IMPACT OF WATER RESOURCES PROJECTS – CASE STUDY OF WARDHA

Study Sponsored by

Greenpeace

FINAL REPORT

April 2012

DEPARTMENT OF CIVIL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY, DELHI

HAUZ KHAS, NEW DELHI 110016, INDIA

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Introduction

The study focuses on the hydrology of Wardha sub basin of Godavari which occupies the area between latitudes 19^0 18’ N and 21^0 58’N and longitudes 77^0 20’E and $79^0$45’ E. The designated sub basin is characterized by some distinctive features including (i) the sub basin is triangular in shape with an average width of nearly 90km, (ii) the sub basin terrain is undulating with accompanying ridges and valleys and (iii) the surface is marked by a medium density forest cover. The annual climatology is defined in terms of three dominant seasonal patterns that features (i) summer season (March – May), (ii) monsoon season (June – October), and (iii) winter (November – February). The soils of Wardha sub-basin are broadly divided into three categories namely (i) Black soil, (ii) Red soil, and (iii) Mixed Black and Red soil. Wardha River, a tributary of Pranhita River, is the principal drainage and the runoff carried by the former constitutes the principal source of water in the region and, accordingly, the sub-basin has also witnessed large scale interventions and related developments. The climatology is monitored at five IMD stations namely Betul, Amravati, Chanda, Nagpur and Yeotmal.

The flow in Wardha is observed at the CWC G&D site at Ghugus where it drains an area of 19759.95 km^2. The site is located upstream of the confluence of Wardha with Penganga.

Water Resources Assessment

The demands on the sub-basin’s water resources have grown steadily over the years and, amongst the diverse nature of the purposes that drives such an incessantly growing demand for water, an increased reliance on irrigated agriculture as well as numerous proposals to set up thermal power capacities are expected to lead to an intensification of competition for the limited water resources. Understandably, therefore, the objective of the study is to assess the sub-basin’s water resources availability and, further, to evaluate the impact of existing and other prospective water resources developmental initiatives on the overall water balance of Wardha sub-basin.

Hydrologic modelling based approach is followed to assess the overall water resources potential of Wardha sub-basin and, additionally, to evaluate the impacts of various development schemes that fall in the following categories:

(i) Schemes currently in operation
(ii) Virgin basin condition
(iii) Schemes under implementation
(iv) Schemes already approved but yet to be implemented.

The hydrologic model of the study area was developed using the SWAT application platform and simulations obtained for the four aforementioned development scenarios.

SWAT modelling based approach

SWAT (for Soil and Water Assessment Tool) is a physically based continuous time simulation model of the land phase Hydrologic Cycle. SWAT is designed with the capability to incorporate information about weather, soil properties, topography, vegetation, and land management practices prevalent in the basin and this enables modelling of the various resident physical processes associated with water movement, sediment movement, crop growth, nutrient cycling amongst others. In addition to being able to simulate virgin conditions, SWAT has the capability to predict impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time.

For modeling purposes, a basin may be partitioned into a number of sub-basins and each of these is further sub-divided into small entities known as Hydrologic Response Units (HRU). A Hydrologic Response Unit is a lumped land area within a sub-watershed that is deemed to be under a distinct, but uniquely similar, attributes for land cover, soil, and management combinations. Input information for each sub-basin is required for the following attributes: (i) climate; (ii) HRUs; (iii) ponds/wetlands; (iv) principal ground water features; and (v) main channel or reach draining the sub-basin.

Water balance is the principal paradigm that drives model simulations in both the land phase of the hydrologic cycle, depicted in Figure , as well as in the routing phase.

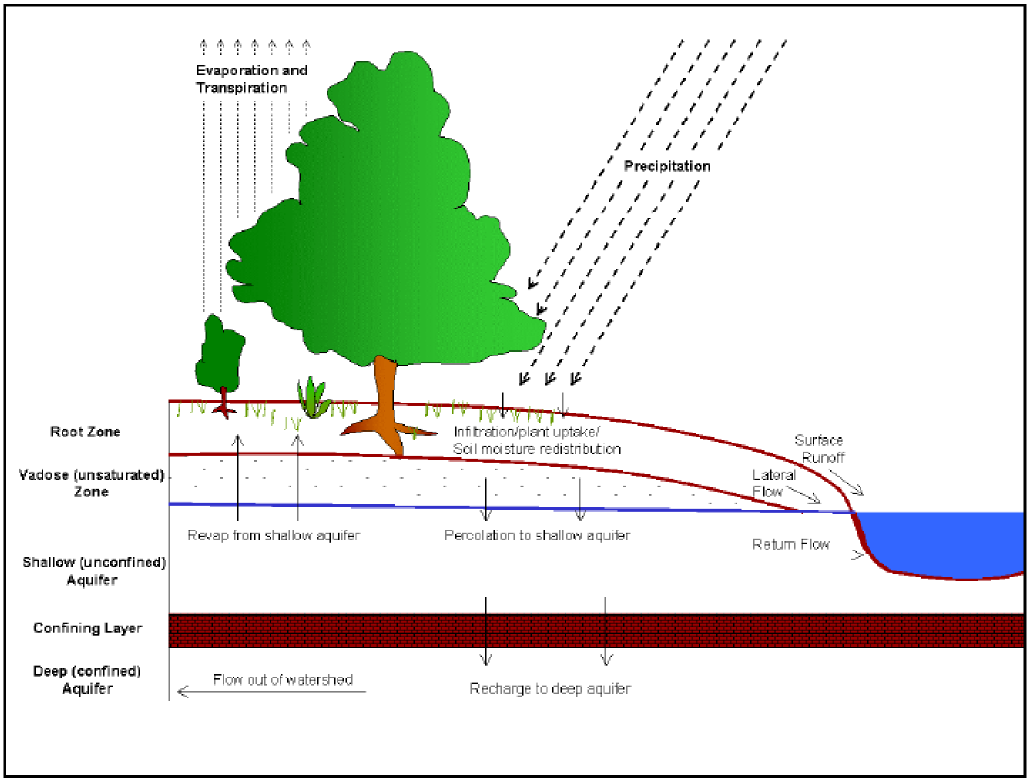

Figure 1: Schematic representation of the hydrologic cycle.

SWAT integrates together the web of hydrological processes which are modelled individually using the corresponding in-built individual component modules. A description of some important components of the hydrologic cycle, as represented in the SWAT modelling framework, is presented below:

Land Phase of the Hydrologic Cycle

The hydrologic cycle, as simulated by SWAT, is based on the water balance equation:

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})$$

where SW_t is the soil water content at the end of the any given period, t, SW_0 is the initial soil water content, t is the length of the characteristic modelling period (usually daily), R_{day} is the amount of precipitation observed on any day of interest, Q_{surf} is the amount of surface runoff, E_a is the amount of evapo-transpiration, w_{seep} is the amount of water entering the vadose zone from the soil profile, and Q_{gw} is the amount of return flow. The subdivision of the watershed enables the model to reflect differences in evapo-transpiration for various crops and soils while runoff is predicted separately for each, internally homogeneous, Hydrologic Response Units, (HRU) and routed to obtain the total simulated runoff at the watershed outlet.

Weather Generator

SWAT accepts recorded/observed rainfall data, temperature data, relative humidity data, solar radiation data and wind speed data as descriptive components of climate. However, in situations where climate data is not available, it uses its in-built weather generator data to generate these climatic variables by deploying long term weather statistics.

Computation of Surface Runoff

In this model, surface runoff, as infiltration excess, is calculated using a modification of the SCS curve number method (USDA Soil Conservation Service, 1972) or the Green & Ampt infiltration method (Green and Ampt, 1911).

Return Flow

Return flow is the fraction of total water precipitation and irrigation application that returns to the stream as a delayed contribution following a tortuous, essentially subsurface, travel and makes up the overall volume of stream flow. SWAT partitions sub-surface water into two distinct systems: a shallow, but essentially unconfined, zone which contributes return flow to streams within the basin and a deep, confined aquifer which also has the potential to contribute return flow to streams outside the basin (Arnold et al., 1993). Water percolating past the bottom of the root zone is partitioned into two fractions—each fraction becomes recharge for one of the aquifers. In addition to return flow, water stored in the shallow aquifer may replenish moisture in the soil profile in very dry conditions or be directly removed by plant. Water in the shallow or deep aquifer may also be removed by pumping.

Evapotranspiration

Evapotranspiration is a collective term for all processes by which water in the liquid or solid phase at or near the earth's surface becomes atmospheric water vapor. Evapotranspiration includes evaporation from rivers and lakes, bare soil, vegetative surfaces, evaporation from within the leaves of plants (transpiration), and sublimation from ice and snow surfaces. The model computes evaporation from soils and plants separately in which, firstly, the potential soil water evaporation is estimated as a function of potential evapotranspiration and leaf area index (area of plant leaves relative to the area of the HRU) and then the actual soil water evaporation is estimated by using exponential functions of soil depth and water content. Plant transpiration is simulated as a linear function of potential evapotranspiration and leaf area index.

The model assumes that potential evapotranspiration is unaffected by micro-climatic processes such as advection or heat-storage effects and is estimated using any of the following three methods namely (i) Hargreaves, (ii) Priestley-Taylor, and Penman-Monteith.

Flood Routing

As water flows downstream, various channel attributes combine together to influence the hydrograph shapes by imparting upon the latter its characteristic attributes of high damping. For this purpose, the routed hydrograph is derived based on the variable storage coefficient method or Muskingum routing method.

Reservoir Outflow

The model offers three alternatives for estimating outflow from the reservoir. The first option allows the user to input measured outflow. The second option, designed for small, uncontrolled reservoirs, requires the users to specify a water release rate. When the reservoir volume exceeds the principle storage, the extra water is released at the specified rate. Volume exceeding the emergency spillway is released within one day. The third option, designed for larger, managed reservoirs, has the user specify monthly target volumes for the reservoir.

Data and its processing

The SWAT model uses a range of input data to construct the conditions of the basin for hydrological simulation. The following is a brief account of the same.

DEM of 90 m resolution:

SRTM dataset from CIAT[1] and available from http://srtm.csi.cgiar.org has been used .

The Digital Elevation Model (DEM) of the study basin (Wardha sub basin) as extracted from SRTM data at 90-m resolution is presented as Figure 2 and forms the basic input for all subsequent processing.

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[1] Jarvis A., H.I. Reuter, A. Nelson, E. Guevara, 2008, Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT).

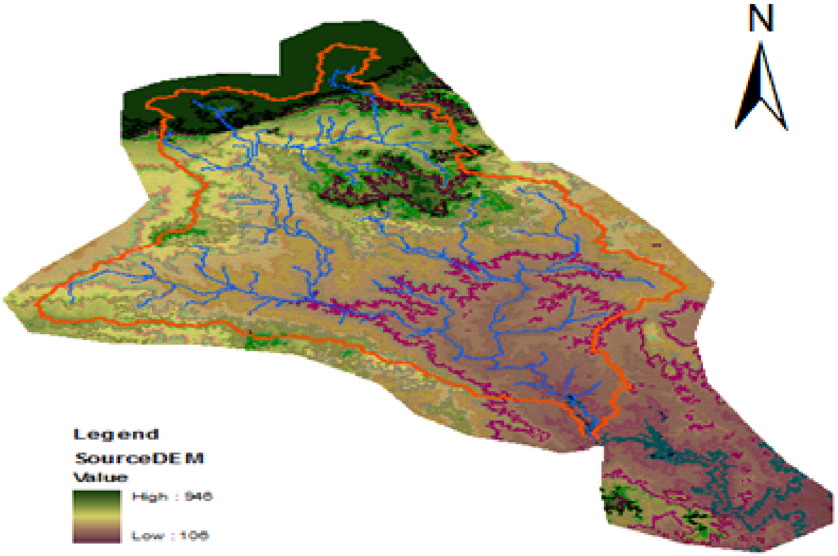

Fig. 2. DEM of Wardha Basin

Watershed Delineation

Watershed delineation, defined in terms of an identified outlet point, is carried out through terrain processing of the DEM, and, in addition, also yields its stream network. The watershed boundary of Wardha sub-basin delineated using the ArcView interface of SWAT is shown along with important drainage features in Figures 3a and 3b for reference. Figure 3a depicts the generated drainage network and the points (based on the confluence of drains) where the basin shall be subdivided into sub-basins. The Figure 3b depicts the location of the manmade structures such as dams.

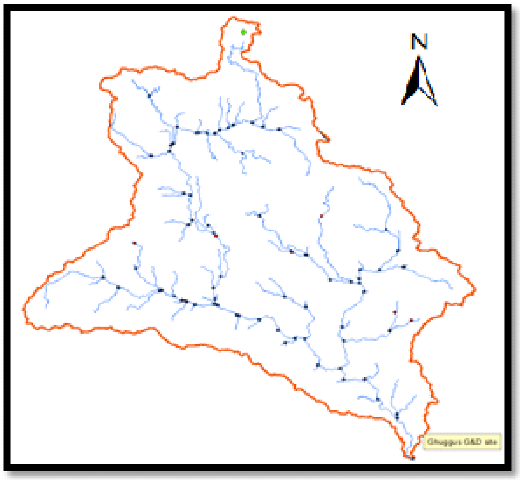

Fig 3a

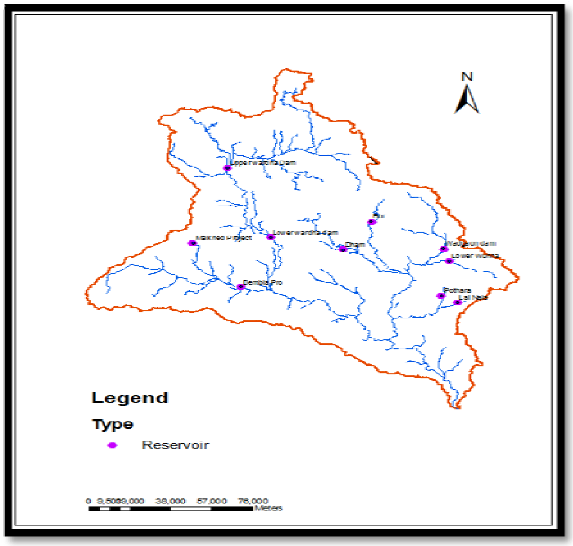

Fig 3b

Land and Soil Cover Data:

The Land use layer was obtained from the database of ‘Global Land Cover Facility’ as available at http://ftp.glcf.umd.edu/index.shtml and the information, as pertaining to the study area, is presented as Figure 4.

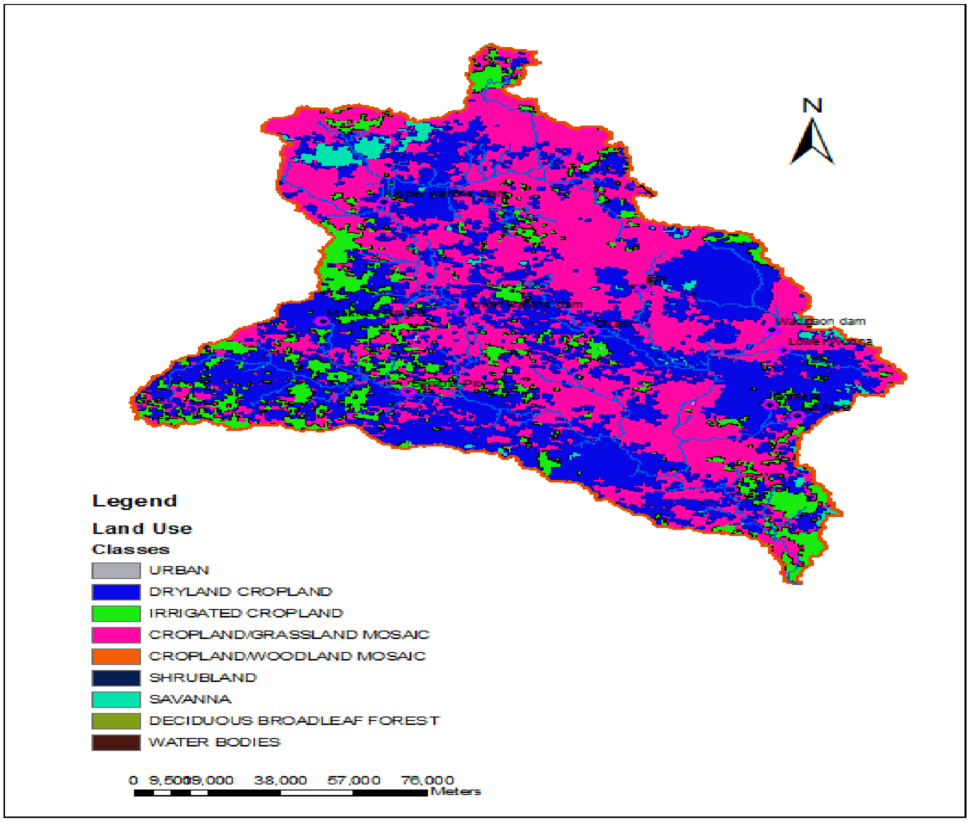

Fig. 4. Land Use map of Wardha sub-basin

Similarly the information on soil types was obtained from FAO Digital Soil Map. The information is available at the official FAO web site hosted at http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116. Examination of the available data shows that the soils of the Wardha sub-basin may broadly be divided into three categories namely (i) black soil, (ii) red soil, and (iii) mixed black and red soil and, in terms of the soil type, clay and clayey loam soils dominate as the principal soil types of the study area as highlighted in Figure 5.

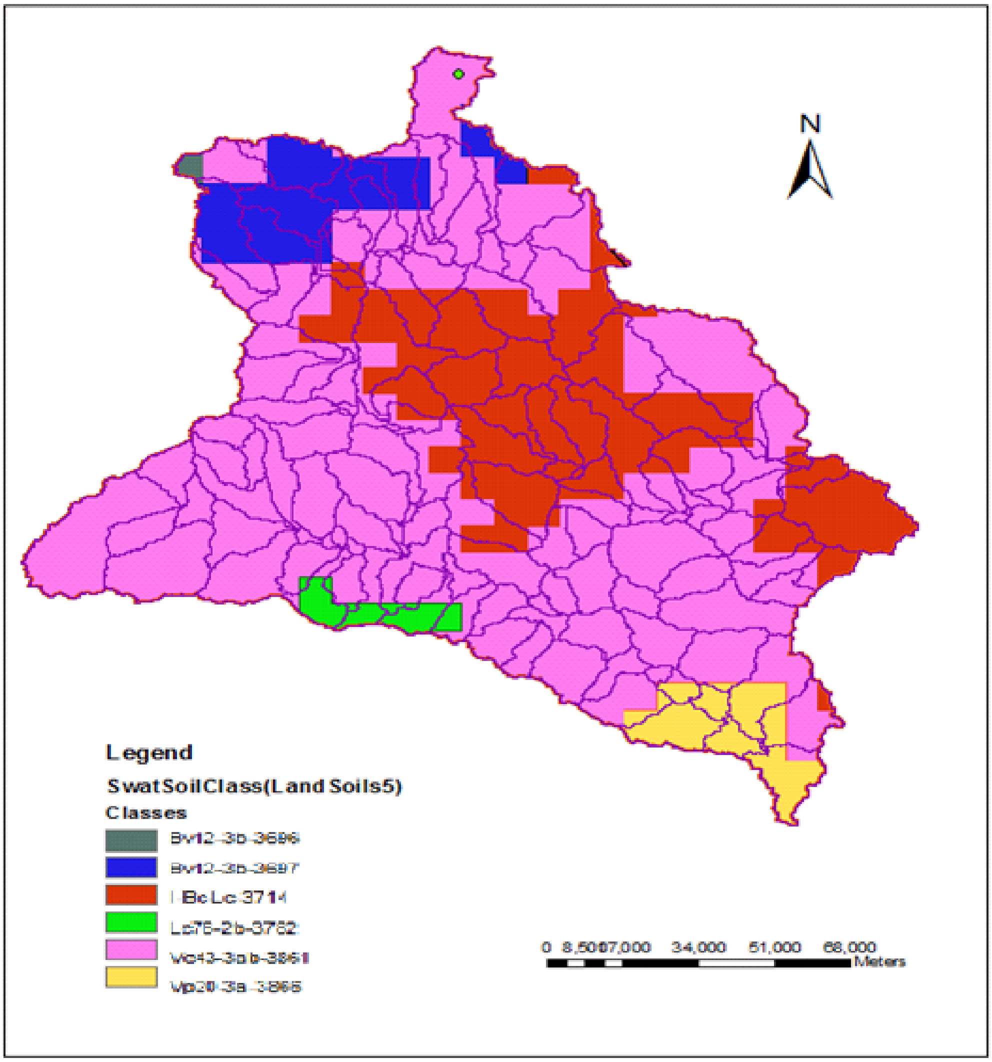

Fig. 5. Soil map of Wardha sub-basin

Sub-basins and HRUs

The model parameterization was derived using the ArcView GIS interface for SWAT (Di Luzio et al., 2001), which provides a graphical support for the disaggregation scheme and thus facilitates the data handling. As a first step, the entire study basin was divided into an appropriate number sub-basins based on the arbitrary threshold that the smallest of these areas has a minimum drainage area of 8,000 hectare and accordingly, based on the threshold and the need for outlets at existing discharge measurement stations, the study area was sub-divided into a total of 155 sub-basins (Figure 6) and 2112 HRUs.

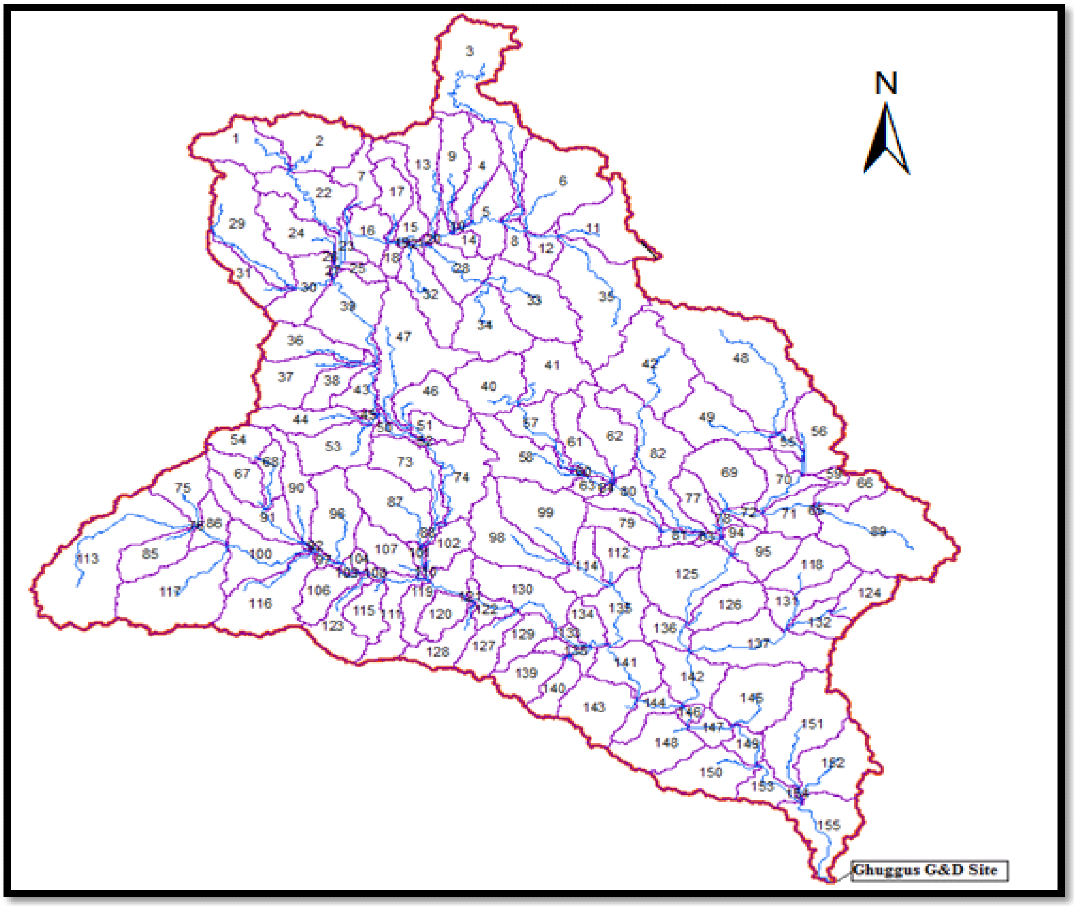

Fig. 6. Sub-basins in Wardha basin

Weather data

Weather data from stations within the region including IMD gridded precipitation data are incorporated to provide the most representative hydro-meteorological history available. Other meteorological data, as required by SWAT, namely solar radiation, wind speed, and relative humidity are estimated using the SWAT weather generator.

The daily rainfall, corresponding to ten reference grid points and as shown in Figure 7, was extracted from the IMD gridded daily rainfall data (provided by IMD using the actual point data) for the period 1969 to 2005. Observations on daily temperature from 1969 to 2005 were also available at five locations shown marked in Figure 7 and were used for hydrological simulation. Other meteorological data required by SWAT (solar radiation, wind speed, and relative humidity) were estimated using the SWAT weather generator as prescribed.

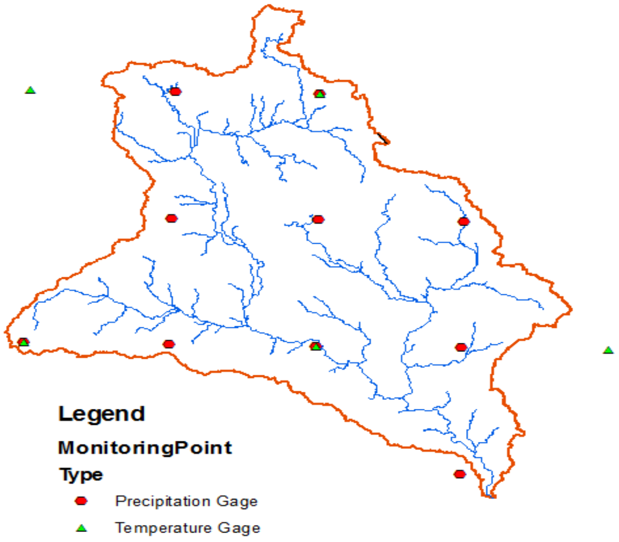

Figure 7: Precipitation & Temperature map of Wardha sub-basin

Dams and other projects

Anthropogenic influences on the natural hydrologic cycle often dominate and substantially determine the current hydrologic regime of a given river basin. Appropriately, therefore, it is imperative for any given modelling framework to accommodate a reasonable representation of these interventions if the model derived simulations have to inspire confidence amongst planners and other users of the derived model based predictions regarding future states of the river basin's hydrology. Accordingly, the present modelling initiative has incorporated all known (existing as well as proposed) projects along with their respectively inferred water utilization details and the process, understandably, starts with identification of these and similar projects to the delineated sub-basins.

The reservoir data were also extracted from the **NATIONAL REGISTER OF LARGE DAMS – 2009**. Beside the location, other attributes such as storage capacity and other features were incorporated and these data were also supplemented by other data obtained from internet based search. Table 1 presents a list of projects that have been considered in the hydrologic study of Wardha sub-basin as described in this report and the corresponding locations are also shown marked in Figure 8.

Table 1. Properties of the reservoirs which are included in the SWAT model

NAME OF PROJECT	RIVER	YEAR OF START	VOLUME (10^3 m^3)
UPPER WARDHA	Wardha	1993	786480.00
BOR	Bor	1965	138750.00
LOWER WARDHA	Wardha	UC	253340.00
MALKHED	Kholad	1972	10900.00
WADGAON	Wadgaon	1997	152600.00
DHAM	Dham	1986	72460.00

LOWER WUNNA (NAND)	Nand	1990	62182.00
BEMBLA	Bembla	UC	322068.00
POTHARA	Pothara	1983	38400.00
LAL NAALA	Pothara	UC	10000.00

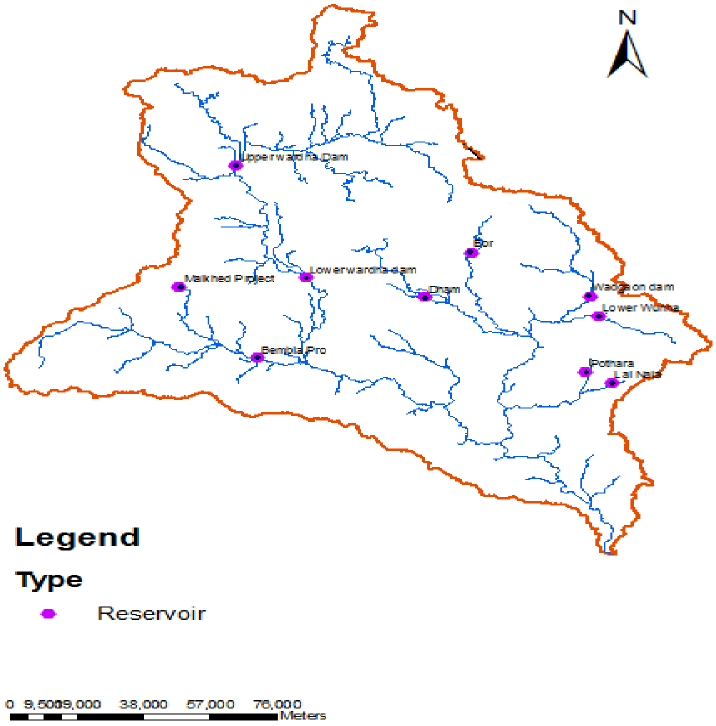

Figure 8: Reservoirs in Wardha sub-basin

Model setup

Model simulations of stream flows were derived on a daily time step for the period from 1969 to 2005 but the results for the first year (1969) were used only as warm up period and, therefore, excluded from further analysis. The SWAT model was setup separately for three different developmental scenarios namely (i) *Virgin basin condition*, (ii) *Current developmental scenario*, and (iii) *Future (projected) developmental scenario*, but, understandably, the final choice of various model parameters was based on the need to obtain reasonable level of agreement between the observed stream flows and model simulations derived for the existing baseline condition. All developments including storage reservoirs and other diversion features, as presented in Table 1, were incorporated in the model setup to enable a realistic capture of the influences of current level of developments on the sub basin's hydrology as observed.

Accordingly, therefore, calibration entailed examination of the important SWAT parameters for their respective influence on quality of derived simulations. Amongst the various model parameters that were adjusted during the process of calibration, runoff simulations were seen to be most sensitive to the Curve Number (CN) value, soil evaporation compensation factor ESCO, available soil water capacity SOL_AWC, surface runoff lag coefficient, SURLAG, ground water delay time, GW DELAY and base flow alpha factor, ALPHA BF. Figures 9 and

10 below show the comparison between observed and model derived simulated runoff at daily and monthly scales respectively while the NSC measure of model efficiency (R^2) is also indicated in the plot of Figure 11 for the simulations presented at monthly time steps.

Once the model was deemed to have been successfully calibrated at the daily scale, the available hydrologic data for the period 1990–2004 were used to obtain SWAT simulation runs for this period on a daily time step basis for all the three aforementioned developmental scenarios.

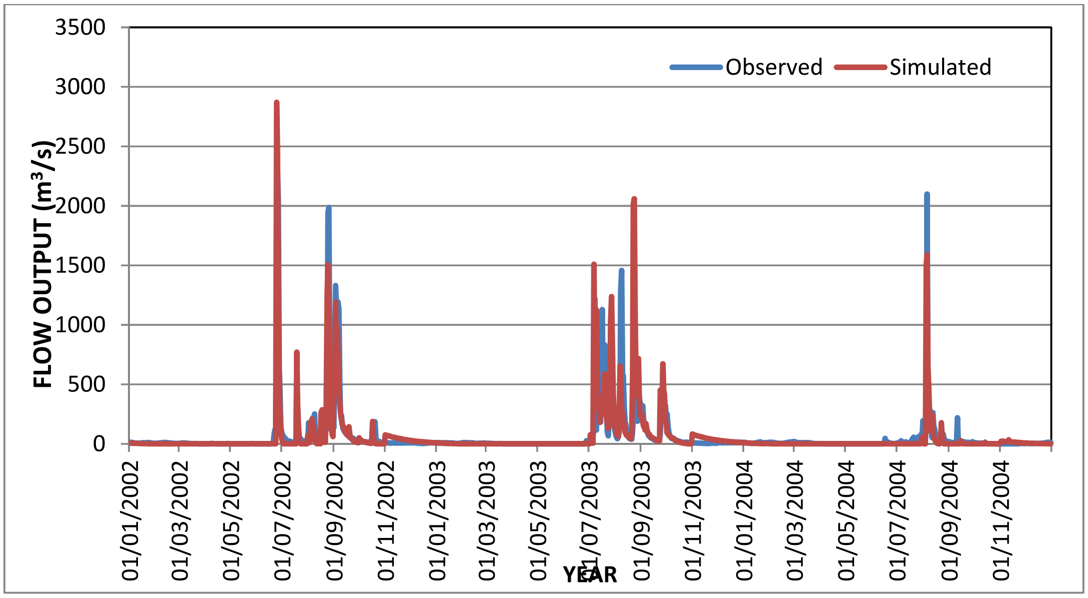

Fig. 9 Comparison of SWAT simulated and measured monthly flow for daily time-scale calibration

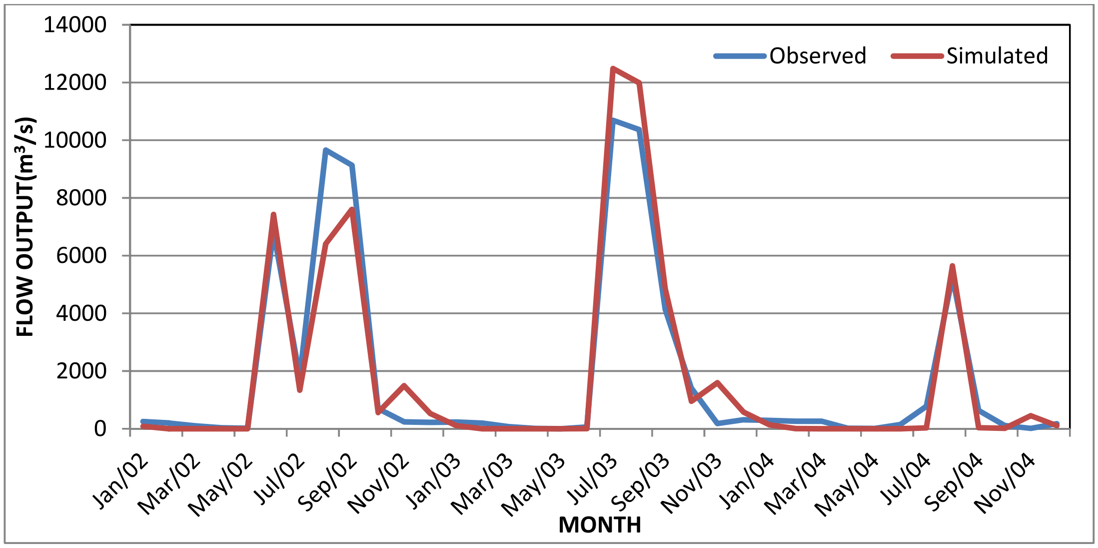

Fig. 10 Comparison of SWAT simulated and measured monthly flow for monthly time-scale calibration

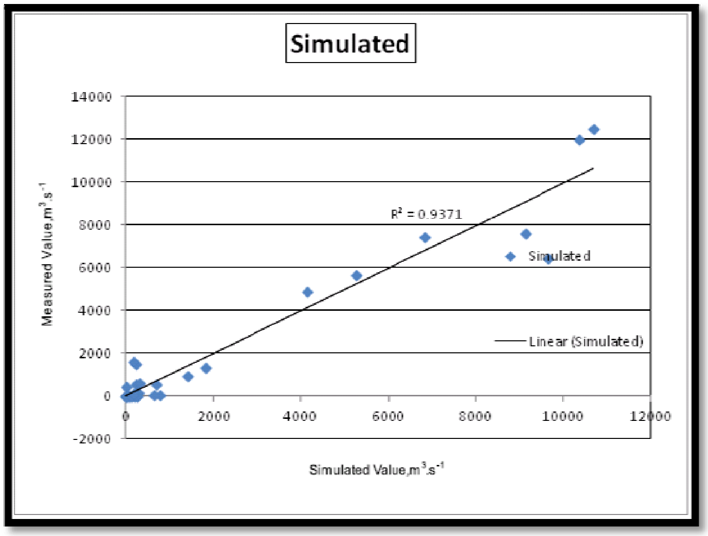

Fig. 11 Scatter plot of SWAT simulated and observed flow at monthly time-scale (SMC)

RESULTS, ANALYSES AND DISCUSSIONS

SWAT simulations of runoff have been derived for the period 1969 to 2005 after carrying out an elaborate calibration process to fine tune the various model parameters. It merits mention that calibration is based on the flow observations that were available only for the period 1991 to 2004 and, once calibrated for this period, the same model setup is deemed to be appropriate for the simulation horizon prior to 1991. For brevity, however, results are presented only for the three year window from 1st January, 2002 to 31st December, 2004. Figure 12 presents a comparison between generated daily scenarios for three years from 1st January, 2002 to 31st December, 2004 and correspond to (i) the virgin (red trace) and (ii) the future (blue trace) conditions. Similarly, Figure 13 presents a similar comparison on a monthly scale between (i) the virgin (blue trace), (ii) present baseline (red trace) and (iii) the future (green trace) conditions.

These figures show a comparison between stream flow regimes for the three indicated developmental scenarios. With the commissioning of projects namely (i) Lower Wunna, (ii) Bor, (iii) Dham, (iv) Upper Wardha Dam , (v) Vadgaon dam, (vi) Malkhed Project, and (vii) Pothara, the annual mean flow at the basin outlet shows a reduction from 3679.19 MCM to 1857.01 MCM. Additionally, construction of reservoir projects namely (i) Bembla Project, (ii) Lal Nala, and (iii) Lower Wardha dam, the annual mean flow at the basin outlet, as simulated by the hydrologic model, shows a further reduction of annual flow to 1419.42 MCM.

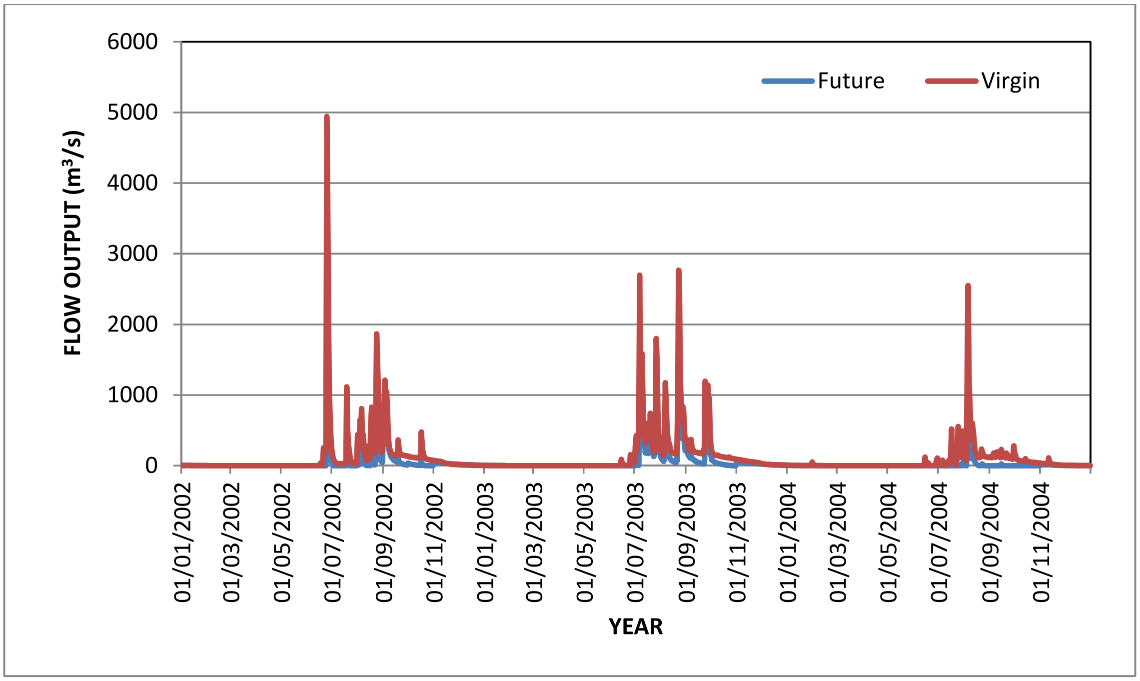

Figure 12. Daily outflow variation for the Wardha basin in *Virgin* and *Future* condition

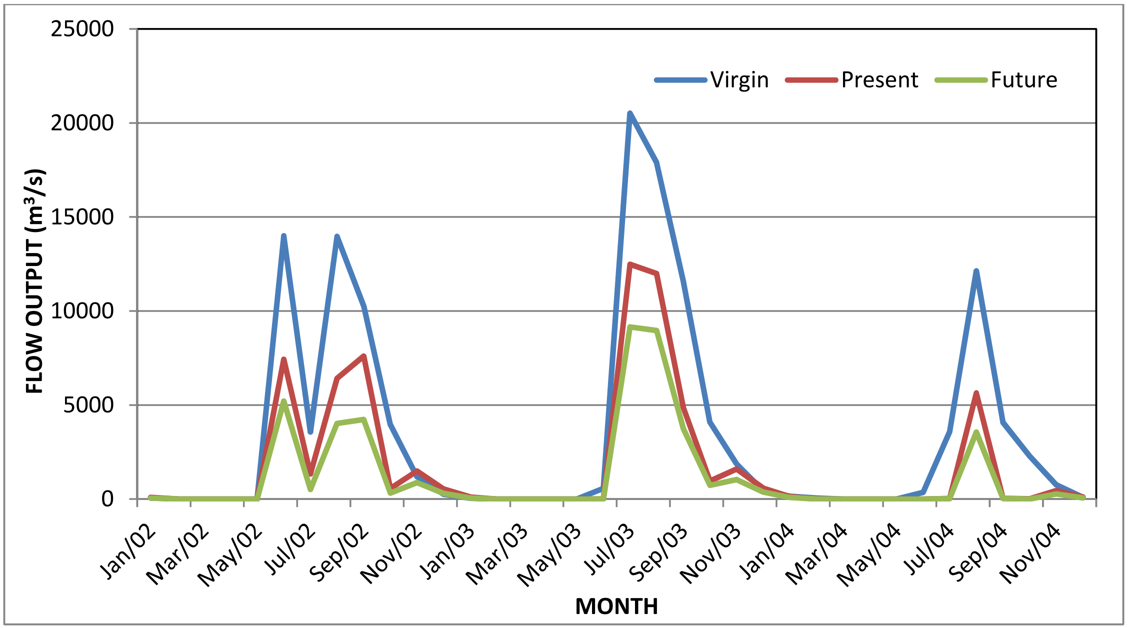

Figure 13. Monthly outflow variation for the Wardha basin in Virgin, Present and Future condition

Further, with an additional projected demand for 552.52 MCM of water expected to be made by the various thermal power plants that are at various stages of the approval process, there would be practically very little water available and management of the facilities, with any stated dependability level would require storage capacities to be created to regulate for dependable flow.

Tables 2, 3, and 4 below present some of the important statistics derived from model simulated runoff for virgin, present (as existing) and future (as proposed) conditions respectively. The statistics are based on averages computed for four horizons namely (i) 1970-80, (ii) 1981-1990, (iii) 1991-2000, and (iv) 2001-04.

Table 2: SIMULATED FLOWS (Mm3) UNDER VIRGIN CONDITIONS

	Average Volume for 1970-80	Average Volume for 1981-90	Average Volume for 1991-2000	Average Volume for 2001-2004
JAN	54.37	56.78	38.46	6.40
FEB	41.27	25.66	7.70	1.23
MAR	9.45	4.34	4.76	0.00
APR	1.12	0.04	0.08	0.00
MAY	0.48	3.61	0.56	0.00
JUN	524.46	602.54	168.70	550.52
JUL	1795.47	2057.75	1351.61	772.50
AUG	3102.31	2996.90	2031.09	1472.00
SEP	1674.55	1788.89	1503.64	697.95
OCT	1114.14	1277.05	785.33	339.33
NOV	493.88	507.93	305.72	110.20
DEC	200.37	197.55	129.59	24.29
ANNUAL	9011.87	9519.06	6327.25	3974.43
MAX. ANNUAL AND YEAR	12848 (1973)	14550(1990)	11860(1994)	5001(2003)
MIN. ANNUAL AND YEAR	5805(1970)	4101(1987)	3122(1997)	1916(2004)

Table 3: SIMULATED FLOWS (Mm^3) UNDER PRESENT CONDITIONS

	Average Volume for 1970-80	Average Volume for 1981-90	Average Volume for 1991-2000	Average Volume for 2001-2004
JAN	39.98	36.22	42.94	7.70
FEB	14.63	6.30	8.49	0.08
MAR	2.69	0.28	0.68	0.00
APR	0.09	0.00	0.00	0.00
MAY	0.01	0.84	0.00	0.00
JUN	114.38	133.06	18.37	340.84
JUL	678.54	852.81	773.54	352.81
AUG	1859.11	1786.24	1249.53	826.74
SEP	833.05	890.58	927.96	284.54
OCT	346.60	553.20	387.59	50.51
NOV	289.33	310.02	260.20	93.54
DEC	130.98	122.92	126.82	32.50
ANNUAL	4309.40	4692.46	3796.13	1989.26
MAX. ANNUAL AND YEAR	7026(1973)	8780(1990)	8398(1994)	2692(2003)
MIN. ANNUAL AND YEAR	1671(1972)	667(1987)	1464(1997)	556(2004)

Table 4: SIMULATED FLOWS (Mm^3) UNDER FUTURE CONDITIONS

	Average Volume for 1970-80	Average Volume for 1981-90	Average Volume for 1991-2000	Average Volume for 2001-2004
JAN	22.85	22.84	27.01	5.05
FEB	0.32	0.44	0.67	0.04
MAR	0.00	0.00	0.00	0.00
APR	0.00	0.00	0.00	0.00
MAY	0.00	0.00	0.00	0.00
JUN	37.34	26.01	0.90	125.14
JUL	52.42	276.13	104.90	242.51
AUG	1240.54	1176.11	847.16	583.35
SEP	451.78	447.60	555.04	194.84
OCT	197.29	333.01	190.55	25.28
NOV	218.67	224.71	181.65	73.85
DEC	99.02	93.92	95.90	25.31
ANNUAL	2320.24	2600.76	2003.78	1275.37

MAX. ANNUAL AND YEAR	4714(1979)	5684(1983)	4678(1992)	2380(2003)
MIN. ANNUAL AND YEAR	508(1972)	229(1987)	355(2000)	387(2004)

These results indicate that the simulation horizon from 2001-2004 has been particularly severe in terms of the deficiency in available water resources. It is pertinent to note that the average annual precipitation over this area for the same time horizon is over 26% less as compared with the average annual precipitation for the horizon from 1970-1980.

CAVEAT

Finally, with regards to the future status of water resources availability within the Wardha basin, the study incorporates only irrigation and thermal power related water demand and has not considered other industrial demands for water resources.

Acknowledgements

We acknowledge the contribution made by Ms Maitree Dasgupta, Ms Vinuta Gopal and Mr Jai Krishna of Greenpeace in making the required data and information available from various sources. We also acknowledge various agencies of Maharashtra such as Maharashtra Water Resources Development Centre, Aurangabad, Vidarbha Irrigation Development Corporation, Nagpur, Vidarbha Statutory Development Board, Nagpur, Central Ground Water Board, Central Region, Nagpur, Central Water Commission - Monitoring (Central) Organization, Nagpur, etc., to have provided data for this report.