00	915.94	0	0.00	0.00	125.00	125.00	125.00	125.00

Table – 4.7

Land Parcels (sq. km) for Middle Tapi Basin in Different Years & Scenarios

Name of Land Parcel	Parcel Identity	Parcel areas (sq. km) in different years									
								2025			
		1965	1987-88	1988-89	1989-90	1990-91	1995-96	BAU	Increase in forest	BAU + Interlink	Increase in Irr. η
Forest & Misc. Trees	P1	5727.56	5769.22	5727.56	5761.11	5774.33	5681.48	5800.00	6100.00	5800.00	5800.00
Permanent Pastures	P2	1101.22	978.06	1101.22	969.98	969.85	787.58	1000.00	1000.00	1000.00	1000.00
Land not available for cult., Waste, & Fallow	P3	3136.12	3054.81	3084.93	2964.40	2800.94	3045.40	2900.00	2600.00	2900.00	2850.00
Land under Reservoirs	P4	6.74	57.93	57.93	57.93	57.93	57.93	120.00	120.00	120.00	120.00
Rainfed Kharif Paddy only	P5	202.78	255.50	245.92	269.90	264.57	286.42	250.00	250.00	250.00	250.00
Rainfed Two Seasonal (Kharif+Rabi)	P6	2854.59	1728.62	1489.70	1657.64	1684.70	3480.23	1600.00	1600.00	1600.00	1500.00
Rainfed Perennial	P7	15.38	0.00	78.89	15.60	30.74	18.98	15.00	15.00	15.00	15.00
Rainfed Other Kharif Followed by Rabi	P8	754.16	1634.01	753.45	2107.21	2167.01	2682.67	2100.00	2100.00	2100.00	2100.00
Rainfed Other Kharif only	P9	7575.77	8250.71	9139.36	8513.29	8570.71	6816.22	7000.00	7000.00	7000.00	6900.00
Rainfed other Kharif + Irrigated Rabi + Fallow	P10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Irrigated Kharif Paddy only	P11	93.66	99.76	72.81	95.82	106.62	85.39	150.00	150.00	150.00	175.00
Irrigated Perennial	P12	409.98	718.28	478.29	656.27	651.51	896.01	1000.00	1000.00	1000.00	1100.00
Irrigated Two Seasonal (Kharif+Rabi)	P13	97.33	253.69	257.73	415.63	404.50	338.05	600.00	600.00	600.00	650.00
Irrigated Two-Seasonal (Rabi+HW)	P14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Irrigated other Kharif + Irrigated Rabi + Fallow	P15	233.42	388.58	234.75	388.05	417.65	670.90	700.00	700.00	700.00	800.00
Fallow in Kharif + Irrigated Rabi + Irrigated HW	P16	47.09	53.32	45.49	62.05	63.18	98.18	125.00	125.00	125.00	150.00
Fallow in Kharif + Irrigated Rabi + Irrigated HW Paddy	P17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Irrigated Rabi only	P18	504.03	420.66	297.15	350.27	283.52	110.00	400.00	400.00	400.00	450.00
Irrigated other Kharif only	P19	51.81	0.00	49.75	0.00	0.00	138.88	160.00	160.00	160.00	160.00
Irrigated other Kharif + fallow Rabi + Irrigated HW	P20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fallow Kharif + Rainfed Rabi	P21	2508.34	1656.85	2205.08	1034.84	1072.26	125.69	1400.00	1400.00	1400.00	1300.00

Table – 4.8

Land Parcels (sq. km) for Lower Tapi Basin in Different Years & Scenarios

Name of Land Parcel	Parcel Identity	Parcel areas (sq. km) in different years									
		1965	1987-88	1988-89	1989-90	1990-91	1995-96	2025			
								BAU	Increase in forest	BAU + Interlink	Increase in Irr. η
Forest & Misc. Trees	P1	3201.66	3047.76	3201.66	3045.64	3045.41	3020.84	3050.00	3400.00	3050.00	3050.00
Permanent Pastures	P2	486.31	368.96	486.31	366.88	366.88	369.20	400.00	400.00	400.00	400.00
Land not available for cult., Waste, & Fallow	P3	1115.26	966.85	512.18	931.28	936.48	965.37	900.00	550.00	900.00	900.00
Land under Reservoirs	P4	3.63	606.71	606.71	606.71	606.71	606.71	610.00	610.00	610.00	610.00
Rainfed Kharif Paddy only	P5	192.78	251.96	376.93	219.56	241.11	278.73	225.00	225.00	225.00	200.00
Rainfed Two Seasonal (Kharif+Rabi)	P6	868.44	381.03	421.72	263.98	358.22	524.42	300.00	300.00	300.00	300.00
Rainfed Perennial	P7	7.61	0.00	335.63	0.00	4.54	0.00	10.00	10.00	10.00	10.00
Rainfed Other Kharif Followed by Rabi	P8	300.47	168.35	298.53	221.12	150.92	307.16	200.00	200.00	200.00	175.00
Rainfed Other Kharif only	P9	2778.65	2939.43	2872.11	3059.39	2889.24	2357.93	2600.00	2600.00	2600.00	2500.00
Rainfed other Kharif + Irrigated Rabi + Fallow	P10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Irrigated Kharif Paddy only	P11	129.37	161.89	81.21	175.22	193.41	305.30	300.00	300.00	300.00	325.00
Irrigated Perennial	P12	95.15	526.51	236.00	602.64	524.77	898.77	800.00	800.00	800.00	850.00
Irrigated Two Seasonal (Kharif+Rabi)	P13	105.80	75.19	46.70	114.49	101.66	137.38	200.00	200.00	200.00	230.00
Irrigated Two-Seasonal (Rabi+HW)	P14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Irrigated other Kharif + Irrigated Rabi + Fallow	P15	47.82	148.56	42.10	142.66	159.94	173.85	225.00	225.00	225.00	250.00
Fallow in Kharif + Irrigated Rabi + Irrigated HW	P16	4.65	18.09	10.04	20.82	17.73	38.13	50.00	50.00	50.00	70.00
Fallow in Kharif + Irrigated Rabi + Irrigated HW Paddy	P17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Irrigated Rabi only	P18	169.92	123.83	116.70	104.61	83.76	0.00	150.00	150.00	150.00	150.00
Irrigated other Kharif only	P19	24.83	0.00	41.06	0.00	0.00	0.00	25.00	25.00	25.00	25.00
Irrigated other Kharif + fallow Rabi + Irrigated HW	P20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fallow Kharif + Rainfed Rabi	P21	862.65	609.88	709.41	520.00	714.22	411.23	350.00	350.00	350.00	350.00

Table – 4.9
Comparison of computed and reported cropped and irrigated areas (sq. km)

Different Areas	Upper Tapi Basin						Middle Tapi Basin						Lower Tapi Basin					
	1965-66	1987-88	1988-89	1989-90	1990-91	1995-96	1965-66	1987-88	1988-89	1989-90	1990-91	1995-96	1965-66	1987-88	1988-89	1989-90	1990-91	1995-96
Net Sown Area (Calculated)	17463	17804	17463	17778	17841	18186	15348	15460	15348	15567	15717	15748	5588	5405	5588	5444	5440	5433
Net Sown Area (Reported)	17463	17805	17463	17841	17828	18187	15349	15461	15349	15567	15642	15748	5588	5405	5588	5445	5423	5418
Gross Sown Area (Calculated)	17916	19450	17916	19452	20266	21246	16383	17536	16382	18124	18365	19199	5941	5740	5939	5829	5768	5952
Gross Sown Area (Reported)	17911	19587	17911	20859	21863	22760	16360	17502	16360	18067	18218	19148	5930	5734	5930	5825	5743	5927
Net Irrigated Area (Calculated)	395	1374	396	1246	1191	1455	1437	1934	1436	1968	1927	2337	578	1054	574	1160	1081	1553
Net Irrigated Area (Reported)	391	1248	391	1226	1128	1360	1404	1776	1404	1869	1828	2302	559	1004	559	1095	1028	1466
Gross Irrigated Area (Calculated)	415	1558	415	1404	1366	1815	1718	2376	1716	2418	2408	3106	630	1221	626	1324	1259	1765
Gross Irrigated Area (Reported)	411	1567	411	1492	1392	1870	1678	2337	1678	2364	2342	3060	610	1198	610	1310	1224	1731

4.6 Domestic and Industrial Requirements

The district-wise human (urban and rural) population in years 1991, 1995, 2020, and 2030 has been given in NWDA (2002) report. The NWDA future projection is based on the UN projection assuming medium variant growth rate. For the years 1987, 1988, 1989, and 1990, the population in different districts was considered to be the same as for the year 1991. For the year 2025, the population in different districts was assumed to lie midway between the population of years 2020 and 2030. Based on the guidelines given in the National Commission Report for Integrated Water Resources Development and Management (1999), the urban population was assumed to be 40 % of the total population in the year 2025. To calculate the population in year 1965, the state-wise population statistics in the years 1961 and 1971 were utilized. Using the State population in years 1961 and 1971 and the ratio of population in various districts to the State population in the year 1991, the population in different districts in the years 1961 and 1971 was computed. The population in the year 1965 in different districts was assumed to lie midway between the population of the years 1961 and 1971. The cattle population in the year 1992 and 2050 has been worked out in the NWDA (2002) report. For the years 1987, 1988, 1989, 1990, and 1995, the cattle population was assumed to be same as for the year 1992. The cattle population for the year 2025 was assumed to lie midway between the population for the year 1992 and 2050.

Knowing the percentage of different districts in different sub-basins, the human (urban and rural) and cattle population in each sub-basin was worked out for various years. Given the population for a specified year, the CPSP model computes the domestic requirements given specified per capita demands for urban, rural and cattle population. Given the percentage limits of surface water use and GW use for meeting these demands, withdrawals from different sources are worked out. The consumptive demand and recharge of remaining water to surface water and GW are also specified.

The urban, rural, and cattle population in the three sub-basins considered in this study in years 1965-66, 1991-92, 1995-96 and 2025 is given in Table – 4.10. For deriving the domestic and industrial demands for different years, various parameters were assumed as given in Table – 4.11. Total rural demand was taken to be the sum of the requirement for rural population and cattle population. The industrial demand was taken equal to the sum of the urban and rural demands. The D&I demands computed for various years are given in Table – 4.12.

Table - 4.10
Human and cattle population considered in three sub-basins in different years

Sub-Basin	1965-66			1991-92			1995-96			2025		
	Total	Urban	Cattle	Total	Urban	Cattle	Total	Urban	Cattle	Total	Urban	Cattle
Upper Tapi Basin	1754861	277366	838724	3086503	837923	1677448	3329154	903798	1677448	4933561	1973425	2332464
Middle Tapi Basin	2474249	389680	1212530	4342287	1176618	2425060	4683663	1269119	2425060	6940845	2776338	3371925
Lower Tapi Basin	510405	78055	253807	895003	229607	507614	965365	247658	507614	1430600	572240	705812

Table - 4.11
Parameters considered for computation of D&I demands

Parameter	Years		
	1965	1991	2025
Supply Norm for Urban Population (LPCD)	140	140	200
Supply Norm for Rural Population (LPCD)	50	50	90
Supply Norm for Cattle Population (LPCD)	25	25	25
Supply of Urban Demands from Surface Water (%)	10	30	55
Supply of Rural Demands from Surface Water (%)	5	15	20
Supply of Industrial Demands from Surface Water (%)	20	30	30
Consumptive Use Norm for Urban Population (LPCD)	30	30	50
Consumptive Use Norm for Rural Population (LPCD)	20	20	25
Consumptive Use Norm for Cattle Population (LPCD)	15	15	15
Consumptive Use Factor for Industrial Demand (%)	20	30	50
Percentage Urban Return to Surface Water	50	70	90
Percentage Rural Return to Surface Water	5	10	20
Percentage Industrial Return to Surface Water	50	70	90

4.7 Proportion of Surface Irrigation to Total Irrigation

To compute the sub-basin-wise proportion of surface irrigation to total irrigation, the details provided by D.E.S. were used. D.E.S. reports the district-wise and source-wise irrigation (from canals, wells, tube wells, tanks, other sources etc.) done in a particular year. The areas of surface irrigation and total irrigation for each

Table - 4.12
Domestic and Industrial water requirement (in 10^6 m^3) in different sub-basins

Year	Item	Upper Tapi Basin							Middle Tapi Basin							Lower Tapi Basin						
		Withdrawls (from)			Consumptive use ET	Returns (to)			Withdrawls (from)			Consumptive use ET	Returns (to)			Withdrawls (from)			Consumptive use ET	Returns (to)		
		TOTAL	SW	GW		TOTAL	SW	GW	TOTAL	SW	GW		TOTAL	SW	GW	TOTAL	SW	GW		TOTAL	SW	GW
1965	Domestic, Rural	34.62	1.73	32.89	16.91	17.71	0.89	16.82	49.11	2.46	46.65	24.07	25.04	1.25	23.79	10.21	0.51	9.70	5.01	5.20	0.26	4.94
	Domestic,Urban	14.17	1.42	12.76	3.04	11.14	5.57	5.57	19.91	1.99	17.92	4.27	15.65	7.82	7.82	3.99	0.40	3.59	0.85	3.13	1.57	1.57
	Industrial	49.00	12.25	36.75	9.80	39.20	19.60	19.60	70.00	17.50	52.50	14.00	56.00	28.00	28.00	15.00	3.75	11.25	3.00	12.00	6.00	6.00
	Total	97.79	15.40	82.39	29.75	68.05	26.05	41.99	139.02	21.95	117.07	42.34	96.68	37.07	59.61	29.20	4.66	24.54	8.86	20.33	7.83	12.50
1991	Domestic,Rural	56.34	6.92	49.42	25.60	30.74	3.07	27.67	79.90	9.77	70.13	36.39	43.52	4.35	39.16	16.78	2.05	14.72	7.64	9.14	0.91	8.22
	Domestic,Urban	42.82	12.85	29.97	9.18	33.64	23.55	10.09	60.13	18.04	42.09	12.88	47.24	33.07	14.17	11.73	3.52	8.21	2.51	9.22	6.45	2.77
	Industrial	100.00	25.00	75.00	30.00	70.00	49.00	21.00	140.00	35.00	105.00	42.00	98.00	68.60	29.40	28.00	7.00	21.00	8.40	19.60	13.72	5.88
	Total	199.16	44.77	154.39	64.77	134.39	75.62	58.76	280.03	62.81	217.22	91.27	188.76	106.02	82.74	56.51	12.57	43.94	18.55	37.96	21.09	16.87
1995	Domestic,Rural	59.57	7.40	52.16	26.89	32.68	3.27	29.41	84.44	10.45	73.99	38.20	46.24	4.62	41.62	17.73	2.20	15.53	8.02	9.71	0.97	8.74
	Domestic,Urban	46.18	13.86	32.33	9.90	36.29	25.40	10.89	64.85	19.46	45.40	13.90	50.96	35.67	15.29	12.66	3.80	8.86	2.71	9.94	6.96	2.98
	Industrial	105.00	26.25	78.75	31.50	73.50	51.45	22.05	150.00	37.50	112.50	45.00	105.00	73.50	31.50	30.00	7.50	22.50	9.00	21.00	14.70	6.30
	Total	210.75	47.51	163.24	68.29	142.47	80.12	62.35	299.30	67.41	231.89	97.10	202.20	113.79	88.40	60.39	13.49	46.89	19.73	40.66	22.63	18.02
2025	Domestic,Rural	118.52	21.58	96.95	39.78	78.74	7.87	70.87	167.57	30.44	137.14	56.46	111.11	11.11	100.00	34.64	6.28	28.35	11.70	22.94	2.29	20.65
	Domestic,Urban	144.06	79.23	64.83	36.01	108.04	75.63	32.41	202.67	111.47	91.20	50.67	152.00	106.40	45.60	41.77	22.98	18.80	10.44	31.33	21.93	9.40
	Industrial	262.50	65.63	196.88	131.25	131.25	91.88	39.38	370.00	92.50	277.50	185.00	185.00	129.50	55.50	76.00	19.00	57.00	38.00	38.00	26.60	11.40
	Total	525.08	166.43	358.65	207.05	318.04	175.38	142.66	740.25	234.41	505.84	292.13	448.12	247.01	201.10	152.41	48.26	104.15	60.14	92.27	50.83	41.45

district were proportionately reduced and the total area of surface irrigation and total irrigation and corresponding percentage of surface irrigation for each sub-basin were computed. The average annual percentage of surface irrigation, so obtained, was distributed monthly considering that surface irrigation would increase during the monsoon season (due to increase in surface water resources in rivers and reservoirs) and then would slowly decline during the lean season. The monthly distribution was made such that the annual average percentage of surface irrigation remains the same as obtained above from the values published by D.E.S. For the future year (2025), the proportion of surface irrigation was increased in the ratio of total capacity of existing and on-going projects to the capacity of existing projects in the three sub-basins. Monthly proportion of surface irrigation to total irrigation for the three sub-basins for different years is given in Table – 4.13.

4.8 Surface Storage Filling/Depletion

This table represents the filling and depletion schedule of total storage capacity within a sub-basin. Information about the total existing and on-going storages was obtained from the NWDA report (2002) and Water Year Book (1998-99) published by the Central Water Commission. Monthly filling and depletion patterns of the Upper Tapi Stage – I (Hathnur dam in the Upper Tapi Basin) for the period 1989 to 1997, Girna dam (in the Middle Tapi Basin) for the period 1987 to 1995, and Ukai dam (in the Lower Tapi Basin) for the period 1987 to 1995 were obtained from the capacity records of different reservoirs in Central Water Commission. The working table of the Ukai reservoir for four years (1987 to 1990) was also obtained from the Office of Superintending Engineer, Surat Irrigation Circle, Surat. Knowing the capacities of the Hathnur ($255*10^6$ m^3), Girna ($523*10^6$ m^3), and Ukai ($7092*10^6$ m^3) dams, surface storage filling/depletion patterns for the Upper, Middle, and Lower Tapi Basins were obtained by proportionately increasing in the ratios of the total existing storages in these sub-basins ($615*10^6$ m^3 in the Upper basin, $872*10^6$ m^3 in the middle basin, and $7170*10^6$ m^3 in the Lower basin).

For estimating the storage filling/depletion patterns according to the average rainfall conditions in different months, monthly storage filling/depletion series in an year was bifurcated into two parts: a) for the monsoon part (June to October) when most of the rainfall occurs which directly affects the filling patterns of reservoirs, and b) for the non-monsoon part when mostly the depletion takes place depending on the demands from the reservoirs. For the monsoon months, regression relationships were developed (using the actual rainfall and storage filling/depletion patterns during 1987 – 90) between the storage filling and the monthly rainfall for the current month (say t), and two previous month (t-1 and t-2). Such relationships were developed for all the three sub-basins separately. Using these relationships, storage filling for the monsoon months was obtained corresponding to the average rainfall in different months for each sub-basin. Storage depletion in the non-monsoon months was obtained by taking the average of 7 to 9 years of the observed values for the three sub-basins separately for the period as mentioned above. The storage filling/depletion pattern for the average conditions, so derived, was fine tuned to represent 70 to 80% storage filling in each average year without any carry over. The filling/depletion pattern, so obtained, represented the average pattern for the present year (1995). For the past year (1965), the storage filling/depletion was assumed to be (255/615) times the average pattern for the Upper Tapi Basin, 10% of the average pattern for the Middle Tapi Basin, and (50/7090) times the average pattern for the Lower Tapi Basin.

The storage filling/depletion pattern for future year (2025) was worked out by proportionately increasing the storage values in terms of the increased capacity of the on-going projects. For the future year, the capacity of on-going projects in the upper basin ($370*10^6$ m^3), in the middle basin ($878*10^6$ m^3), and in the lower basin ($300*10^6$ m^3) were added to the existing capacities in these sub-basins and the average monthly filling and depletion pattern (corresponding to year 1995-96) was proportionately modified. Monthly filling and depletion schedules in three sub-basins for different years are given in Table – 4.14.

Table – 4.13
Proportion of surface irrigation to total irrigation

Month	1965	1987-88	1988-89	1989-90	1990-91	1995-96	2025
Upper Tapi Basin							
June	0.09	0.11	0.16	0.14	0.16	0.22	0.36
July	0.11	0.13	0.20	0.18	0.20	0.28	0.44
August	0.13	0.16	0.24	0.21	0.24	0.33	0.53
September	0.13	0.16	0.24	0.21	0.24	0.33	0.53
October	0.13	0.16	0.24	0.21	0.24	0.33	0.53
November	0.13	0.16	0.24	0.21	0.24	0.33	0.53
December	0.11	0.13	0.20	0.18	0.20	0.28	0.44
January	0.09	0.11	0.16	0.14	0.16	0.22	0.36
February	0.09	0.11	0.16	0.14	0.16	0.22	0.36
March	0.07	0.08	0.12	0.11	0.12	0.17	0.27
April	0.07	0.08	0.12	0.11	0.12	0.17	0.27
May	0.04	0.05	0.08	0.07	0.08	0.11	0.18
Middle Tapi Basin							
June	0.17	0.08	0.12	0.11	0.12	0.42	0.80
July	0.22	0.10	0.16	0.14	0.16	0.53	0.95
August	0.28	0.13	0.20	0.18	0.20	0.63	0.95
September	0.28	0.13	0.20	0.18	0.20	0.63	0.95
October	0.28	0.13	0.20	0.18	0.20	0.63	0.95
November	0.28	0.13	0.20	0.18	0.20	0.63	0.95
December	0.22	0.10	0.16	0.14	0.16	0.53	0.95
January	0.17	0.08	0.12	0.11	0.12	0.42	0.80
February	0.17	0.08	0.12	0.11	0.12	0.42	0.80
March	0.14	0.06	0.10	0.09	0.10	0.32	0.60
April	0.11	0.05	0.08	0.07	0.08	0.32	0.60
May	0.11	0.05	0.08	0.07	0.08	0.21	0.40
Lower Tapi Basin							
June	0.21	0.13	0.20	0.18	0.20	0.42	0.43
July	0.28	0.18	0.27	0.24	0.27	0.55	0.58
August	0.32	0.21	0.31	0.28	0.31	0.65	0.67
September	0.32	0.21	0.31	0.28	0.31	0.65	0.67
October	0.32	0.21	0.31	0.28	0.31	0.65	0.67
November	0.32	0.21	0.31	0.28	0.31	0.65	0.67
December	0.28	0.18	0.27	0.24	0.27	0.55	0.58
January	0.23	0.15	0.22	0.20	0.22	0.46	0.48
February	0.23	0.15	0.22	0.20	0.22	0.46	0.48
March	0.18	0.12	0.18	0.16	0.18	0.37	0.38
April	0.18	0.12	0.18	0.16	0.18	0.37	0.38
May	0.12	0.07	0.11	0.10	0.11	0.23	0.24

Table – 4.14
Surface storage filling/depletion schedules

Month	1965	1987-88	1988-89	1989-90	1990-91	1995-96	2025
Upper Tapi Basin							
June	-24.88	-150.00	-150.00	-118.18	149.53	-60.00	-96.10
July	12.44	-200.00	200.00	-98.88	-238.76	30.00	48.05
August	74.63	135.00	165.00	202.59	103.71	180.00	288.30
September	66.34	65.00	135.00	250.82	231.53	160.00	256.25
October	51.83	50.00	115.00	161.59	258.06	125.00	200.20
November	-10.37	-30.00	0.00	-48.24	0.00	-25.00	-40.00
December	-20.73	-20.00	0.00	-50.65	0.00	-50.00	-80.10
January	-16.59	-10.00	-20.00	-31.35	-21.71	-40.00	-64.10
February	-24.88	-25.00	-50.00	-69.94	-55.47	-60.00	-96.10
March	-33.17	-50.00	-100.00	-106.12	-108.53	-80.00	-128.10
April	-41.46	-60.00	-150.00	-127.82	-156.76	-100.00	-160.15
May	-33.17	-55.00	-145.00	-69.94	-154.35	-80.00	-128.15
Middle Tapi Basin							
June	5.00	26.65	38.31	14.99	5.00	50.00	100.35
July	15.50	0.00	39.97	58.30	3.33	155.00	311.10
August	12.50	104.93	73.29	39.97	273.16	125.00	250.85
September	11.00	0.00	419.73	86.61	83.28	110.00	220.75
October	6.00	-5.00	126.58	33.31	101.60	60.00	120.40
November	-7.00	-8.33	-36.64	-71.62	0.00	-70.00	-140.50
December	-7.50	-11.66	-91.61	-48.30	-51.63	-75.00	-150.50
January	-8.50	-23.32	-106.60	-41.64	-66.62	-85.00	-170.60
February	-7.50	-23.32	-78.28	-44.97	-98.27	-75.00	-150.50
March	-6.50	-26.65	-73.29	-21.65	-101.60	-65.00	-130.45
April	-6.50	-16.66	-111.59	-34.98	-73.29	-65.00	-130.45
May	-6.50	-29.98	-123.25	-6.66	-76.62	-65.00	-130.45
Lower Tapi Basin							
June	0.35	8.09	222.42	-361.94	27.30	50.00	52.10
July	13.22	466.07	3796.30	1464.94	1806.65	1875.00	1953.45
August	14.81	991.79	1965.38	3966.15	3782.14	2100.00	2187.85
September	6.35	-236.57	1055.48	428.66	197.14	900.00	937.65
October	-4.23	-430.69	-504.49	-1161.64	-88.97	-600.00	-625.10
November	-4.58	-222.42	-691.52	-821.94	-1190.96	-650.00	-677.20
December	-4.76	-320.49	-887.66	-645.02	-1451.79	-675.00	-703.25
January	-4.41	-220.40	-956.40	-543.92	-1259.70	-625.00	-651.15
February	-3.35	-231.52	-517.63	-424.62	-440.80	-475.00	-494.85
March	-4.23	-320.49	-670.29	-608.62	-476.18	-600.00	-625.10
April	-4.23	-359.92	-530.77	-702.64	-493.37	-600.00	-625.10
May	-4.94	-349.81	-956.40	-663.21	-542.91	-700.00	-729.30

4.9 Import and Export

There is no import of water from outside of the basin in any of the sub-basins. Also, no water is exported from the Upper and Middle Tapi basins. However, water is exported from the Lower Tapi basin (from the Ukai dam and Kakrapar weir). Using the working table for four years of record (1987-88, 1988-89, 1989-90, and 1990-91), the average monthly diversion pattern of water in the Ukai-Kakrapar canal system was worked out and assuming that 90% of this water is exported outside the Tapi basin (the canal system originating from the Ukai reservoir transfers most of the water to command areas in other basins), the same was specified in the export table of the Lower Tapi basin. In the NWDA study, it is estimated that $1554*10^6$ m^3 of excess water is available at the Ukai dam. Assuming this water to be transferred through the proposed Par-Tapi-Narmada interlinking scheme from the Ukai dam for meeting the demands in water deficit areas in North Gujarat, the same has been specified as export in the future scenario where interlinking aspect is analyzed. The export pattern of water from the Lower Tapi basin is presented in Table – 4.15.

Table – 4.15
Export of water from Lower Tapi sub-basin

Month	1965	1987-88	1988-89	1989-90	1990-91	1995-96	2025	2025+ Interlink
June	0.00	225.00	195.58	231.17	225.43	219.29	219.29	349.29
July	0.00	300.34	75.84	201.12	333.69	227.75	227.75	357.75
August	0.00	120.93	145.98	205.43	193.08	166.36	166.36	296.36
September	0.00	327.81	148.27	331.57	124.39	233.01	233.01	363.01
October	0.00	335.20	201.03	366.63	222.90	281.44	281.44	411.44
November	0.00	202.55	313.59	293.78	307.60	279.38	279.38	409.38
December	0.00	236.78	233.46	223.81	227.58	230.41	230.41	360.41
January	0.00	124.09	216.17	270.06	287.08	224.35	224.35	354.35
February	0.00	140.41	238.79	270.98	243.25	223.36	223.36	353.36
March	0.00	204.95	303.49	305.22	103.58	229.31	229.31	359.31
April	0.00	221.50	323.69	326.07	355.66	306.73	306.73	436.73
May	0.00	215.81	412.03	277.83	340.67	311.59	311.59	441.59

4.10 Groundwater Potential

District-wise information related to the normal natural groundwater recharge, canal irrigation groundwater recharge, provision of D&I and other uses from GW, utilizable groundwater resource for irrigation, and available groundwater resource for future use were obtained from the CGWB report on Groundwater Resources of India (1995). The district-wise information was proportionately reduced and accumulated for all the districts falling within a sub-basin to get the groundwater recharge and potential for each sub-basin. The groundwater related information for each sub-basin is given in Table - 4.16.

Table - 4.16
Groundwater recharge and potential for each sub-basin

Sub-basin	Normal Natural Recharge to GW (10^6 m^3)	Canal Irrigation Recharge to GW (10^6 m^3)	Provision for D&I & Other Uses (10^6 m^3)	Utilizable GW Resources for Irrigation (10^6 m^3)	GW Resource for Future Use (10^6 m^3)
Upper Tapi Basin	3425.16	194.82	1057.95	2305.79	1901.39
Middle Tapi Basin	2335.24	473.92	901.86	1716.61	952.39
Lower Tapi Basin	1068.53	518.60	324.83	1136.06	974.68

* * *

CHAPTER – 5
ANALYSIS OF RESULTS FOR TAPI BASIN

5.1 General

As mentioned in the previous chapter, the Tapi basin was divided into three sub-basins to allow segregation of areas having similar hydrologic attributes. Further, within a sub-basin, the areas were divided into land parcels to account for different response characteristics of various land uses. The CPSP model was calibrated for the average year (1989-90) and then validated for the years 1988-89 and 1990-91. The validated model was used to determine the response of the basin corresponding to past and future scenarios of water use and water transfer using monthly time step. The calibration, validation and analysis of model results are detailed in following sections.

5.2 Computation of Observed Flows in Various Sub-basins

For the calibration and validation of CPSP model, an important variable is the observed and simulated river flows at the outlet of three sub-basins. For the upper Tapi basin, the monthly flows at Burhanpur and Yerly gauging sites were added to get total flows from the sub-basin. For the middle Tapi basin (up to Gidhade gauging site), the flows at Gidhade were not available for the period 1987-91. So the observed monthly flows at Sarangkheda gauging site for the period 1987–91 were proportionately reduced in the ratio of the catchment areas to get the monthly flows at Gidhade gauging site. For the lower Tapi basin, flows at Kathode gauging site were used for comparison. The monthly flows from upper, middle, and lower Tapi basins for the four years of record are given in Table – 5.1.

5.3 Calibration and Validation of CPSP Model

Important parameters of the CPSP model that need to be calibrated for different sub-basins include: proportion of excess rainfall that goes as quick runoff (PERQR), proportion of excess rainfall that goes as groundwater recharge (PERGR), recession coefficient for GW reservoir (RCGR), and soil moisture capacities of different land

Table – 5.1

Monthly observed flows (10^6 m^3) in three sub-basins of Tapi basin

Month	**Upper Tapi Basin** (Estimated from Tapi @ Burhanpur and Purna @ Yerly)				**Middle Tapi Basin** (Estimated from Tapi @ Sarangkheda)				**Lower Tapi Basin** (Estimated from Tapi @ Kathode)			
	1987-88	**1988-89**	**1989-90**	**1990-91**	**1987-88**	**1988-89**	**1989-90**	**1990-91**	**1987-88**	**1988-89**	**1989-90**	**1990-91**
June	397	499	420	1129	566	395	396	873	941	439	591	754
July	332	3750	753	3133	631	3786	1255	2700	679	1161	647	422
August	771	3396	3154	7095	1159	3309	4062	7398	254	1564	859	3466
September	261	2952	1244	2475	253	4877	2135	3041	214	3195	1447	3112
October	86	2948	136	1285	16	3915	203	1645	235	3032	865	1709
November	66	131	27	205	60	183	24	306	255	380	438	1078
December	11	51	14	72	9	32	9	55	280	521	519	1133
January	4	32	11	42	1	12	5	9	301	841	528	1092
February	2	17	7	19	1	5	0	4	296	453	343	429
March	1	13	3	10	4	12	0	2	253	695	676	421
April	0	12	1	4	1	8	9	23	303	376	647	215
May	0	3	0	0	4	9	8	13	346	736	629	137
Total	1932	13805	5771	15469	2706	16543	8107	16070	4356	13393	8189	13969

parcels. Some irrigation system variables and constants, such as proportion of additional evapotranspiration needs that are met through irrigation, proportions of residual return flows returning to surface water and GW from surface irrigation, and proportions of residual return flows returning to surface water and GW from groundwater irrigation were also required to be specified for the entire basin.

Calibration of the model was made for the year 1989-90 (average year) for two time steps: annual and monthly. First, based on the normal natural recharge to groundwater reservoir in the three sub-basins, the values of PERQR and PERGR were adjusted so that the rainfall recharge in the year 1989-90 matches as close to the reported average natural recharge as possible. Second, the observed annual river flows (in volume units) out of the sub-basins were compared with the simulated flows. At this step, the soil moisture capacities in the three sub-basins were modified so that the annual observed and simulated river flows match to the extent possible. Third, the monthly observed river flows out of the sub-basins were compared with the monthly simulated flows. At this step, mainly the RCGR values were adjusted so that the recession flows in the lean season (mainly due to base flow from groundwater reservoir) match with the observed flows.

Since the calibration and validation of the model was done for continuous years of record, the initial conditions of various storage reservoirs (groundwater storage, surface storage, and soil moisture storage) for a year were taken as the year-end storage values of the previous year. Since the year 1987-88 was a dry year, values of different storages at the beginning of year 1988-89 were taken to be zero. Annual results of model application for the four continuous years of record are presented in Table – 5.2. Monthly results for three different years are plotted in Figure 5.1 to 5.3.

Table – 5.2
Observed and Simulated Annual Flows (10^6 m^3) in Three Sub-basins

Year	Upper Tapi Basin		Middle Tapi Basin		Lower Tapi Basin	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
1987	1932	1158	2706	1799	4355	1079
1988	13804	16648	16542	18477	13393	16110
1989	5771	7692	8107	10880	8188	10060
1990	15469	15894	16070	17518	13969	15516

Normal natural recharge to groundwater for the upper, middle and lower Tapi basin was computed as 3425, 2335, and 1068 million cubic meter respectively. Rainfall recharge obtained by the CPSP model for different sub-basins and different years are given in Table - 5.3.

Table - 5.3
Computed Rainfall Recharge (10^6 m^3) to Groundwater Reservoir

Year	Hydrologic Condition	Upper Tapi Basin	Middle Tapi Basin	Lower Tapi Basin
1987-88	Dry	490.78	611.17	37.95
1988-89	Wet	7586.43	1646.00	1039.25
1989-90	Average	3517.66	2317.44	1524.43
1990-91	Wet	7242.65	1455.50	587.55

5.4 Discussion of Validation Results

Various parameters of the CPSP model calibrated and validated using the continuous time series data (annual and monthly) of three years are presented in Table – 5.4. Various irrigation variables and constants are shown in Table – 5.5.

Table – 5.4
Values of Model Constants & Soil Moisture Capacities for Different Sub-basins

Model Parameters	Calibrated Values		
	Upper Tapi Basin	Middle Tapi Basin	Lower Tapi Basin
Model Constants			
Proportion of excess rainfall which goes to quick runoff	0.56	0.45	0.6
Proportion of excess rainfall which goes to ground water storage	0.44	0.55	0.4
Exponential index for Actual ET Estimation	0.5	0.5	0.5
Recession coefficient for ground water reservoir	0.5	0.4	0.4
Soil Moisture Capacities (mm)			
Forest & Misc. Trees	250	350	400
Permanent Pastures	100	125	150
Land not available for Cultivation, Waste, & Fallow	75	100	125
Land under Reservoirs	50	50	75
Rainfed Kharif Paddy only	175	200	250
Rainfed Two Seasonal (Kharif+Rabi)	125	150	200
Rainfed Perennial	125	150	200
Rainfed Other Kharif Followed by Rabi	125	150	200
Rainfed Other Kharif only	125	150	200
Rainfed other Kharif + Irrigated Rabi + Fallow	125	150	200
Irrigated Kharif Paddy only	175	200	250
Irrigated Perennial	125	150	200
Irrigated Two Seasonal (Kharif+Rabi)	125	150	200
Irrigated Two-Seasonal (Rabi+HW)	125	150	200
Irrigated other Kharif + Irrigated Rabi + Fallow	125	150	200
Fallow in Kharif + Irrigated Rabi + Irrigated HW	125	150	200
Fallow in Kharif + Irrigated Rabi + Irrigated HW Paddy	175	200	250
Irrigated Rabi only	125	150	200
Irrigated other Kharif only	125	150	200
Irrigated other Kharif + fallow Rabi + Irrigated HW	125	150	200
Fallow Kharif + Rainfed Rabi	125	150	200

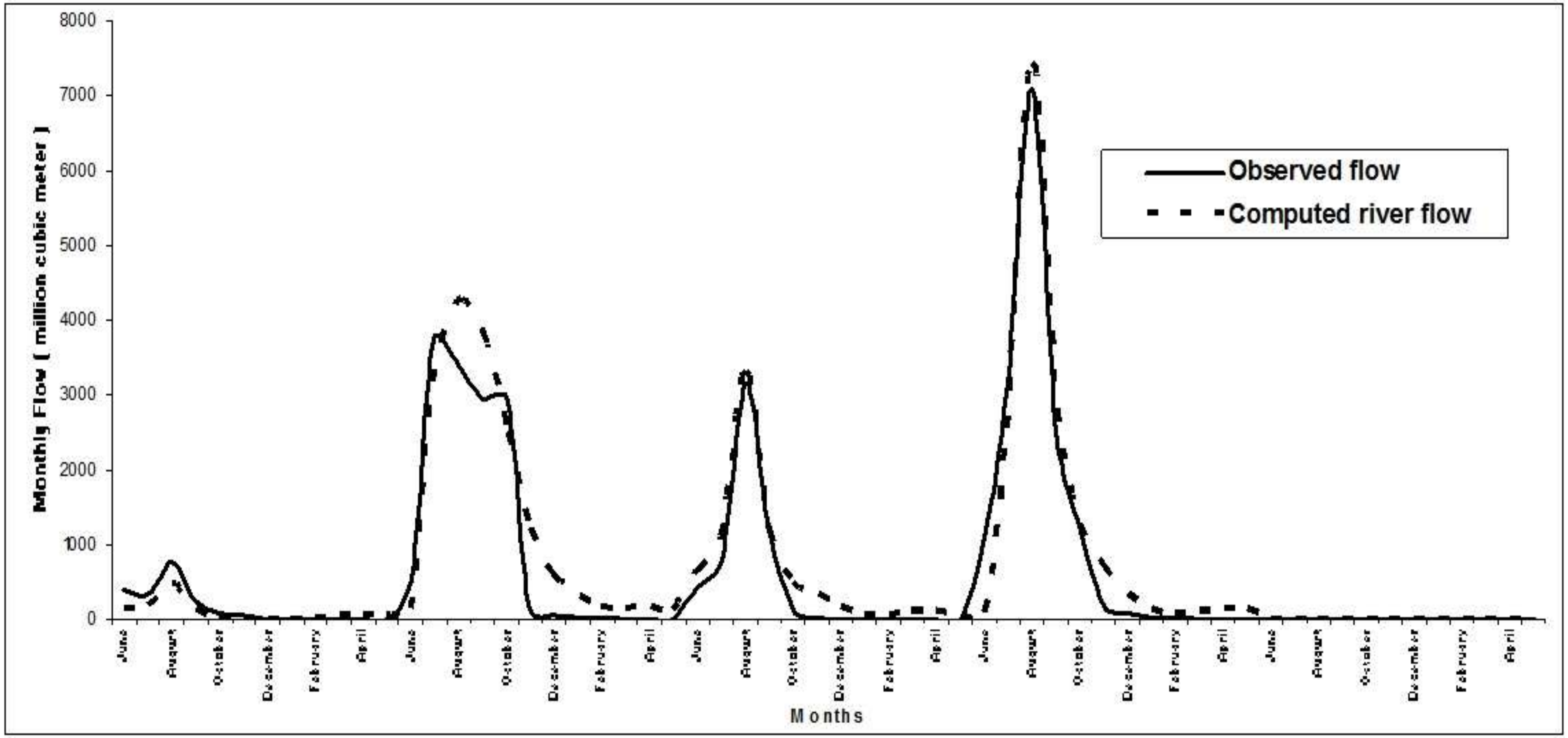


Figure – 5.1 Observed and simulated monthly flows in calibration & validation period (1987-1990) in the Upper Tapi Sub-basin

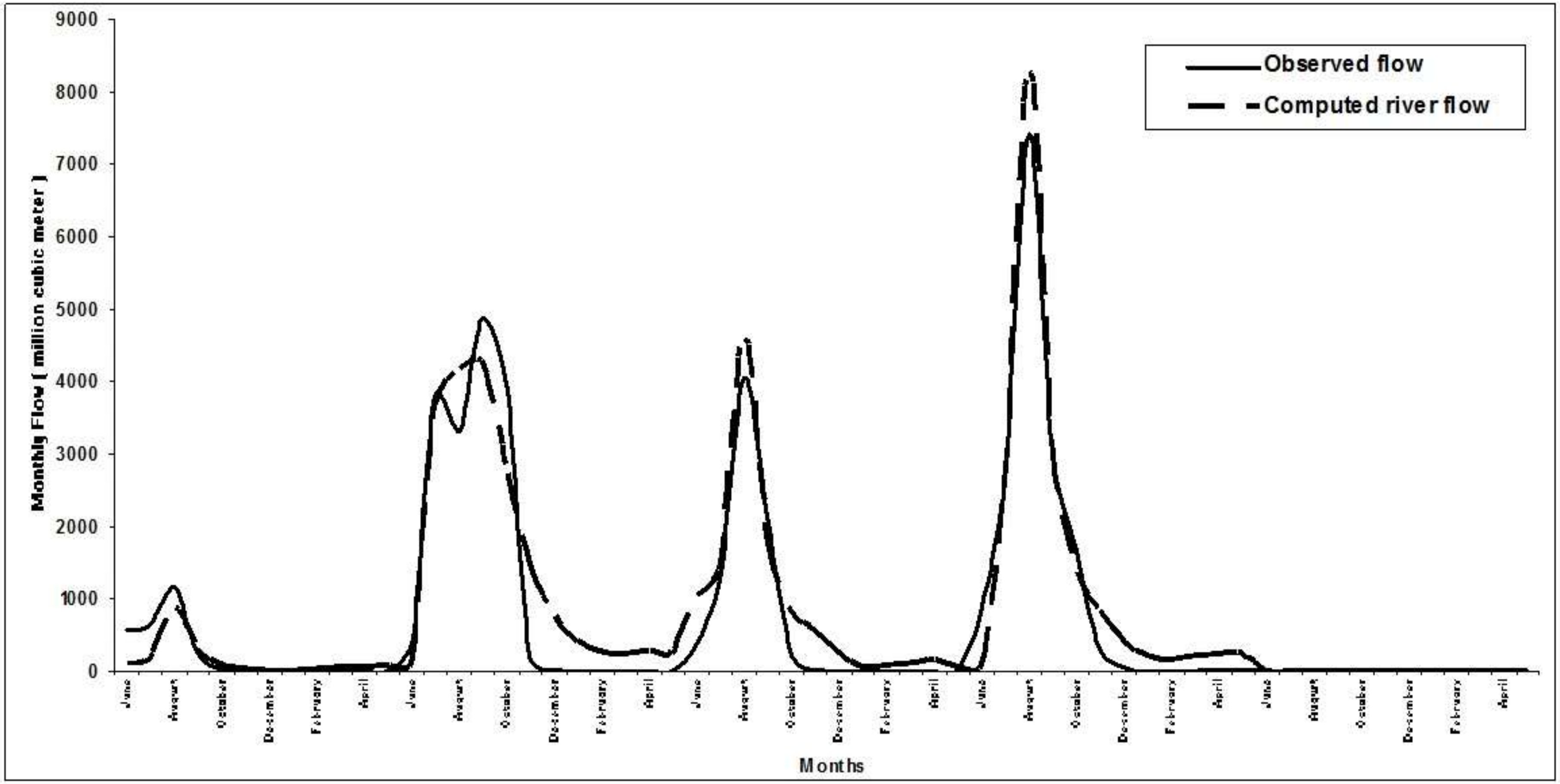


Figure – 5.2 Observed and simulated monthly flows in calibration & validation period (1987-1990) in the Middle Tapi Sub-basin

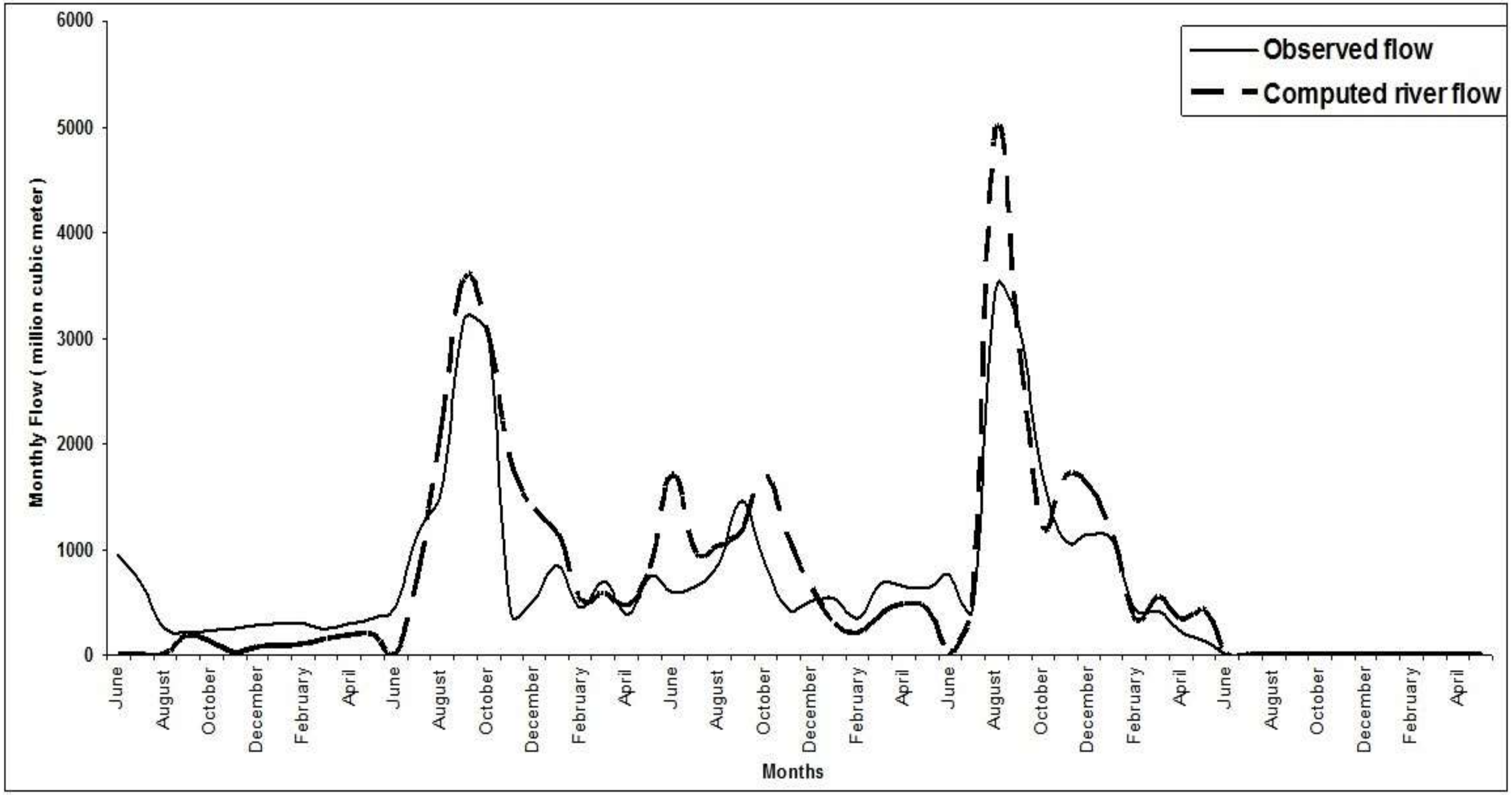


Figure – 5.3 Observed and simulated monthly flows in calibration & validation period (1987-1990) in the Lower Tapi Sub-basin

Table – 5.5
Irrigation system variables and constants for various scenarios

Irrigation System Variables & Constants	Values of parameters for different scenarios									
	1	2	3	4	5	6	7	8	9	10
	Dry	Wet	Average	Random	Past	Present	Future (2025)	Future (2025) + Forest Inc.	Future (2025) + Interlink	Future (2025) + Irr. Eff. Inc.
Proportion of return flows evaporating through water logged areas and swamps from surface irrigation	0.3	0.2	0.25	0.2	0.25	0.25	0.25	0.25	0.25	0.25
Proportion of residual return flows returning to surface waters from surface irrigation	0.2	0.4	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.3
Proportion of residual return flows returning to ground waters from surface irrigation	0.8	0.6	0.7	0.6	0.7	0.7	0.7	0.7	0.7	0.7
Proportion of return flows evaporating through water logged areas and swamps from GW irrigation	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Proportion of residual return flows returning to surface waters from GW irrigation	0.05	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Proportion of residual return flows returning to ground waters from GW irrigation	0.95	0.8	0.9	0.8	0.9	0.9	0.9	0.9	0.9	0.9
Surface water conveyance and distribution efficiency	0.35	0.35	0.35	0.35	0.3	0.35	0.35	0.35	0.35	0.5
Ground water conveyance and distribution efficiency	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.75
Proportion of additional evapotranspiration needs which would be met through irrigation	0.75	1	0.9	1	0.7	0.9	0.9	0.9	0.9	0.9

The soil moisture capacities (difference of water content between field capacity and permanent wilting point) were estimated by the formula:

$$WD = 10 * G_A * H * (w_{fc} - w_{pwp}) \qquad \ldots(1)$$

where 'WD' is the available soil moisture capacity in mm, 'w_{fc}' is the water content of soil at field capacity expressed as percent on dry weight basis, 'w_{pwp}' is the water content of soil at permanent wilting point expressed as percent on dry weight basis, 'G_A' is the apparent specific gravity of the soil, and 'H' is the effective soil depth (root depth) in m. For the black cotton soil mostly found in the Tapi basin, the apparent specific gravity of 1.6 m, water content at field capacity of 25%, and water content at permanent wilting point of 10% were assumed. So, for a root depth of 1.25 m, the soil moisture capacity comes out to be 300 mm. For the Upper Tapi basin, it was considered that soil depth is limited and so the root depth under forests was assumed to be 1.25 m. For the Middle and Lower sub-basins, the soil depth was not considered a limiting factor. Similarly, for agricultural crops, effective soil depth (root depth) of 50 cm was assumed for the Upper sub-basin while for the Middle sub-basin, the soil moisture capacity was increased by 25 cm for all the agricultural parcels. On the basis of simulation analysis for the Lower sub-basin, the soil moisture capacities were further enhanced.

From the comparison of observed and simulated river outflows for various sub-basins at monthly and annual time steps, it is noted that the observed and simulated values match to a considerable extent. Similarly, for the average year 1989-90 for which the model parameters have been calibrated, it is observed that the normal rainfall recharge to groundwater matches quite close to the normal natural recharge in various sub-basins.

Using the calibrated parameters, the model runs were taken with the observed data for the year 1988-89 and 1990-91. Year 1988-89 has received considerably high rainfall as compared to the average rainfall in all the three sub-basins. In the year

1990-91, there is considerably high rainfall as compared to average rainfall in the upper and middle Tapi basins while in lower basin, it is quite close to the average rainfall. For all the three years of calibration and validation, the monthly observed and simulated flows closely match in all the three sub-basins.

The calibrated and validated parameters were used to analyze and visualize various *PAST*, *PRESENT*, and *FUTURE* scenarios in the Tapi basin. These are discussed in the following.

5.5 Analysis of Different Water Resources Development Scenarios

After calibration and validation of the parameters of CPSP model, the same was used to predict the past, present, and future scenarios. For all such scenarios, average rainfall in various months (obtained through arithmetic average of the long-term average rainfall of various rainfall stations, as given in Table - 4.2) was used. Various assumptions for analyzing different scenarios are described in the following:

a) *PAST* scenario

For the *PAST* period, land use, cropping pattern, and source-wise and crop-wise irrigation statistics of one year in 1960s were obtained from reports of D.E.S. for various districts within the Tapi basin. The capacities of Hathnur dam in the Upper sub-basin and Kakrapar weir in the Lower sub-basin were considered and correspondingly, the surface storage filling/depletion values were modified. Long-term average rainfall was considered as input to the basin and no export was considered in the *PAST* scenario from the Lower sub-basin. Further, surface irrigation efficiency of 30%, groundwater use efficiency of 60% and proportion of additional ET needs met through irrigation were assumed to be 70%.

b) *PRESENT* scenario

For analyzing the *PRESENT* scenario, year 1995-96 was considered as this was the most recent year for which much of the data required in CPSP model (land use, cropping pattern, and source-wise and crop-wise irrigation data) were available from

D.E.S. records. An approximation of the likely surface storage filling/depletion pattern corresponding to the average rainfall values in different months in the three sub-basins was found by regression analysis as described in Chapter-4. The storages of only the existing projects in the three sub-basins were considered under this scenario. Long-term average rainfall was assumed as input to the basin. Using the working table of Ukai reservoir for four years of record (1987-88, 1988-89, 1989-90, and 1990-91), the average monthly diversion pattern of water in the Ukai-Kakrapar canal system was worked out and assuming that 90% of this water is exported outside the Tapi basin (the canal system originating from the Ukai reservoir transfers most of the water to command areas in other basins), the same was specified as export pattern in all the scenarios from the Lower Tapi basin. Surface irrigation efficiency of 35%, groundwater use efficiency of 60% and proportion of additional ET needs met through irrigation were assumed to be 90% for this case.

c) *FUTURE* scenarios

For analyzing the probable future conditions, seven different *FUTURE* scenarios were analyzed: a) Future (2025) with business as usual (BAU), b) Future (2025) considering 10% increase in the forest area at the expense of uncultivated area, c) Future (2025) considering inter-basin transfer of water through ILR project, d) Future (2025) with BAU and increase in the efficiency of irrigation water use [15% in surface water use (35 to 50%) and 15% in groundwater use (60 to 75%)]. Various land use parcels were modified looking at the pattern in the past and the developmental aspects of each particular scenario. It is assumed that with the completion of on-going projects, the irrigated area would increase in future. This is described in Chapter – 4. The capacity of on-going storage projects was added to the existing projects and correspondingly, the average monthly storage filling and depletion pattern and proportion of surface irrigation values were modified. In the scenario analysing interlinking options, it is envisaged to export $1554*10^6$ m^3 of additional water from the Ukai dam. This export is divided equally in 12 months and added to the existing average export pattern from the Lower sub-basin.

With this input data, the model runs were taken for different scenarios. The overall basin results with respect to different aspects of water use under various scenarios are presented in Table – 5.6 to Table – 5.14. The results in graphical form are presented subsequently.

Table – 5.6
Overall water balance (10^6 cu m) for Tapi basin under different scenarios

	Past Scenario	Present Scenario	Future Scenarios						
			BAU	Increased Forest cover	BAU + Interlink	BAU + Improved Irr. Eff.	Increased Forest + Irr. Eff.	Interlink + Improved Irr. Eff.	Interlink + Increased Forest + Irr. Eff.
Rainfall	54359	54359	54359	54359	54359	54359	54359	54359	54359
Imports	0	0	0	0	0	0	0	0	0
GW flow from other basins	0	0	0	0	0	0	0	0	0
Total consumptive use	46414	48837	50258	50492	50258	50352	50586	50352	50586
Total river flows	7271	2543	995	602	706	842	712	1119	730
Surface export	0	2933	2933	2933	4493	2933	2933	4493	4493

Table – 5.7
River and surface water balance (10^6 cu m) for Tapi basin under different scenarios

	Past Scenario	Present Scenario	Future Scenarios						
			BAU	Increased Forest cover	BAU + Interlink	BAU + Improved Irr. Eff.	Increased Forest + Irr. Eff.	Interlink + Improved Irr. Eff.	Interlink + Increased Forest + Irr. Eff.
Quick runoff from rainfall	4456	4476	4447	4304	4447	4443	4301	4443	4301
Base flow	2436	1158	1035	999	1024	1180	1091	1193	1187
Returns to surface from surface irrigation	83	482	844	844	844	525	525	525	525
Returns to surface from GW irrigation	49	113	98	98	98	59	59	59	59
Returns to surface from D&I withdrawals	71	217	473	473	473	473	473	473	473
Imports	0	0	0	0	0	0	0	0	0
Surface withdrawals for irrigation in the basin	469	1831	1886	1735	1853	1147	999	1019	822
Surface withdrawals for D&I in the basin	42	128	449	449	449	449	449	449	449
Natural and induced recharge from river to GW	687	990	634	1000	867	1309	1356	1096	1533
Outflow to sea	7271	2543	995	602	706	842	712	1119	730
Export	0	2933	2933	2933	4493	2933	2933	4493	4493

Table – 5.8
Groundwater balance (10^6 cu m) for Tapi basin under different scenarios

	Past Scenario	Present Scenario	Future Scenarios						
			BAU	Increased Forest cover	BAU + Interlink	BAU + Improved Irr. Eff.	Increased Forest + Irr. Eff.	Interlink + Improved Irr. Eff.	Interlink + Increased Forest + Irr. Eff.
Natural recharge from rainfall	3290	3307	3285	3183	3285	3283	3181	3283	3181
Returns to GW from surface irrigation	193	1125	1969	1969	1969	1224	1224	1224	1224
Returns to GW from GW irrigation	443	1018	884	884	884	530	530	530	530
Returns to GW from D&I withdrawals	114	169	385	385	385	385	385	385	385
Natural and induced recharge from river to GW	687	990	634	1000	867	1309	1356	1096	1533
GW irrigation withdrawals, including GW pumping to surface canals	1192	2838	2473	2473	2473	2287	2287	2287	2287
GW withdrawals for D&I use	224	442	969	969	969	969	969	969	969
Base flow to rivers	2436	1158	1035	999	1024	1180	1091	1193	1187
GW pumping to canals to meet shortages	34	1347	3714	3865	3747	3272	3421	3401	3598

Table – 5.9
Monthly river flows (10^6 cu m) at outlet of Tapi basin under different scenarios

	Past Scenario	Present Scenario	Future Scenarios						
			BAU	Increased Forest cover	BAU + Interlink	BAU + Improved Irr. Eff.	Increased Forest + Irr. Eff.	Interlink + Improved Irr. Eff.	Interlink + Increased Forest + Irr. Eff.
June	0	0	0	0	0	0	0	0	0
July	1507	0	0	0	0	0	0	0	0
August	2832	111	0	0	0	0	0	0	0
September	1704	3	0	0	0	0	0	0	0
October	690	438	219	70	173	172	129	152	142
November	340	367	126	103	105	124	87	135	93
December	148	366	134	105	102	131	106	153	102
January	39	302	113	71	67	83	84	137	82
February	10	135	58	36	34	44	42	75	45
March	0	289	122	77	73	95	95	164	93
April	1	200	80	50	47	70	66	122	68
May	2	332	142	89	104	123	105	180	104

Table – 5.10
Irrigated cropped area (10^6 sq m) and withdrawal (10^6 cu m) for irrigation in Tapi basin under different scenarios

	Past Scenario	Present Scenario	Future Scenarios						
			BAU	Increased Forest cover	BAU + Interlink	BAU + Improved Irr. Eff.	Increased Forest + Irr. Eff.	Interlink + Improved Irr. Eff.	Interlink + Increased Forest + Irr. Eff.
Irrigated cropped area (ICA) under Kharif crops	638	1699	1985	1985	1985	2380	2380	2380	2380
ICA under Rabi crops	1176	2251	2940	2940	2940	3520	3520	3520	3520
ICA under HW	63	186	215	215	215	270	270	270	270
ICA under two seasonal [K+R]	224	595	1050	1050	1050	1255	1255	1255	1255
ICA under two seasonal [R+HW]	0	0	0	0	0	0	0	0	0
ICA under perennial crops	662	1955	2300	2300	2300	2580	2580	2580	2580
Total withdrawal for irrigation	1728	10297	14721	14872	16314	12912	13061	14601	14798

Table – 5.11
Distribution of net land area (10^6 sq m) in Tapi basin under different scenarios

	Past Scenario	Present Scenario	Future Scenarios						
			BAU	Increased Forest cover	BAU + Interlink	BAU + Improved Irr. Eff.	Increased Forest + Irr. Eff.	Interlink + Improved Irr. Eff.	Interlink + Increased Forest + Irr. Eff.
Area under nature sector use	26719	25086	25000	25000	25000	24950	24950	24950	24950
Area under food-rainfed agriculture	30753	33484	30500	30500	30500	29515	29515	29515	29515
Area under food-irrigated agriculture	2410	5346	7000	7000	7000	8135	8135	8135	8135

Table – 5.12
Distribution of net irrigated area (10^6 sq m) by source in Tapi basin under different scenarios

	Past Scenario	Present Scenario	Future Scenarios						
			BAU	Increased Forest cover	BAU + Interlink	BAU + Improved Irr. Eff.	Increased Forest + Irr. Eff.	Interlink + Improved Irr. Eff.	Interlink + Increased Forest + Irr. Eff.
Net irrigated surface water	471	2251	4293	4293	4293	4908	4908	4908	4908
Net irrigated GW	1939	3095	2707	2707	2707	3227	4908	4908	4908

Table – 5.13
Distribution of gross irrigated area (10^6 sq m) in Tapi basin under different scenarios

	Past Scenario	Present Scenario	Future Scenarios						
			BAU	Increased Forest cover	BAU + Interlink	BAU + Improved Irr. Eff.	Increased Forest + Irr. Eff.	Interlink + Improved Irr. Eff.	Interlink + Increased Forest + Irr. Eff.
Gross irrigated kharif paddy	228	406	475	475	475	525	525	525	525
Gross irrigated other kharif	410	1294	1510	1510	1510	1855	1855	1855	1855
Gross irrigated rabi	2663	7141	7140	7140	7140	7595	7595	7595	7595
Gross irrigated HW	63	186	215	215	215	270	270	270	270
Gross irrigated-two seasonal kharif/rabi	224	595	1050	1050	1050	1255	1255	1255	1255
Gross irrigated two seasonal rabi/hw	0	0	0	0	0	0	0	0	0
Gross irrigated perennials	662	1955	2300	2300	2300	2580	2580	2580	2580

Table – 5.14
Consumptive use (ET) by use sector in Tapi basin under different scenarios

	Past Scenario	Present Scenario	Future Scenarios						
			BAU	Increased Forest cover	BAU + Interlink	BAU + Improved Irr. Eff.	Increased Forest + Irr. Eff.	Interlink + Improved Irr. Eff.	Interlink + Increased Forest + Irr. Eff.
Nature sector, beneficial	15360	14185	14587	15467	14587	14587	15467	14587	15467
Nature sector, non beneficial	4595	4550	4139	3493	4139	4108	3462	4108	3462
Agriculture sector beneficial	19411	23752	23837	23471	23837	24461	24461	24461	24461
Agriculture sector non-beneficial	7315	6166	7502	7502	7502	7054	7054	7054	7054
D&I (People sector)	81	185	559	559	559	559	559	559	559

Table – 5.15
Composition of consumptive use in agricultural sector in Tapi basin under different scenarios

	Past Scenario	Present Scenario	Future Scenarios						
			BAU	Increased Forest cover	BAU + Interlink	BAU + Improved Irr. Eff.	Increased Forest + Irr. Eff.	Interlink + Improved Irr. Eff.	Interlink + Increased Forest + Irr. Eff.
Rainfed agriculture	23897	22625	21568	21568	21568	20830	20830	20830	20830
Irrigated lands from rainfall	1541	3647	4713	4713	4713	5486	5486	5486	5486
Additional use on irrigated lands from irrigation	1155	2684	3656	3290	3656	4172	4172	4172	4172
Additional use from reservoirs, (chargeable to irrigation)	16	366	413	413	413	413	413	413	413
Water logged areas chargeable to irrigation	118	595	989	989	989	614	614	614	614

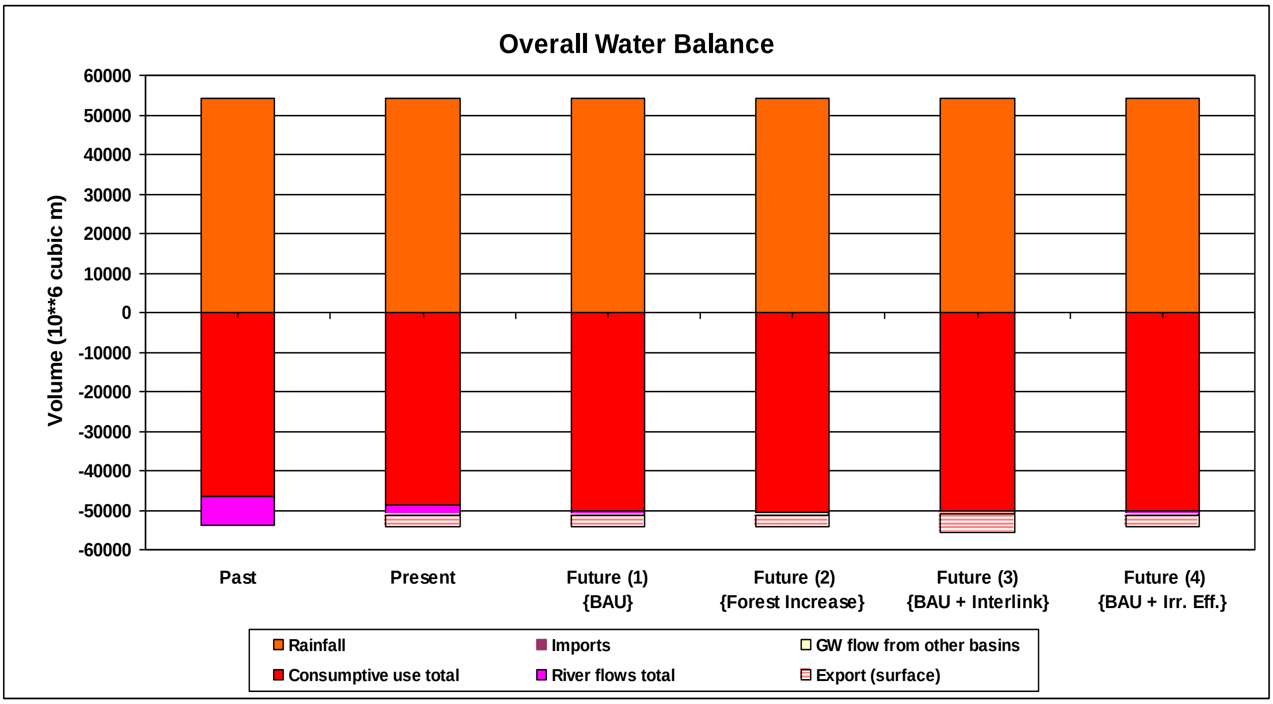
Table – 5.16
Composition of withdrawals in Tapi basin under different scenarios

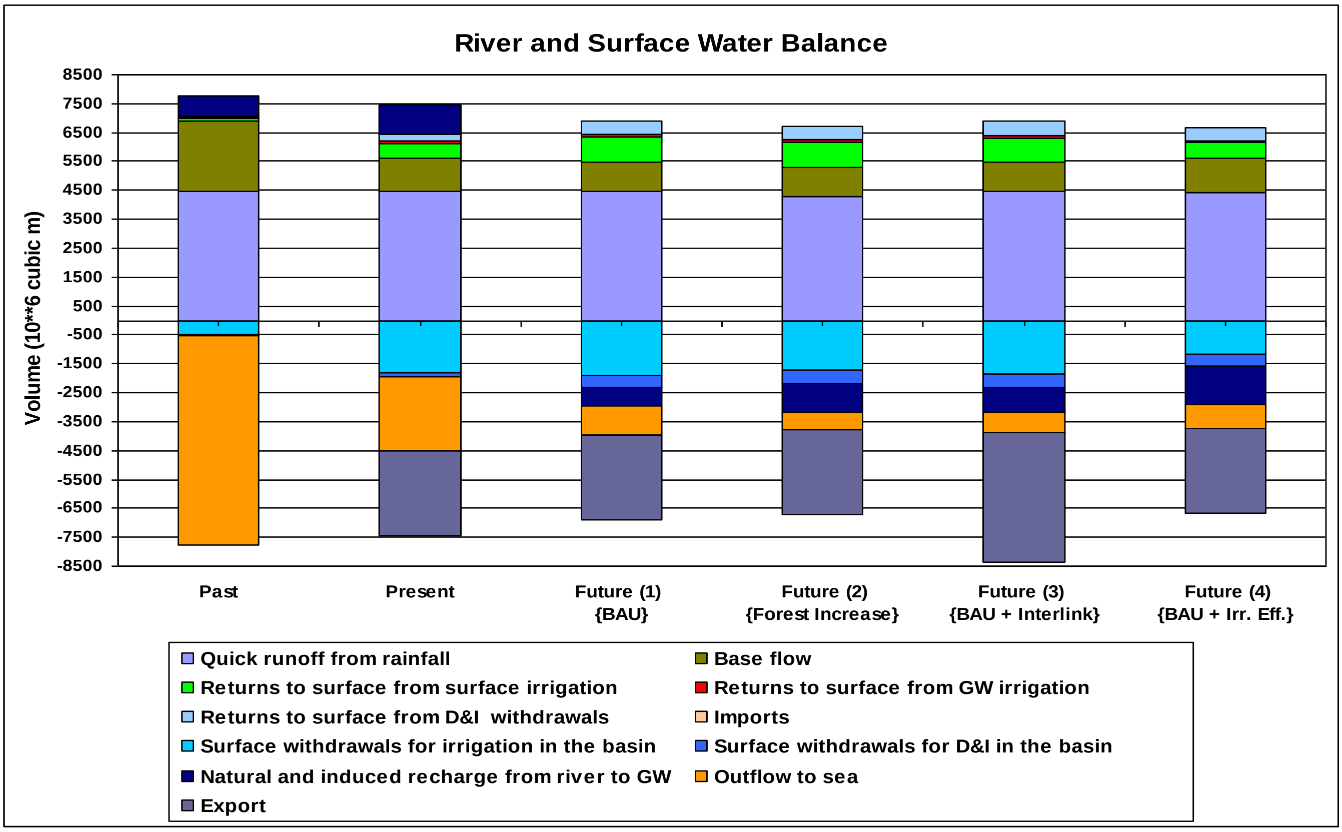
	Past Scenario	Present Scenario	Future Scenarios						
			BAU	Increased Forest cover	BAU + Interlink	BAU + Improved Irr. Eff.	Increased Forest + Irr. Eff.	Interlink + Improved Irr. Eff.	Interlink + Increased Forest + Irr. Eff.
Surface irrigation	726	6553	9502	9502	11062	8321	7912	9881	9881
GW irrigation, excluding GW pumping to surface canals	1234	2966	2922	2922	2922	2736	3256	2736	2736
D&I from SW	224	442	969	969	969	969	559	969	969
D&I from GW	42	128	449	449	449	449	969	449	449
GW pumping to canals	34	1347	3714	3865	3747	3272	3421	3401	3598

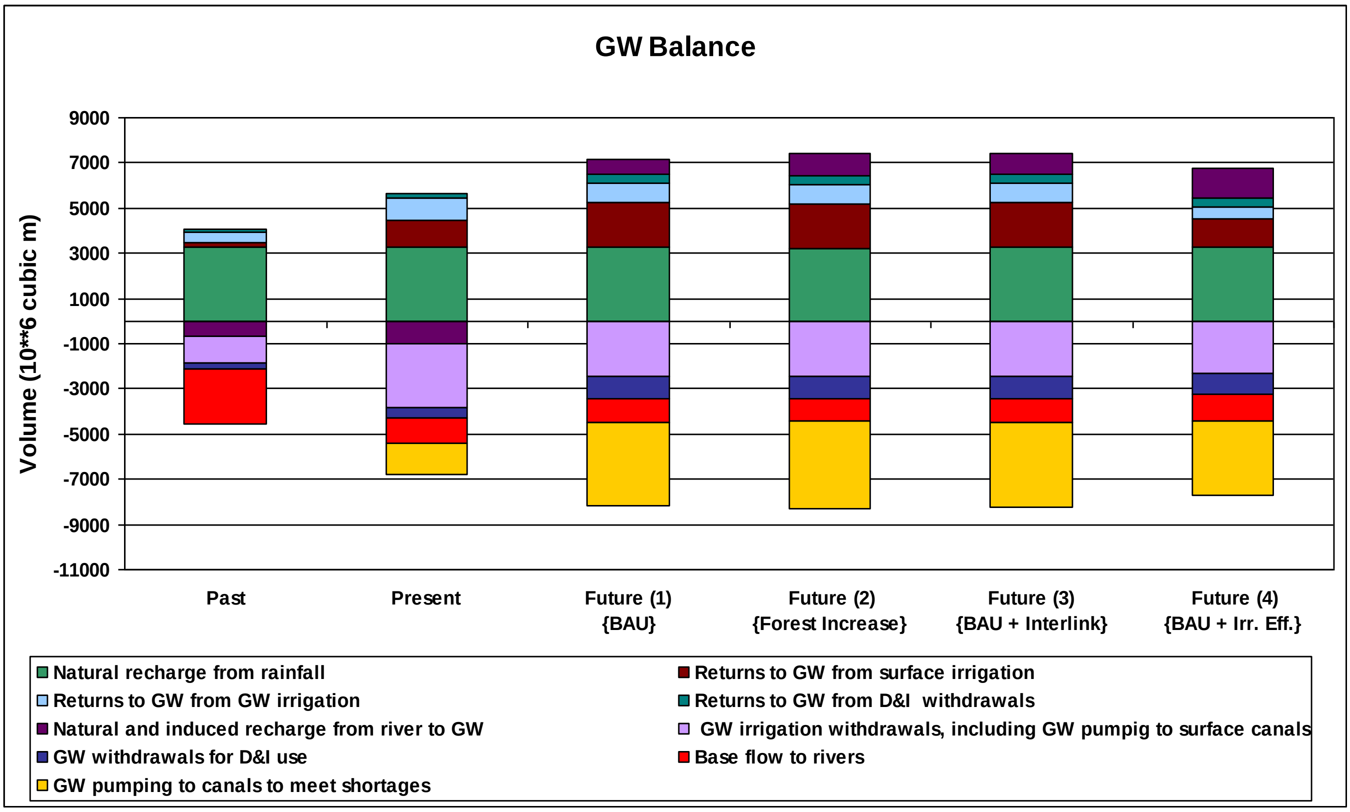
Overall results for the Tapi basin under different developmental scenarios are summarized in Table - 5.17 where the water availability in the basin and water uses for people, nature, and food are specified. From the results of various scenarios, it is seen that major part of the basin resources are utilized towards the water requirement for food and nature. Total available water (which is only from the basin rainfall), is around $54359*10^6$ m^3. Presently, around 56% of the available water is consumed for

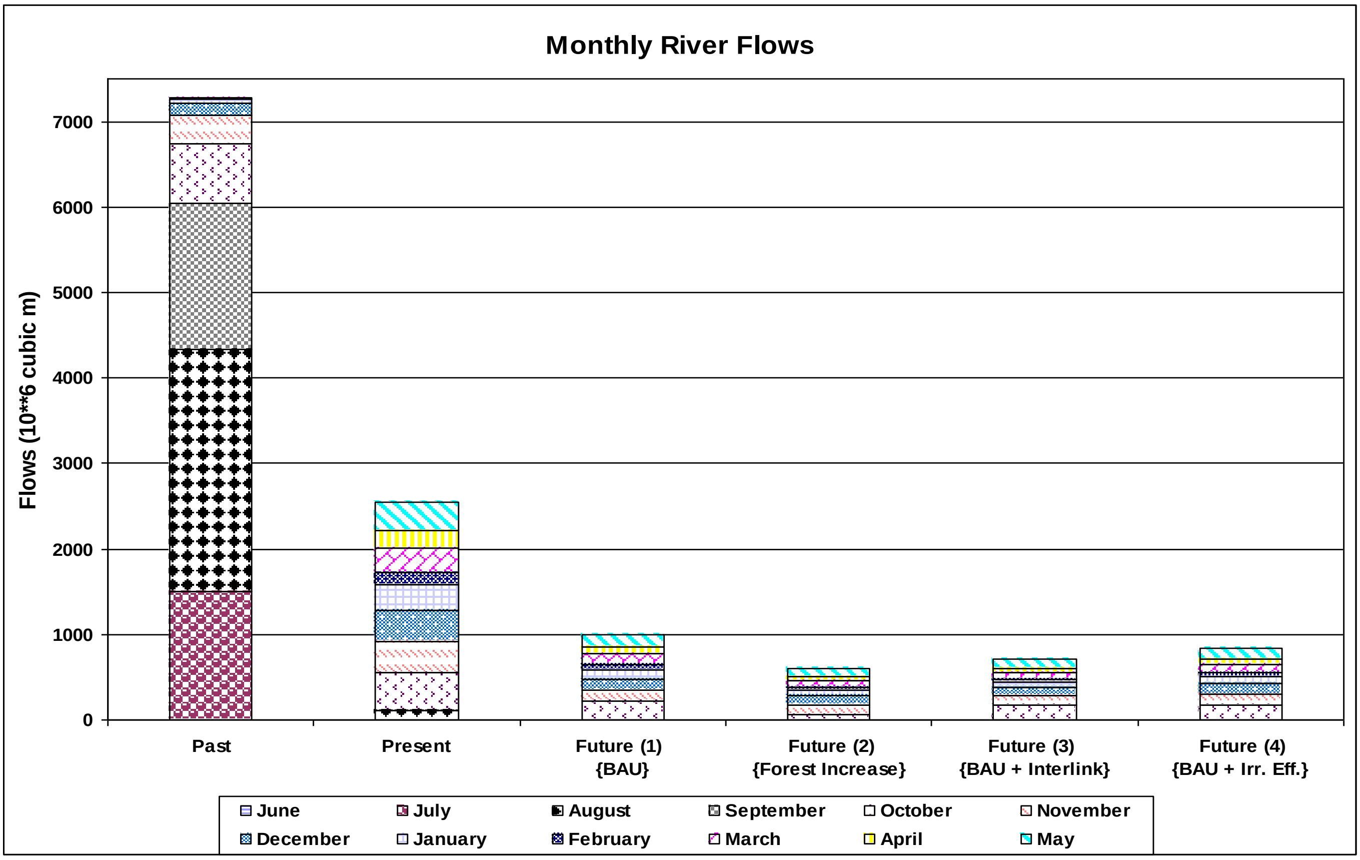
Table – 5.17 Water availability and use (10^6 cu m) in Tapi basin under different scenarios

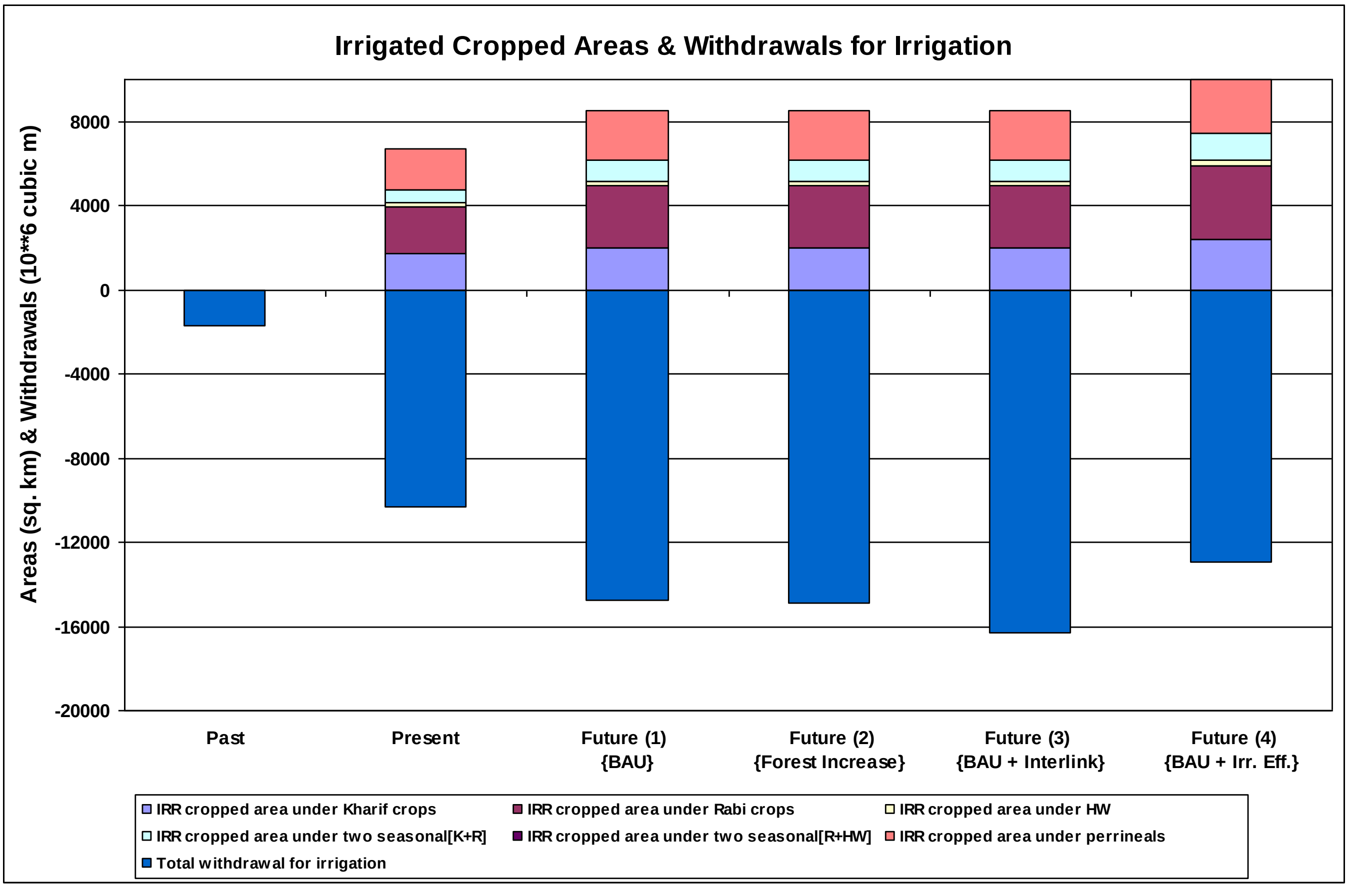
Description	Past Scenario	Present Scenario	Future Scenarios						
			BAU	Increased Forest cover	BAU + Interlink	BAU + Improved Irr. Eff.	Increased Forest + Irr. Eff.	Interlink + Improved Irr. Eff.	Interlink + Increased Forest + Irr. Eff.
Water available									
- Precipitation	54359	54359	54359	54359	54359	54359	54359	54359	54359
- Net export	0	2933	2933	2933	4493	2933	2933	4493	4493
Total available water	54359	51426	51426	51426	49866	51426	51426	49866	49866
Water for food									
- Consumptive use of rainfed agriculture	23897	22625	21568	21568	21568	20830	20830	20830	20830
- Consumptive use of irrigated agriculture from rainfall	1514	3647	4713	4713	4713	5486	5486	5486	5486
- Additional consumptive use of irrigated agriculture	1155	2684	3656	3290	3656	4172	4172	4172	4172
Total for food	26592	28956	29937	29571	29937	30488	30488	30488	30488
% of total available	48.92	56.31	58.21	57.50	60.03	59.29	59.29	61.14	61.14
Water for people									
Consumptive use for D&I use	81	185	559	559	559	559	559	559	559
Total for people	81	185	559	559	559	559	559	559	559
% of total available	0.15	0.36	1.09	1.09	1.12	1.09	1.09	1.12	1.12
Water for nature									
1. Consumptive use from forest	15360	14185	14587	15467	14587	14587	15467	14587	15467
2. Consumptive use from non-cultivated land	4595	4550	4139	3493	4139	4108	3462	4108	3462
3. Outflows to sea including low flows	7271	2543	995	602	706	842	712	1119	730
Total for nature	27225	21277	19720	19561	19432	19537	19641	19814	19659
% of total available	50.08	41.37	38.35	38.04	38.97	37.99	38.19	39.73	39.42
Storage changes									
➢ Surface storage changes	0	0	0	0	-1482	0	0	-1482	-1482
➢ Groundwater storage changes	-533	-1158	-1035	-886	-824	-977	-1091	-1332	-1187
➢ Soil moisture storage changes	1423	1423	1428	1437	1428	1429	1438	1429	1438

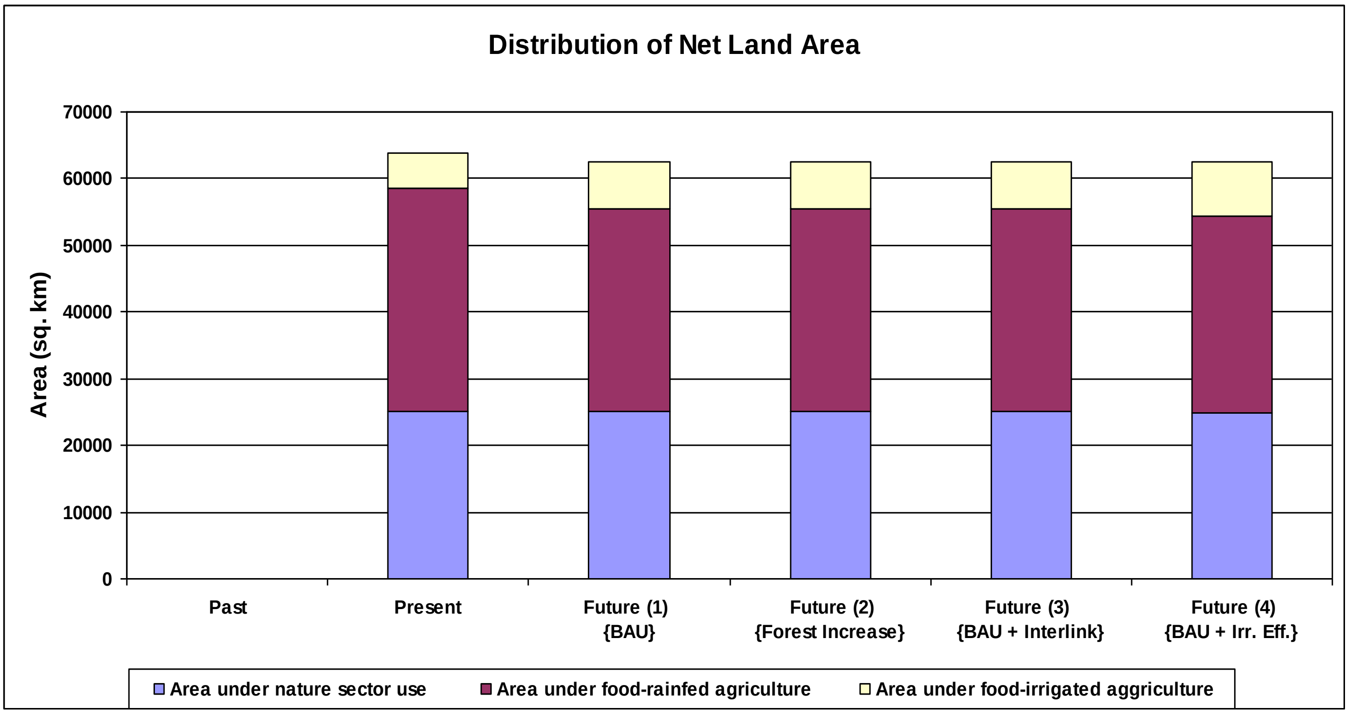

Overall Water Balance
Volume (10**6 cubic m)
60000
50000
40000
30000
20000
10000
0
-10000
-20000
-30000
-40000
-50000
-60000
Past
Present
Future (1) {BAU}
Future (2) {Forest Increase}
Future (3) {BAU + Interlink}
Future (4) {BAU + Irr. Eff.}
Rainfall
Imports
GW flow from other basins
Consumptive use total
River flows total
Export (surface)

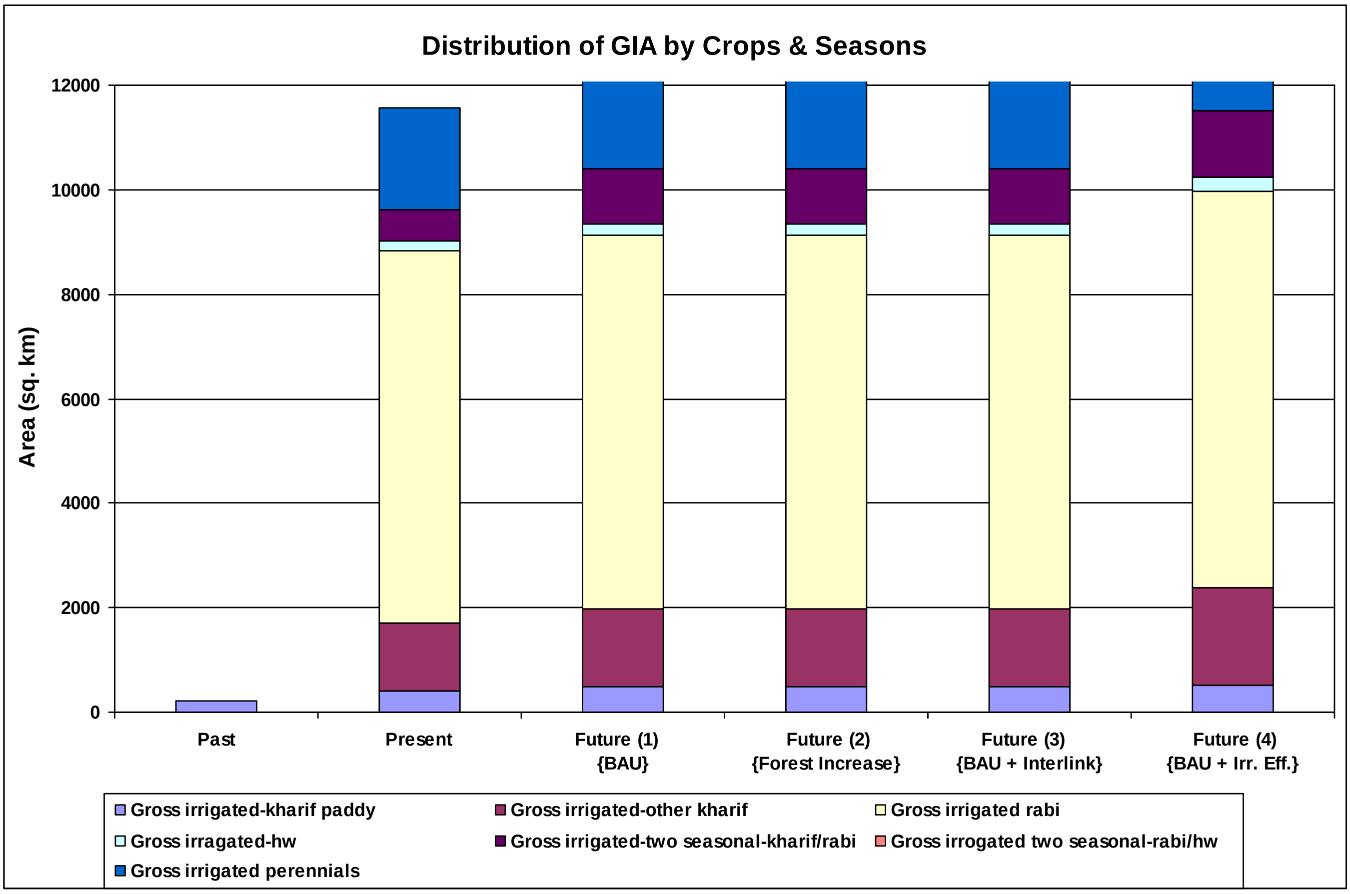

River and Surface Water Balance
Volume (10**6 cubic m)
8500
7500
6500
5500
4500
3500
2500
1500
500
-500
-1500
-2500
-3500
-4500
-5500
-6500
-7500
-8500
Past
Present
Future (1) {BAU}
Future (2) {Forest Increase}
Future (3) {BAU + Interlink}
Future (4) {BAU + Irr. Eff.}
Quick runoff from rainfall
Base flow
Returns to surface from surface irrigation
Returns to surface from GW irrigation
Returns to surface from D&I withdrawals
Imports
Surface withdrawals for irrigation in the basin
Surface withdrawals for D&I in the basin
Natural and induced recharge from river to GW
Outflow to sea
Export

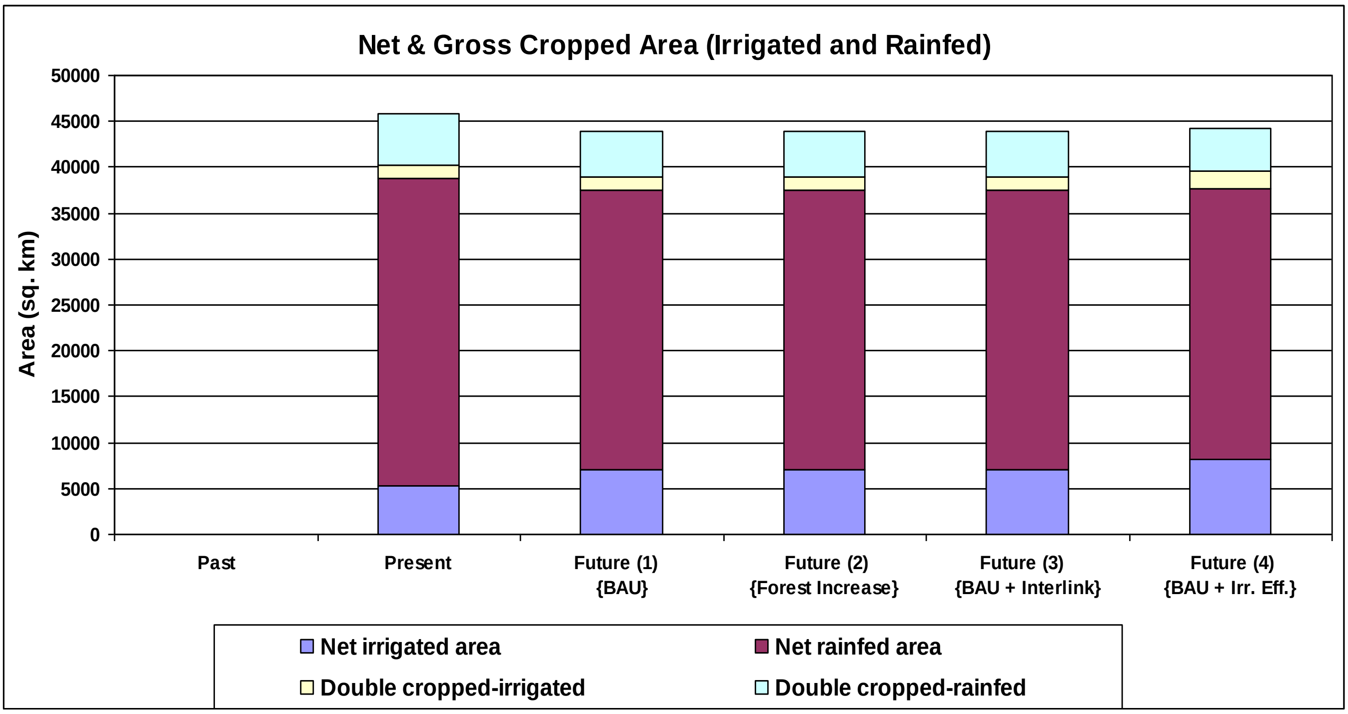

GW Balance
Volume (10**6 cubic m)
9000
7000
5000
3000
1000
-1000
-3000
-5000
-7000
-9000
-11000
Past
Present
Future (1) {BAU}
Future (2) {Forest Increase}
Future (3) {BAU + Interlink}
Future (4) {BAU + Irr. Eff.}
Natural recharge from rainfall
Returns to GW from surface irrigation
Returns to GW from GW irrigation
Returns to GW from D&I withdrawals
Natural and induced recharge from river to GW
GW irrigation withdrawals, including GW pumpig to surface canals
GW withdrawals for D&I use
Base flow to rivers
GW pumping to canals to meet shortages

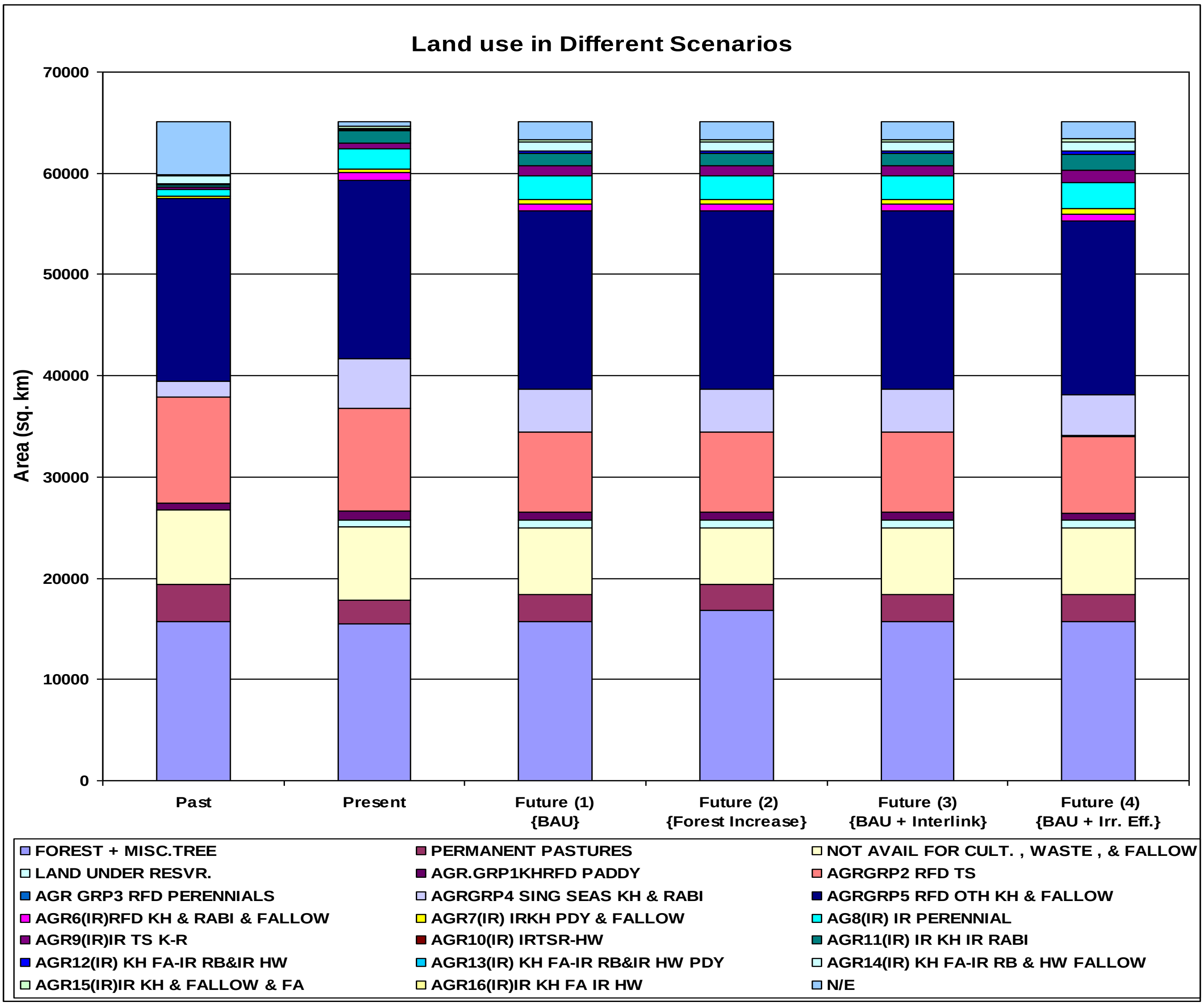

Monthly River Flows
Flows (10**6 cubic m)
7000
6000
5000
4000
3000
2000
1000
0
Past
Present
Future (1) {BAU}
Future (2) {Forest Increase}
Future (3) {BAU + Interlink}
Future (4) {BAU + Irr. Eff.}
June
July
August
September
October
November
December
January
February
March
April
May

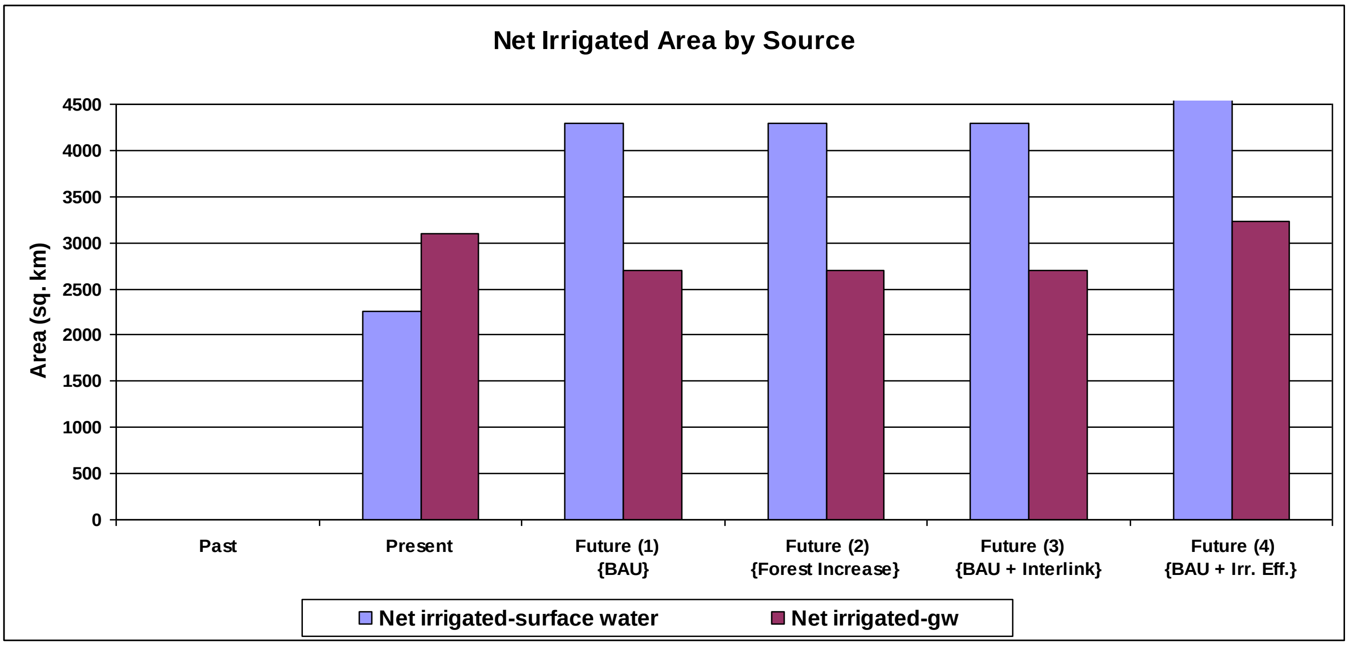

Irrigated Cropped Areas & Withdrawals for Irrigation
Areas (sq. km) & Withdrawals (10**6 cubic m)
8000
4000
0
-4000
-8000
-12000
-16000
-20000
Past
Present
Future (1) {BAU}
Future (2) {Forest Increase}
Future (3) {BAU + Interlink}
Future (4) {BAU + Irr. Eff.}
IRR cropped area under Kharif crops
IRR cropped area under Rabi crops
IRR cropped area under HW
IRR cropped area under two seasonal[K+R]
IRR cropped area under two seasonal[R+HW]
IRR cropped area under perrineals
Total withdrawal for irrigation

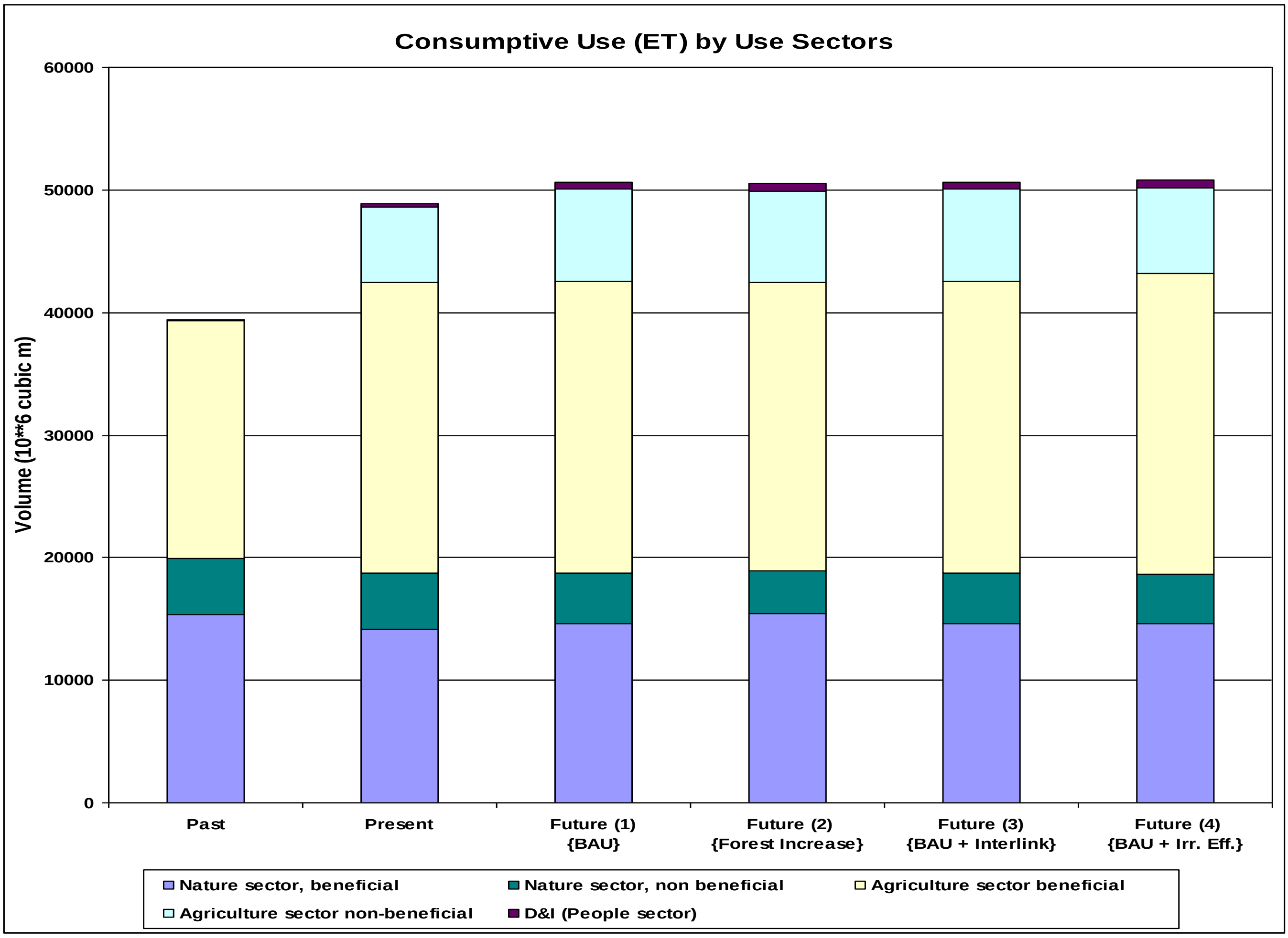

Distribution of Net Land Area
Area (sq. km)
70000
60000
50000
40000
30000
20000
10000
0
Past
Present
Future (1) {BAU}
Future (2) {Forest Increase}
Future (3) {BAU + Interlink}
Future (4) {BAU + Irr. Eff.}
Area under nature sector use
Area under food-rainfed agriculture
Area under food-irrigated aggriculture

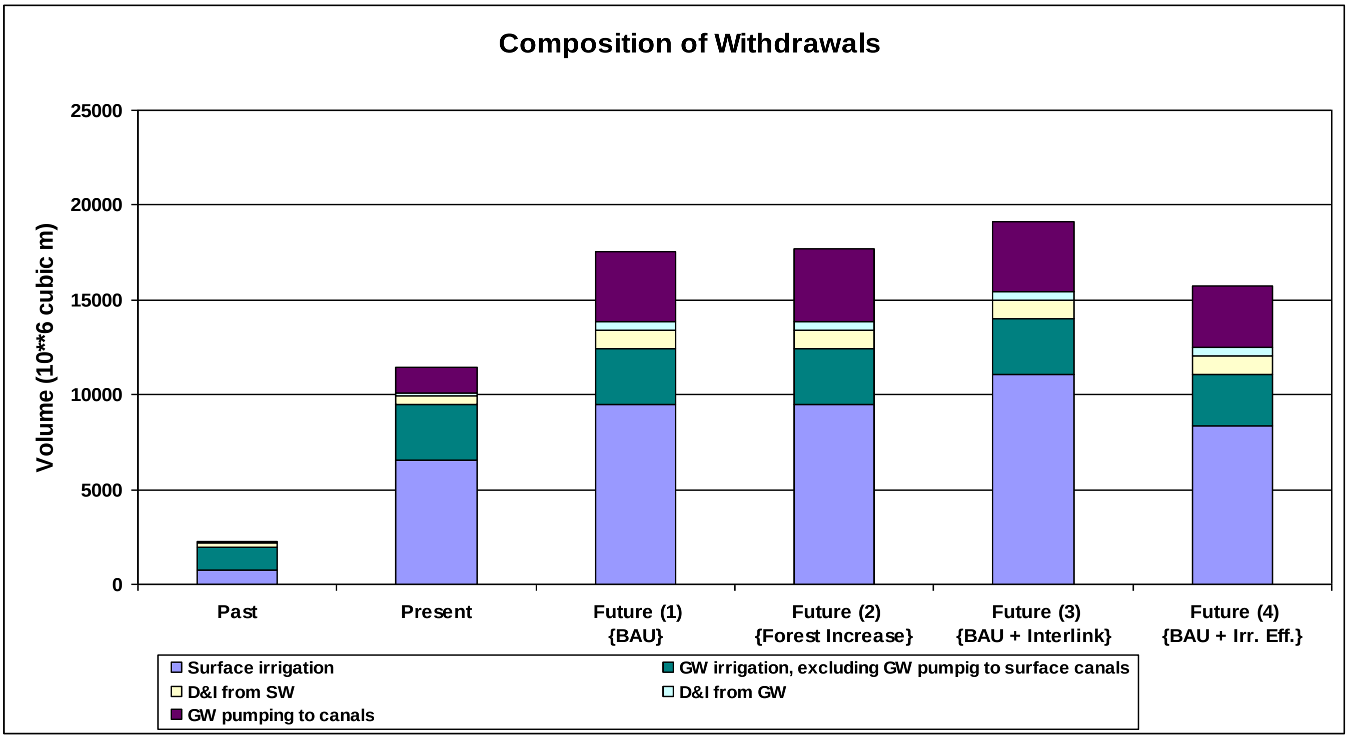

Distribution of GIA by Crops & Seasons
Area (sq. km)
12000
10000
8000
6000
4000
2000
0
Past
Present
Future (1)
{BAU}
Future (2)
{Forest Increase}
Future (3)
{BAU + Interlink}
Future (4)
{BAU + Irr. Eff.}
Gross irrigated-kharif paddy
Gross irrigated-other kharif
Gross irrigated rabi
Gross irragated-hw
Gross irrigated-two seasonal-kharif/rabi
Gross irrogated two seasonal-rabi/hw
Gross irrigated perennials

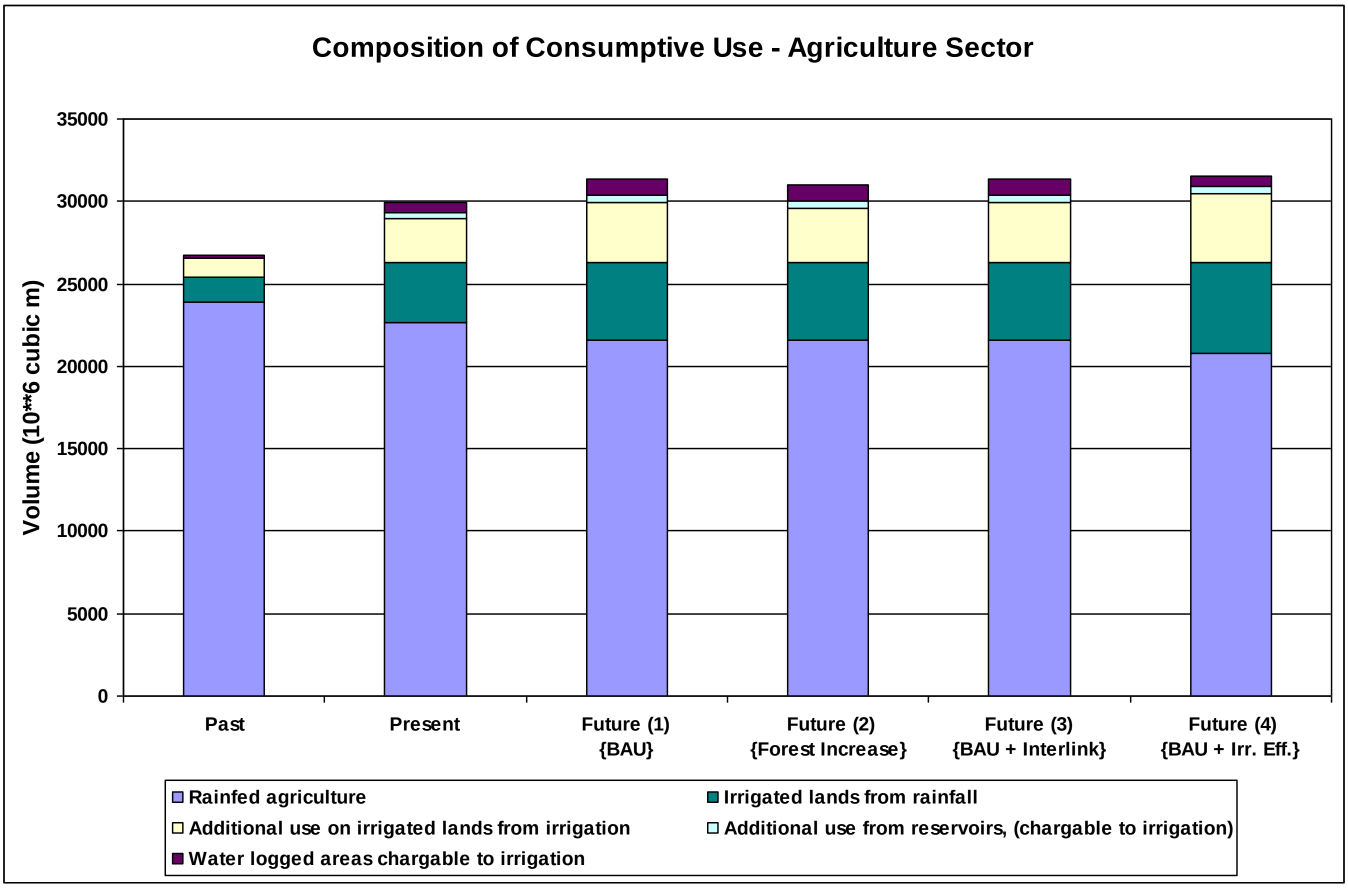

Net & Gross Cropped Area (Irrigated and Rainfed)
Area (sq. km)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Past
Present
Future (1)
{BAU}
Future (2)
{Forest Increase}
Future (3)
{BAU + Interlink}
Future (4)
{BAU + Irr. Eff.}
Net irrigated area
Net rainfed area
Double cropped-irrigated
Double cropped-rainfed


Land use in Different Scenarios
Area (sq. km)
70000
60000
50000
40000
30000
20000
10000
0
Past
Present
Future (1) {BAU}
Future (2) {Forest Increase}
Future (3) {BAU + Interlink}
Future (4) {BAU + Irr. Eff.}
FOREST + MISC.TREE
PERMANENT PASTURES
NOT AVAIL FOR CULT. , WASTE , & FALLOW
LAND UNDER RESVR.
AGR.GRP1KHRFD PADDY
AGRGRP2 RFD TS
AGR GRP3 RFD PERENNIALS
AGRGRP4 SING SEAS KH & RABI
AGRGRP5 RFD OTH KH & FALLOW
AGR6(IR)RFD KH & RABI & FALLOW
AGR7(IR) IRKH PDY & FALLOW
AG8(IR) IR PERENNIAL
AGR9(IR)IR TS K-R
AGR10(IR) IRTSR-HW
AGR11(IR) IR KH IR RABI
AGR12(IR) KH FA-IR RB&IR HW
AGR13(IR) KH FA-IR RB&IR HW PDY
AGR14(IR) KH FA-IR RB & HW FALLOW
AGR15(IR)IR KH & FALLOW & FA
AGR16(IR)IR KH FA IR HW
N/E


Net Irrigated Area by Source
Area (sq. km)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Past
Present
Future (1) {BAU}
Future (2) {Forest Increase}
Future (3) {BAU + Interlink}
Future (4) {BAU + Irr. Eff.}
Net irrigated-surface water
Net irrigated-gw


Consumptive Use (ET) by Use Sectors
Volume (10**6 cubic m)
60000
50000
40000
30000
20000
10000
0
Past
Present
Future (1) {BAU}
Future (2) {Forest Increase}
Future (3) {BAU + Interlink}
Future (4) {BAU + Irr. Eff.}
Nature sector, beneficial
Nature sector, non beneficial
Agriculture sector beneficial
Agriculture sector non-beneficial
D&I (People sector)


Composition of Withdrawals
Volume (10**6 cubic m)
25000
20000
15000
10000
5000
0
Past
Present
Future (1) {BAU}
Future (2) {Forest Increase}
Future (3) {BAU + Interlink}
Future (4) {BAU + Irr. Eff.}
Surface irrigation
GW irrigation, excluding GW pumpig to surface canals
D&I from SW
D&I from GW
GW pumping to canals



the production of food while around 42 % is consumed by the nature sector in the form of consumptive use from forests and uncultivated land. Requirement of water for domestic and industrial sector is hardly 0.36 % which will grow up to 1.12 % in future. In the agricultural sector, most of the consumption is made from the rainfed area through evapo-transpiration and present consumption by irrigated agriculture is around 28 % of the consumption by rainfed agriculture. However, with the completion of on-going projects and the increase in irrigated area, the consumption by the irrigated agriculture in future is likely to increase to 39 % of the rainfed agriculture. It needs to be mentioned here that for all the years of analysis, steady groundwater conditions were achieved in various sub-basins (which are obtained through a number of iterations of groundwater reservoir simulation).

Among the components of water consumption by the nature sector, it is seen that forests are highest consumers of water and account for nearly 67 % of the water requirements by nature. Presently, forest area is spread over nearly 24 % of the basin area. Under one scenario, the effect of expansion of forest area on the water resources of the Tapi basin has been simulated. It is seen that by increasing the forest area by about 10%, around 880 * 10^6 m^3 of additional water would be consumed. The storage change values indicate a net positive balance (considering the sum of surface water, groundwater, and soil water storage) in the present conditions and all future scenarios which do not include the interlink option. When export through interlink is made from the Lower Tapi basin, the net storage change becomes negative, thus indicating the infeasibility of the proposed transfer. In the present scenario and all future scenarios, some outflow from the basin to the sea is observed. However, even if this water is exported from the Lower sub-basin, the net storage balance remains negative.

From the model results for various scenarios, it is inferred that under presumed conditions of average basin rainfall, land parcels, domestic and industrial water demands, and evapotranspiration requirements, availability of water in the basin is just sufficient to meet existing demands and export of water from the basin. With the completion of on-going projects, it would be feasible to sustain the increased future demands from the available water resources. However, in view of the limited water resources of the basin, it would not be sustainable to increase the forest area in the basin. If the forest cover is to be increased, which should ideally be, then all attempts should be made to improve the irrigation efficiency and reduce the water export outside of the basin so that the development is sustainable. Further, the model results do not support the additional export of water (1554 * 10^6 m^3) through the proposed interlinking scheme.

* * *

Chapter - 6

CONCLUSIONS

The CPSP model has been applied to the Tapi river basin for analyzing the water availability and utilisation under various past, present, and future scenarios of water resources development. The catchment area of the Tapi basin is covered in the States of Madhya Pradesh, Maharashtra and Gujarat. Various types of data, such as land use, cropping pattern, irrigated areas, domestic and industrial requirements, rainfall, evapotranspiration, storage details etc. were obtained from the relevant Central and State Water Resources Departments. These data were converted to the form used by the CPSP model. The procedure for the preparation of land parcels (which requires rigorous analysis before input to the model) was automated to a considerable extent.

The Tapi basin was divided into three sub-basins (Upper Tapi sub-basin up to Hathnur with area of 29430 sq. km, Middle Tapi sub-basin from Hathnur up to the Gidhade gauging site with area of 25320 sq. km, and Lower Tapi sub-basin from the Gidhade gauging site up to the sea with area of 10395 sq. km). The CPSP model was calibrated (using the data of year 1989-90) and validated (with data of years 1988-89 and 1990-91) for all the three sub-basins using the historical data of ground water recharge and annual and monthly river flows at the outlets. Rainfall, discharge, and actual storage data of major reservoirs in these sub-basins for the calibration and validation period were obtained from the State departments, NWDA (2002) report, and CWC. Using the observed and simulated flows, model parameters (soil moisture capacities of different land parcels, runoff and recharge coefficients etc.) were calibrated and validated for the three sub-basins. For most of the cases, the results illustrated a good match between the observed and simulated values.

Using the calibrated parameters for various sub-basins, model runs were taken for analyzing various past, present, and future water resources development scenarios. For this purpose, average rainfall pattern and average evapo-transpiration conditions were assumed. The past scenario was analyzed for the year 1965-66 for which various land-parcel and irrigation details were obtained from the D.E.S. records and storage structures prevalent in the past conditions were considered. Similarly, for the present scenario, data base was developed to represent the conditions for the year 1995-96. Seven future scenarios were analyzed for the year 2025: i) Business as usual (BAU), ii) 10% increase in forest cover, iii) inter-basin transfer of water from the Ukai dam in the Lower Tapi sub-basin, iv) increased irrigation efficiency; v) increased forest cover + irrigation efficiency, vi) inter-basin transfer + increased irrigation efficiency, and vii) inter-basin transfer + increased forest + irrigation efficiency.

Overall results for the Tapi basin indicate that major part of the basin resources are utilized towards the water requirement for food and nature. Total available water (which is only from the basin rainfall), is around 54359 * 10^6 m^3. Presently, around 56% of the available water is consumed for the production of food while around 42 % is consumed by the nature sector in the form of consumptive use from forests and uncultivated land. Requirement of water for domestic and industrial sector is hardly 0.36 % which will grow up to 1.12 % in future. In the agricultural sector, most of the consumption is made from the rainfed area through evapo-transpiration and present consumption by irrigated agriculture is around 28 % of the consumption by rainfed agriculture. However, with the completion of on-going projects and the increase in irrigated area, the consumption by the irrigated agriculture in future is likely to increase to 39 % of the rainfed agriculture. Among the components of water consumption by the nature sector, it is seen that forests (spread over nearly 24 % of the basin area) are highest consumers of water and account for nearly 67 % of the water requirements by nature. The storage change values indicate a net positive balance (the sum of surface water, groundwater, and soil water storage) in the present conditions and all future scenarios except the ones with inter-linking option. When export through interlink is made from the Lower Tapi basin, the net storage change becomes negative, thus indicating the infeasibility of the water transfer. In the present scenario and all future scenarios, some outflow from the basin to the sea is also observed.

From the model results for various scenarios, it is inferred that under presumed conditions of average basin rainfall, land parcels, domestic and industrial water demands, and evapo-transpiration requirements, availability of water in the basin is just sufficient to meet the present needs with respect to the existing demands and existing export of water from the basin. With the completion of on-going projects, it would be feasible to sustain the increased future demands from the available water resources. However, the model results do not support the additional export of 1554 * 10^6 m^3 amount of water through the inter-linking scheme.

Finally, regarding the CPSP model, it needs to be emphasized that it is a very detailed model which rigorously computes various components of water balance of a basin so as to simulate the basin conditions quite close to reality. However, looking at the intricacies of relationship of various components of the model and higher chances of error which are difficult to detect and which could be due to minor mistakes in specifying the correct addresses of connected cells, it is felt that it would be more appropriate if such a model is written in a structured programming language (such as FORTRAN, Visual Basic or Visual C++ etc.) in a well-defined logical sequence.

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