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BRISS: A Web-Based Dynamic Decision Support Tool for Brahmaputra River Basin

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Abstract: A web-based dynamic DSS tool for water resources policy planning for Brahmaputra River Basin (named as **BRISS: B**rahmaputra **R**iver **I**nformation and **S**imulation **S**ystem) has been discussed**.** The complexities associated with dynamics of water consumption and availability on basin scale has been addressed in BRISS through use of predictive and analytic capabilities of system dynamics model. The model component has been integrated with a RDBMS-based information system to enhance its applicability. BRISS has been presented as a web-based DSS using thick client and thin server approach and some examples of policy analysis have been carried out and presented. Water availability and consumption scenario for the year 2025 and 2050 have been generated for Brahmaputra Basin. The results show that over the years the total water consumption for the basin has gone up substantially whereas supply remained the same. Wide seasonal fluctuations in river flow due to monsoon driven hydrological regime for the river have been observed. Simulated results show that the basin will face water shortage during the months of December to February before the year 2050 if necessary corrective measures are not taken. Constructions of flood storage reservoir i.e. that stores water during high flood and augment flow during lean flow, may be considered as a policy option.

Key words: Web-based DSS, system dynamics simulation, information system, Brahmaputra river.

Introduction

Growing demand for water and resulting conflict over increasingly scarce fresh water resources have generated considerable interest among scientists and planners for its efficient management. Since rivers are the most potential source of freshwater to meet future water requirements, Water Resources Management Planning are generally carried out on river basin scale. Complexity of decision making process concerning water resources management on basin scale calls for use of sophisticated yet easy to decision support tools for processing vast amount of diverse information.

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Water availability and consumption pattern in any river basin is dynamic over time period; hence assessment of future water availability and consumption is required for policy planning. Scenario of future water availability, consumption etc. are important constraints in river basin decision making which needs to be visualized so as to evolve effective strategy/planning of water resources consumption and distribution keeping availability in mind. This requires understanding of behaviour pattern of future use. The system dynamics method has that predictive and analytic capability to address the complexities associated with the dynamics of water availability and supply on river basin scale for policy planning. Since the works on SD reported by Forrester (1961), the method has been applied to a number of environmental studies. Applications of SD in the field of water resources, although quite a few, include river basin planning (Palmer et al.,1999), long term water resource planning and policy analysis (Simonovic and Fahmy, 1999), reservoir operation (Ahmad and Simonovic, 2000) and sustainability analysis (Xu et al, 2002). But all these models are stand alone type and there is no real possibility for water resources stakeholders (decision makers, scientists, policy makers and the public) to interactively test these models. Building a river basin SD model and making it accessible through internet can bring real progress with respect to stakeholders' involvement in problem understanding and breakthrough in participatory decision making. The applicability of such a river basin SD model can be further enhanced by integrating it with an information system for generating the capacity to manage large volume of river basin related information in a common structure.

The aspects as discussed above have been incorporated in **BRISS** (**B**rahmaputra **R**iver **I**nformation and **S**imulation **S**ystem) and are presented in this paper.

The River

The Brahmaputra river is one of the largest river system of the world. It covers a drainage area of 580,000 square km, 50.5 percent of which lie in China, 33.6 percent in India, 8.1 percent in Bangladesh and 7.8 percent in Bhutan. Its basin in India is shared by Arunachal Pradesh (41.88%), Assam (36.33% i.e. 70,634 square km), Nagaland (5.57%), Meghalaya (6.10%), Sikkim (3.75%) and West Bengal (6.47%). The basin has a length of about 1540 km in East-West direction and maximum width of 682 km in North-South direction (Goswami and Das, 2000). The up-stream portion of the basin lying in Tibet in China and Arunachal Pradesh in India comprises mountain ranges and narrow valley. The Indian state of Assam falls in the middle stream and consists of hills, forest, tea garden and a valley having about 80 km width. The study area has been shown as Figure 1.

Therefore, it is appropriate that a comprehensive study of the Brahmaputra River water resources is made as early as possible. Any decision to manipulate such a complex

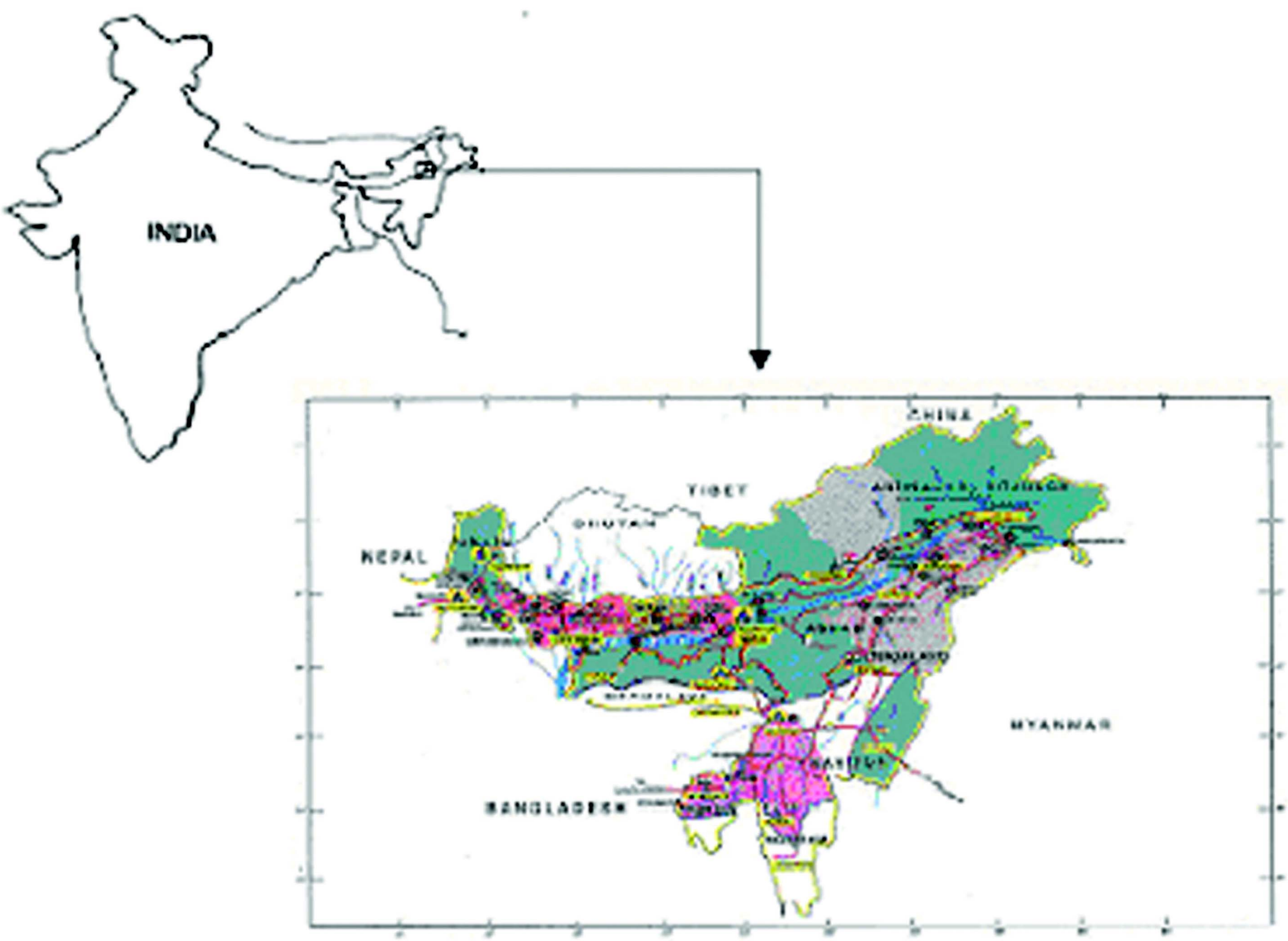


Figure 1: The study area.

water resource system like Brahmaputra requires sound understanding of the regional water resource system and also how the system will react to a particular policy.

The Structure of BRISS

BRISS consists of a River Basin Information System built on RDBMS concept and River Basin Simulation Model using System Dynamics theory. In the present set up under study the river basin database has been built using 'Oracle 8i' database. The internet access to database has been provided using 'Oracle web DB' (an Oracle Product). SD software Stella has been used for building River Basin SD model. Considering that in the study area a client's computer would be connected to the internet through low end communication (telephone lines with poor bandwidth), proposed implementation of BRISS has been through thick client and thin server concept.

When any client accesses BRISS through his web browser, screen as shown in Figure 2 will be displayed on his computer screen.

The built-in information system of BRISS can be used for on-line data entry, report generation and simulation. However, discussion here has been restricted to simulation only. When a user accesses the menu option 'Run Simulation' he is led to the SD model of the Brahmaputra river basin (BRSD).

BRSD (Brahmaputra River SD model): has been designed as a dynamic DSS tool that allows users to explore a wide variety of water consumption and availability scenario for Brahmaputra Basin. By estimating future consumption and availability, user can assess how various assumptions actually affect the performance of the water resources system. 'What if ?' type of scenario can be generated using BRSD and sustainability of the water resources of the river basin can be determined.

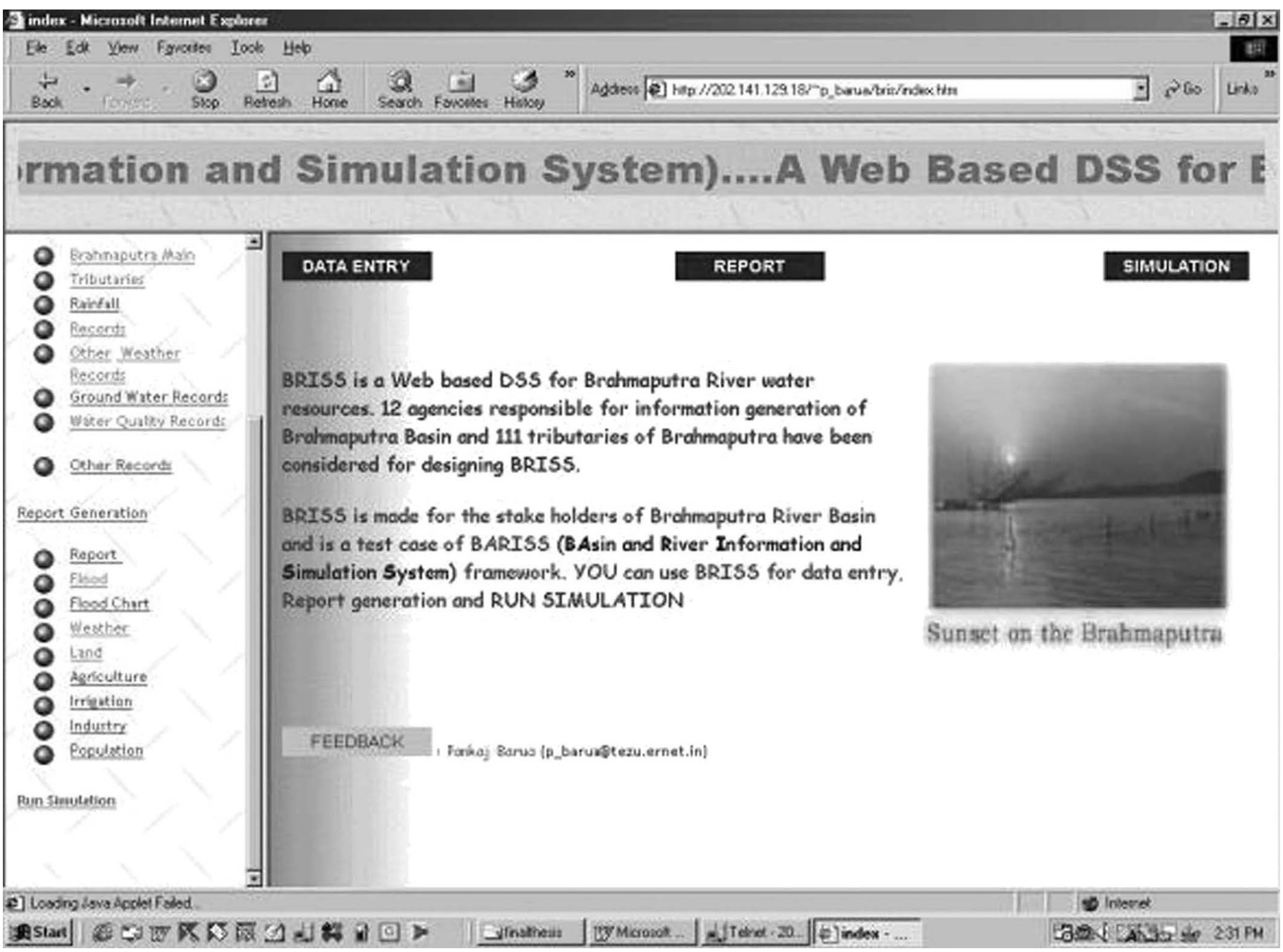


Figure 2: Index page of BRISS.

Model Description

This section describes the water balance equations which formed the basis of the Brahmaputra River SD model.

Total Water Available

The total water available has been estimated as

$$S = S_S + S_G + S_R$$

$$S_S = S_{EW} + S_{TR} + \text{Rainfall} + S_{RS} - D_{SW} - S_{OUT} - \text{Evaporation}$$

$$S_{GW} = S_{EW} + S_{Recharge} - D_{GW}$$

where S = Total available water, S_S = Available surface water, S_G = Available ground water, S_R = Return flow from uses, S_{EW} = External flow into the basin, S_{TR} = Tributary inflow, S_{RS} = Return flow to surface water from uses, D_{SW} = Water demand met from surface water, S_{OUT} = Surface water outflow from the basin, S_{GW} = Total groundwater potential of the basin, $S_{Recharge}$ = Groundwater recharge from rainfall, surface water and return flow from uses, and D_{GW} = Water demand met from ground water.

Water Consumption Estimation

The total water consumption for the Brahmaputra river basin has been estimated as

$$D = D_{Pop} + D_{Ind} + D_{Irrig} + D_{Envr}$$

where D = Total water consumption, D_{Pop} = Population water consumption, D_{Ind} = Industrial water consumption, D_{Irrig} = Irrigation water requirement and D_{Envr} = Environmental water requirement.

Population water consumption has been estimated by multiplying projected population and per capita water consumption (a decision variable). Each of the projected population from urban, rural and immigration has been considered and multiplied by the respective per capita consumption to estimate population water consumption. The normal per capita consumption for urban and rural population have been taken from Planning Commission of India estimate (GOI, 1999) and that of immigration population have been author's estimate.

Arable land in the basin gets converted to irrigated land. This conversion depends on water availability and government policy. Crops considered for estimating irrigation water consumption have been paddy, jute and other crops. Paddy occupies nearly 95% of the total irrigated land and paddy and jute require huge amount of water for growth. The water required for irrigation has been estimated as per procedure outlined in FAO (Food and Agricultural Organization of UNO) Irrigation and Drainage Paper by Doorenbos and Pruitt (1977). This FAO paper illustrates methods to calculate crop water needs based on climatic factor and subsequently irrigation water needs for a geographical area in a very simple manner. The net irrigation water requirements have been defined here as the volume of water needed to compensate for the deficit between potential evapotranspiration and effective precipitation over the growing period of the crop. It varies considerably with climatic conditions, seasons, crops and soil types. For a given week/month/year, the crop water balance can be expressed as

$$\text{IWR} \cong \{ Kc, ET, P, \Delta S \}$$

where IWR is the net irrigation water requirement needed to satisfy crop water demand; Kc is a coefficient varying with crop type and growth stage; ET is the evapotranspiration, depending on climatic factors; P is the precipitation; and ΔS is the change in soil moisture from previous week/month/year.

In the specific case of paddy crop irrigation and jute crop irrigation additional water is needed for flooding to facilitate land preparation and for plant protection. In that case, irrigation water requirement has been considered as the sum of rainfall deficit and the water needed to flood the fields. For the present study, irrigation water requirement has been computed for the basin in a dynamic manner considering among others the seasonal water availability, arable land conversion to irrigated land, government investment and utilization of existing facility.

Water consumption figures for industry are often expressed in terms of cubic metres or litres of water used per unit of product produced. For example for steel production water use is measured as M^3/ton of steel produced. The method of manufacture used by a particular industry affects its water use. Some industries are relatively consistent in their water use because they use the same processes and the same equipment. The per unit consumption of these industries are more or less uniform all over the world. There are some industries where such consumption data are available from a wide range of sources; for other industries the data available are limited. For industries that consume significant quantities of water, water consumption varies in approximately linear manner with increase in production. Hence apart from actual production, planned production capacity (desired production) of an industrial plant is important in establishing the water consumption.

Industries considered for estimating industrial water consumption for Brahmaputra basin in the present study have been: Agricultural processing, Petroleum crude refining, Heavy industries, Forest products, Power and textile. These are the actual classes of industries as per the classification of Department of Industries of the State Government. Since there have been no studies to estimate per capita consumption of the industries under local conditions, compiled tabulated data from other sources (Leeden, 1975; DFID, 2005) have been used for this study.

Not all the water that is abstracted from surface source (e.g. river) or a ground water source (e.g. tubewell) by an industrial plant or by population is consumed. A significant quantity gets recycled into the surface as well as ground water. In the present study, it has been assumed that 30% of the water abstracted for population use would be actually consumed and rest would return to the surface water or be retained as ground water. Similarly for industrial use 20% would be consumed and rest would return to the surface water or be retained as ground water (after Mohile, 2001).

The environmental flow requirements (EFR) of river basins have been attracting increasing attention in recent years. The increasing demands of irrigation, domestic and industrial sectors in the past have been met without consideration of the needs of freshwater ecosystems themselves. Most of the Indian rivers including Brahmaputra have monsoon-driven hydrological regimes, where 60 to 80% of the total flow occurs in 3-4 wet months. Such rivers fall into a category of highly variable flow regimes. The total EFR for most of Indian rivers, estimated by Amarsinghe (2004), range between 20 and 27% of the renewable water resources. It is also suggested in the study that environmental allocations of less than 20% of the total flow may degrade any river beyond the limits of possible rehabilitation and may decrease the ability of a river to cope with pollution loads. For the present study, therefore, the environmental water requirement has been taken as 27% of the total available water.

Water Resources System Evaluation

In this study sustainability index (SI) as introduced by Xu et al. (2002) and defined as the ratio of aggregated possible water deficit relative to the corresponding supply in the same region has been calculated.

$$SI = (S - D)/S, \text{ when } S>D;$$
$$= 0, \text{ when } S<D$$

where D is the water consumption and S is the available water supply.

SI value greater than 0.2 corresponds to low or no stress of water supply, which implies that water consumption is less than or equal to 80% of the water supply. SI value smaller than 0.2 reflects vulnerable condition and SI value zero or less indicates unsustainable water supply.

The Model

The Brahmaputra River SD Model (BRSD) has been built as part of BRISS (Brahmaputra River Information and Simulation System) using ‘STELLA Research version 5’. The simulation menu of BRISS leads to BRSD model (Figure 3). For simulation a user may query for data through BRISS and use it to run the simulation.

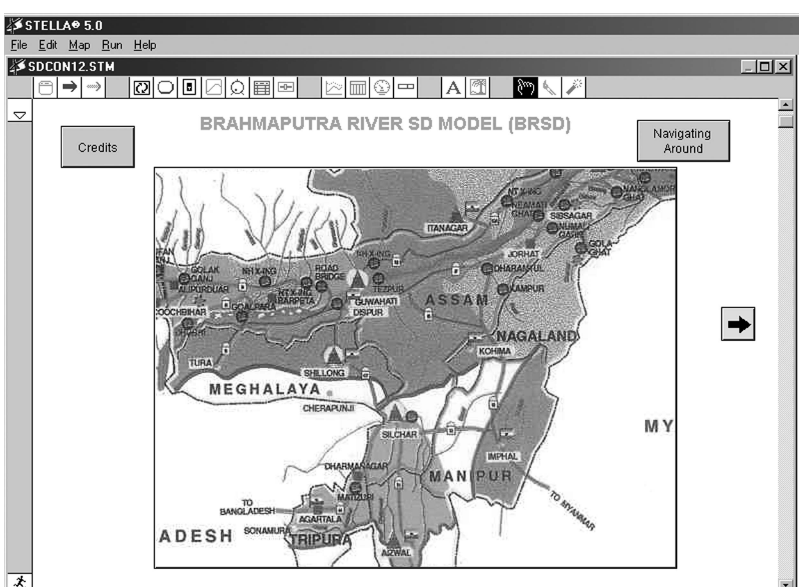


Figure 3: Welcome menu of BRSD.

Model Validation

Available historical data during 1971-2001 of Brahmaputra river basin have been used for validating BRSD model using behaviour reproduction test. Figure 4 shows the graphs for the model simulated and actual behaviour of some population, land and industry parameters and root mean square error values.

Model Application and Scenario Generation

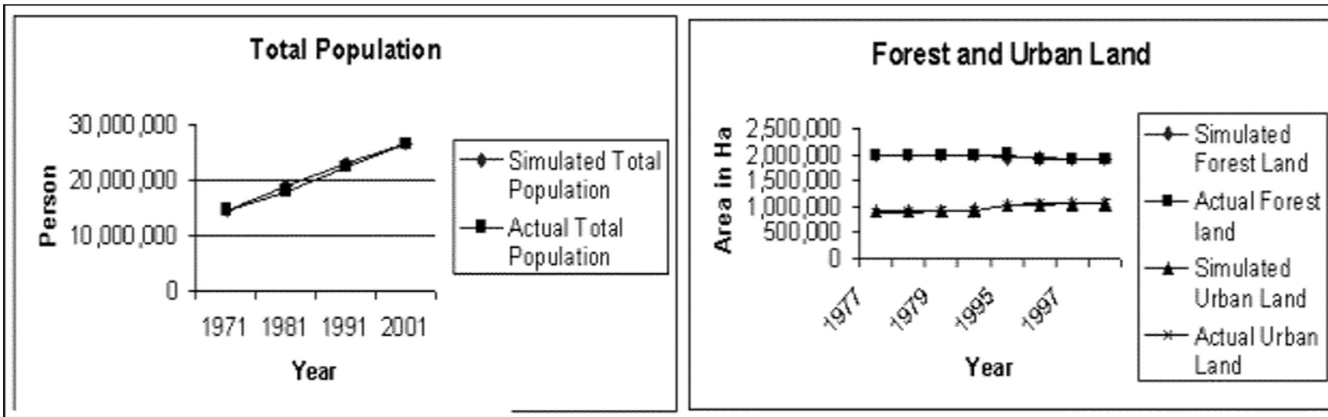
After validation and sensitivity analysis (not shown), sensitivity analysis BRSD model has been used for scenario generation. Six possible scenarios as described in Table 1 have been evaluated.

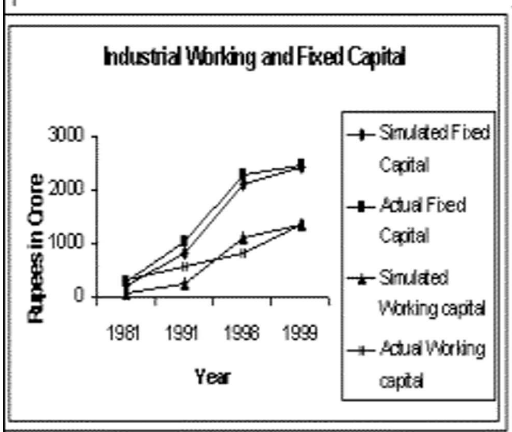
The results of the scenarios generated through simulation have been presented as Figure 5 and it shows that when simulated with minimum flow condition (Scenarios E and F), Brahmaputra River Basin appeared to be deficit in water as evident from the Sustainability Index. When simulated with Mean (Scenarios C and D) and maximum flow (Scenarios A and B) condition the river basin water status appeared to be sustainable till 2050. Further simulation revealed (Figure 6) that the water status is unlikely to cross the benchmark sustainability index of 0.20 till 2125 after which the scenario turns to be unsustainable. Since huge differences in water availability could be observed between minimum and maximum flow condition, water storage in dams to augment the lean season flow may be a possible policy option. Therefore some efforts have been made to assess the pattern of seasonal water availability and consumption.

Table 1: Scenarios Evaluated

Water flow in river	*Water uses*	*Scenario*
Maximum	Normal	A
Maximum	High	B
Mean	Normal	C
Mean	High	D
Minimum	Normal	E
Minimum	High	F

Normal = Rural population water requirement 20 lpcd, Urban population water requirement 100 lpcd, Immigration Population water requirement 15 lpcd, Floating Population water requirement 50 lpcd, Cropping Intensity 1.25.
High = Rural population water requirement100 lpcd, Urban population water requirement 400 lpcd, Immigration Population water requirement 40 lpcd, Floating Population water requirement 75 lpcd, Cropping Intensity 1.30.





Root Mean Square Error of behaviour reproduction test

	Population			*Land*			*Industry*	
	RP	UP	Total	Forest	Irrigated	Urban	FC	WC
Root Mean Square Error (%)**	2.80	4.73	1.62	1.88	5.45	1.81	23.17	79.56

** Root Mean Square Error
=100 * SQRT (SUM ((Simulated Value- Actual Value)/Actual Value)^2 / No. of Observation)

Figure 4: Model validation.

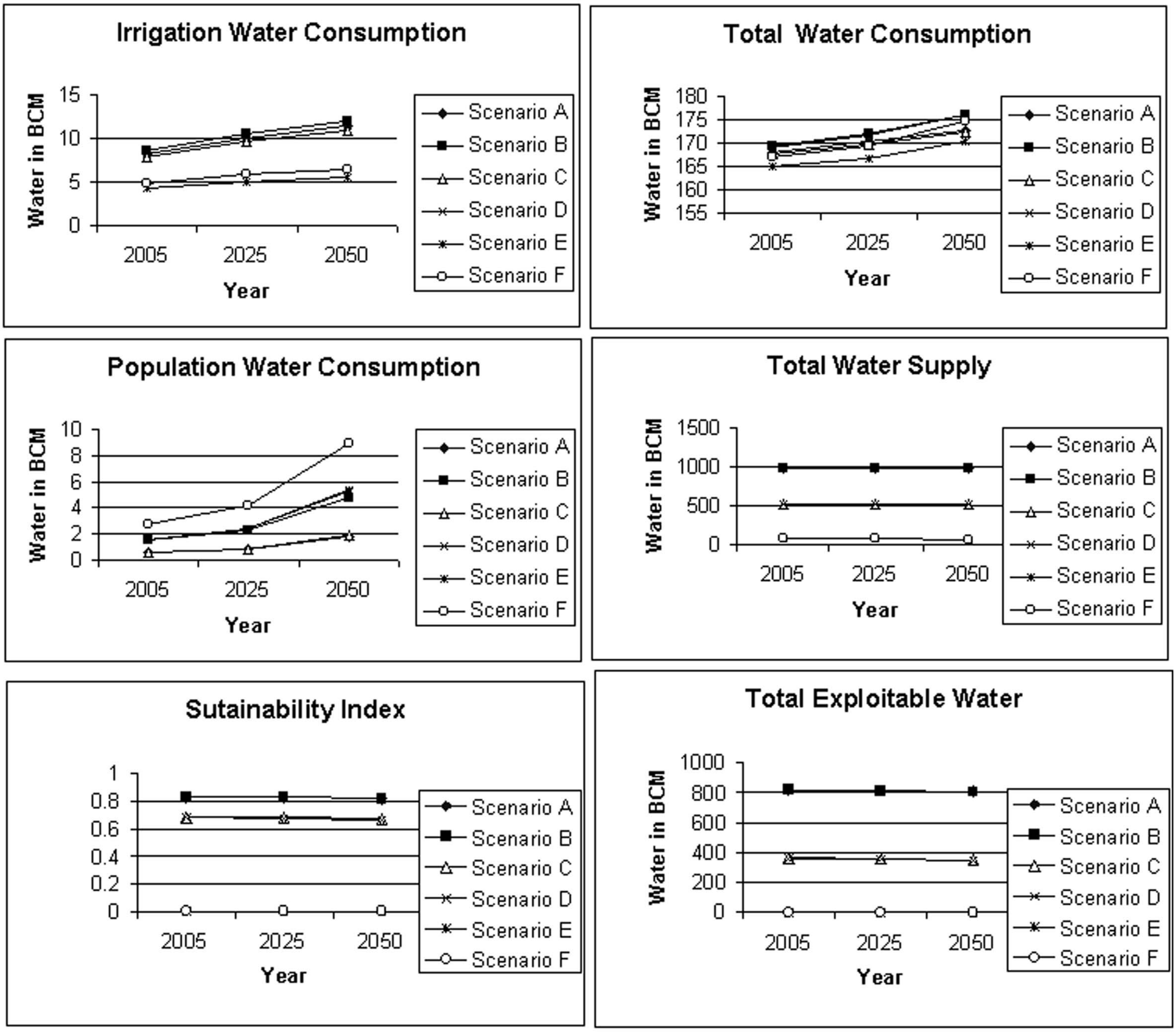


Figure 5: Water availability status of Brahmaputra Basin up to year 2050.

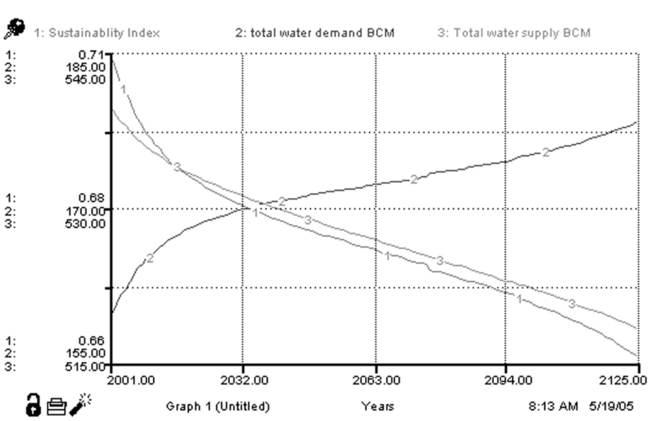


Figure 6: Scenario beyond 2050.

Seasonal Variability

To assess seasonal water availability Monte Carlo technique has been carried out to simulate the time series data of discharge rate of Brahmaputra river and its tributaries and forecast discharge for the years 2025 and 2050 on weekly basis. These forecasted values of weekly/ monthly average discharge rate along with average monthly rainfall and evaporation values have been used in the BRSD model to assess seasonal water availability. The population and industry water consumption have been assumed to be of constant rate throughout the year. The irrigation water consumption dynamics have been assessed by using seasonal crop area, rainfall and evaporation records for the river basin.

Scenario Comparison: Graphs in Figure 7 show the comparative status of Total Exploitable Water (Total Forecasted Availability – Total Forecasted Consumption) and Sustainability Index for the Brahmaputra Basin during the years 2025 and 2050. It has been clearly revealed that the Total Exploitable Water for the basin has gone down substantially during 2050 throughout the months. It has also been revealed that the Sustainability Index although remain mostly above 0.60 from March to November in both the years, the same has gone down drastically during January in 2050 and touched 0.00 during December 2050. It has been mentioned earlier that 0.20 has been considered as the benchmark for Sustainability Index and therefore water status for Brahmaputra Basin during 2050 is a matter of concern.

Comparison with earlier studies: The Brahmaputra Basin has not been studied extensively till now. There has been no report of any study to assess the dynamics of water availability and consumption using System Dynamics theory. Most of the studies that the authors came across (dealing with Brahmaputra River Basin) have been done as part of routine government business. Simulated results of some of the parameters of BRSD model developed as part of the present study have been compared with the available reports and presented in Table 2.

Table 2: Comparison with earlier studies

Parameter	*Year of Projection*	*Projected Value*		*Reference*	*Procedure/Method used for making projection*
		BRSD	*Other study*		
Total Population	2010	30248550	3011300	NEDFI, 2005	Not available
Population Water Consumption	2050	4.77 BCM	5.147 BCM	Mohile 2001	The referred study includes farm animal water as well. Detailed procedure not available
Total Population	2016	32.72 Million	29.7 Million	GOI, 1999	Not available

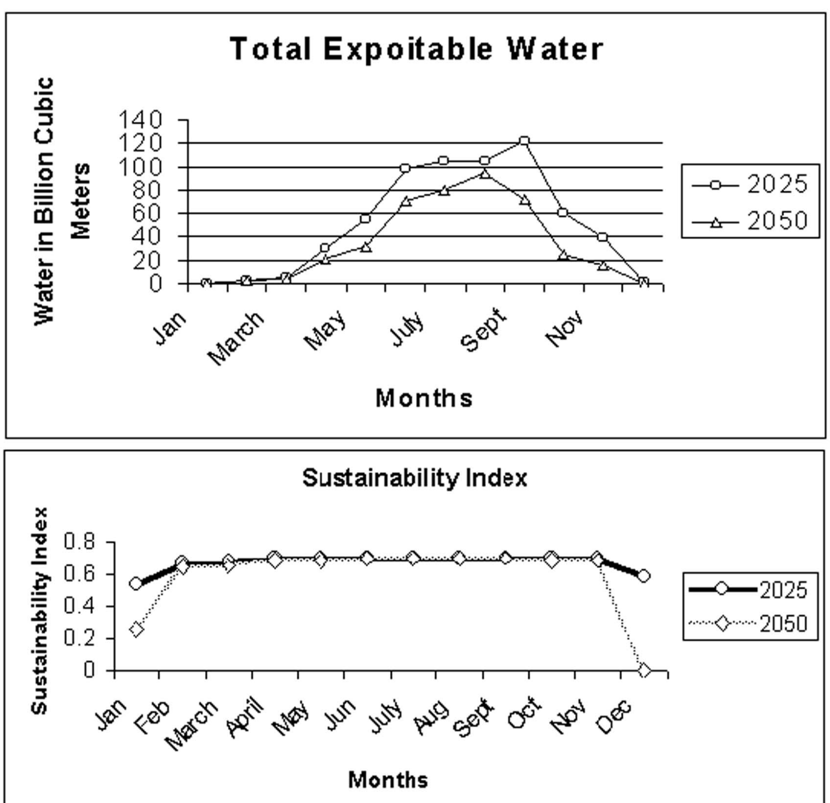


Figure 7: Comparative status of water availability.

Conclusion

This paper is an attempt to address some of the complexities associated with the river decision making process, make it simpler (through use of modern tools and approaches) and available for public sharing. A web-based dynamic DSS for one of the large river system of the world i.e. Brahmaputra River has therefore been developed and named as **BRISS**: **B**rahmaputra **R**iver **I**nformation and **S**imulation **S**ystem. Considering that water availability and consumption in any river basin is time and space variant, a SD model has been used as model base in **BRISS** to assess the dynamics water demand and supply. Policy analysis using the SD model of **BRISS** shows that

- Water consumption pattern for Brahmaputra Basin has shown a rising trend when simulated with BRSD model during years 2025- 2050.
- Water availability in the River Basin has shown wide seasonal variation.
- Water supply remained more or less same whereas the consumption has been rising; therefore water availability status for the basin has been going down over the years.
- With the present consumption pattern the basin will face water scarcity during the lean season (December to February) before the year 2050.
- Flood storage reservoir to store excess water during high flood and augment flow during lean season may be an option.

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