INTEGRATED RIVER BASIN MANAGEMENT & UNESCO MULTI-CRITERIA ANALYSIS

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1.0 Introduction

All major ancient civilizations were developed in the river valleys because river served as source of water, food, transportation and protection to the mankind. On contrary, nowadays even a small, slow-flowing stream or gentle river could cause severe damage to the people and their businesses by flooding. With the changing patterns of rainfall and global climate, river basin management is a matter of greater concern now. Not only river plains are vulnerable to riverine or fluvial flooding but also places far away from river are prone to surface water flooding due to heavy rainfall. A river basin (or 'catchment') is the entire area drained by a river, including its tributaries.

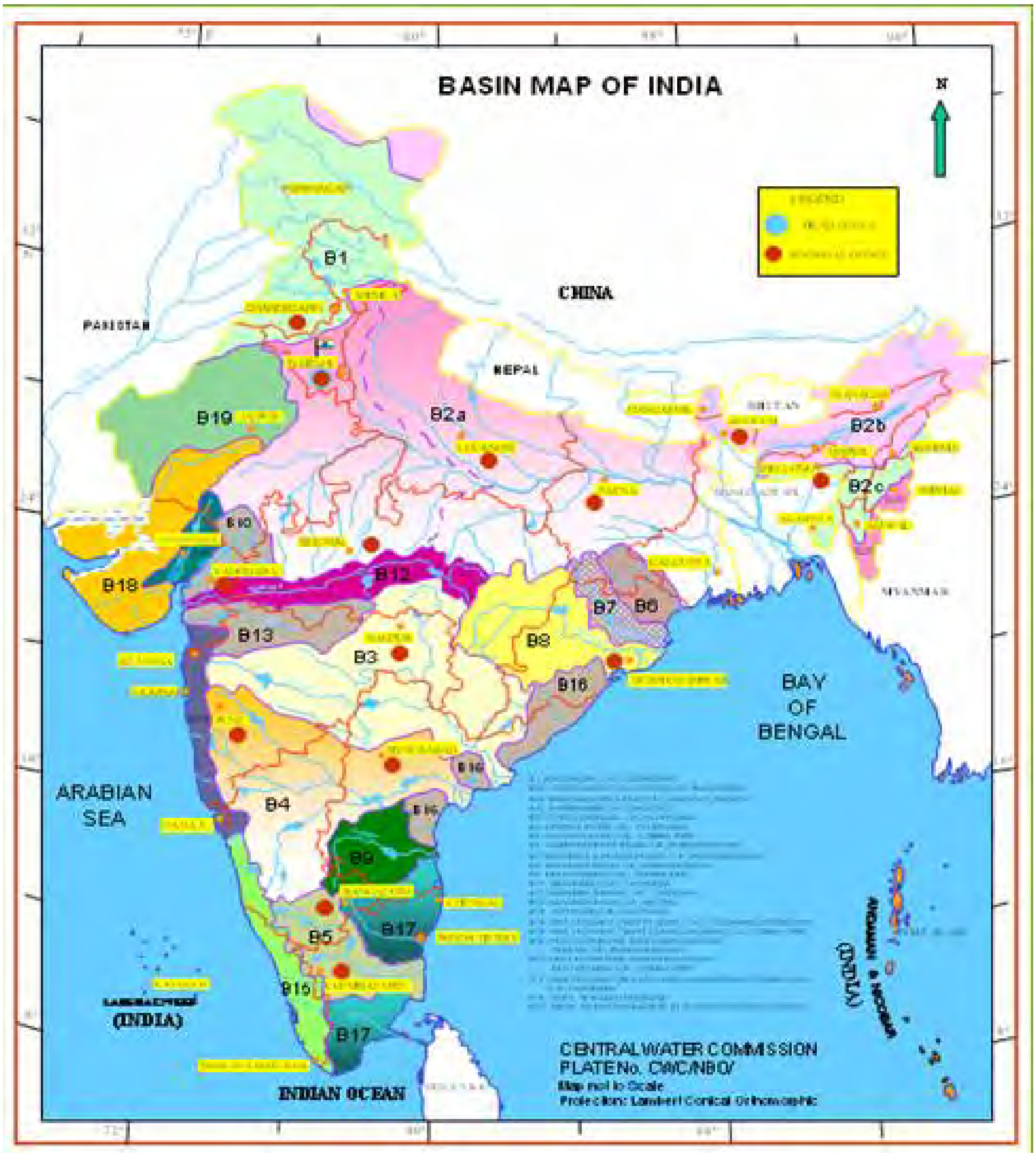

Fig 1: Indian Rivers

In India, rivers play an important role in the lives of the people. The river systems provide irrigation, potable water, cheap transportation, electricity, and the livelihoods to a large number of people all over the country. Not only during ancient time but nowadays also all the major cities of India are located by the banks of rivers. The rivers also have an important role in Hindu mythology and are considered holy by all Hindus in the country. Twenty two (22) major rivers along with their numerous tributaries constitute the river system of India. Most of the rivers drain into the Bay of Bengal; however, some of the rivers whose courses take them through the western part of the country and towards the east of the state of Himachal Pradesh empty into the Arabian Sea. Parts of Ladakh, northern parts of the Aravalli range and the arid parts of the Thar Desert have inland drainage.

Water resources of Indian sub-continent face following challenges:

- Highly Uneven in Space and Time
- Nearly 80% of the annual rainfall takes place in only 3 to 4 months
- Brahmaputra - Barak - Ganga System accounts for about 60% of total surface water resources
- Western and Southern regions experience severe deficit in water availability
- Drought - Flood - Drought Syndrome is witnessed years after years

Due to above, there is a pressing need to explore and evolve a framework for efficient management of Indian River System.

1.1 Need for River Basin Management

The river basin is a functional region that includes the key interrelationships and interdependencies of concern for water and land management from upstream to downstream.

From the earliest civilizations up till now, river basins have played an important role in sustaining communities of people and other forms of life. A quick glance at history demonstrates the intimate connection between the stability of a group of people, its economic and social development, and the availability and reliability of water. This has rightly led many authors to define the first developed social groupings as hydraulic civilizations (Caponera, 1992). All major human migrations and the birth of towns and communities have been closely correlated with the search for, and the settlement around, naturally irrigated areas and valleys adequately supplied with water.

River basins are the natural entities in which freshwater appears, the ultimate source of nearly all water used and nowadays also the receptors of most wastewater. River basins play a pivotal role not only in the water cycle, but also in nearly all other life cycles as a crucial source of bio-diversity. Multiple sector interests are predominantly served and covered by the resource base of river basins: drinking water supply, agriculture, hydropower generation, recreation, transport, etc.

River basins are used ever more intensively and many of them are under pressure. In some cases human pressure is reaching the maximum sustainable level or has already surpassed this level. Severe water competition is resulting between users, sectors and countries. Conflicts between upstream and downstream are on the increase. Such conflicts may be exacerbated in international river basins, where socioeconomic inequities among them are often much greater, as are differences in power, and where conflicts may lead to loss of life and a reduced capacity of governments to respond to domestic needs (Murphy, 1997). The slightly exaggerated term “water wars” is appearing now and then in newspapers (Jaspers, 2000). The incidence of floods in quantity and in severity is also considered to be increasing. Causal links with unbalanced human occupation and watershed destruction are also likely.

Management of river basins becomes necessary as freshwater and other services provided by basins become scarce and competition increases for their use. Appropriate measures to overcome these problems can be achieved by considering hydrological functions of river basins. Hydrological unit or hydrological cycle is wide and complex encompassing land, water and atmosphere in one single relation, which determine the quality and quantity of water in this relation. To address several environmental problems that are associated in hydrological function in a certain area, it is appropriate to use a specific natural system, where as much decisive factors as possible are included. People have adopted river basin as the most understandable natural system that links all water-related decisive factors, such as forest, soil, river and coast.

Policies for the use and protection of water resources in a country are set by national governments. Although the implementation of these policies is effective at many scales, where policies are implemented at the basin scale, there is the opportunity to deliver 'whole basin' solutions and to resolve upstream-downstream (for a river) and region-to-region (for a lake or groundwater resource) controversies. The 'whole basin' approach allows the assessment of impact at a system level. In other words, national policies, as well as international agreements and regional conventions for transboundary waters, are applied to natural basins.

In addition, Water policies and new legal frameworks are prepared in order to embody new principles and strategies for integrated water resources management (Global Water Partnership, 2000) as there is a broad consideration that water is a finite and vulnerable resource (ICWE, 1992). Whenever implementation of water policies and strategies is at stake, it is unavoidable to consider river basins as logical units for water and environmental resources management (Savenije, 2000).

1.2 Hydrological Processes in River Basin

Following hydrological processes take place after rainfall occurs in a river basin:

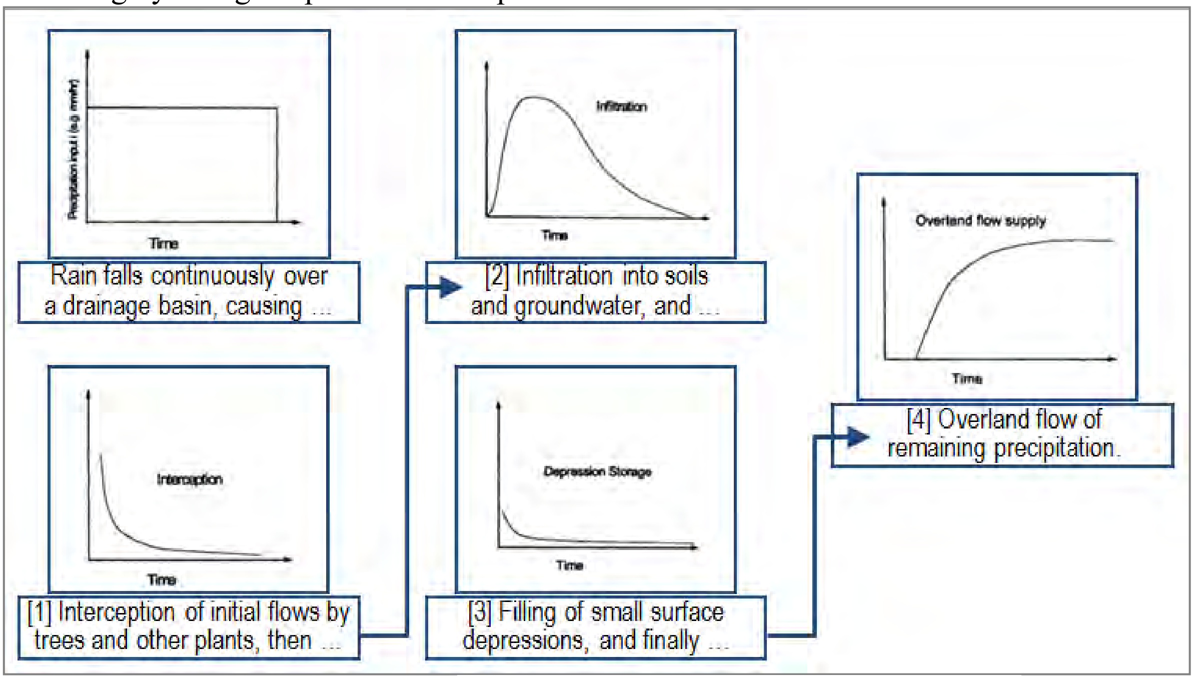

Fig 2: Hydrological Process in a River Basin

In above fig-2, it is assumed that rainfall occurs over a drainage basin uniformly in space and time. Before the rainwater reaches the ground, it is intercepted by trees, leaves, canopy etc. Very minimal amount of water is intercepted in this process and exponentially decreases with time. When rainwater hits the ground, a major portion is infiltrated into soils and some portion fills the small surface depression. Initially the rate of infiltration is very high if soil is dry and later on it is less once the soil gets saturated. Finally the remaining precipitation flows over the surface known as overland flow, subsequently it joins other such streams and drains to a water body as runoff. Even water intercepted is also evaporated or infiltrated or becomes part of overland flow. Some of infiltrated water also joins runoff as a base flow.

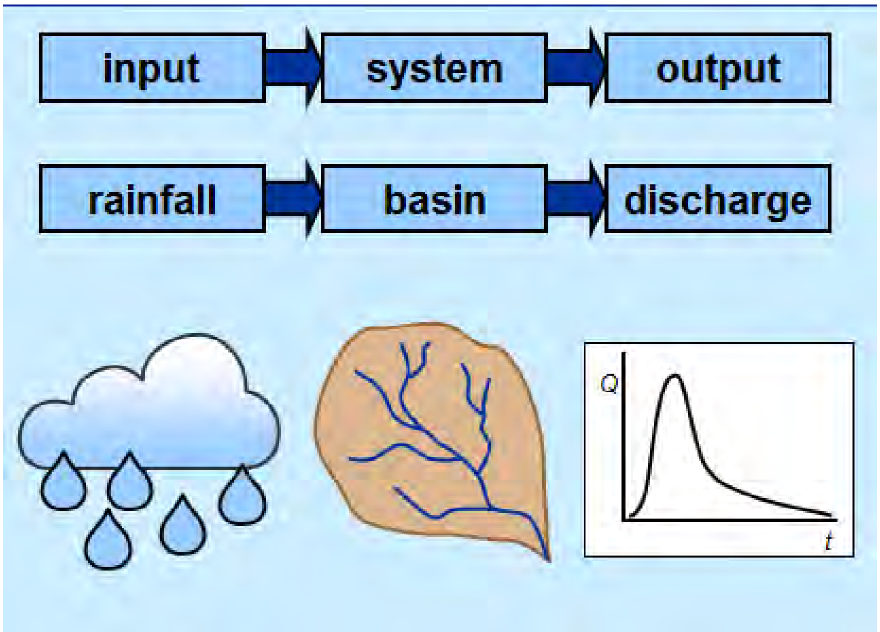

Fig 3: Process of rainfall-runoff

Conclusively, the overall response of basin to rainfall is runoff or discharge which is drained by the river.

2.0 Integrated river basin management (IRBM)

"Integrated river basin management (IRBM) is the process of coordinating conservation, management and development of water, land and related resources across sectors within a given river basin, in order to maximise the economic and social benefits derived from water resources in an equitable manner while preserving and, where necessary, restoring freshwater ecosystems." (Global Water Partnership, 2000.)

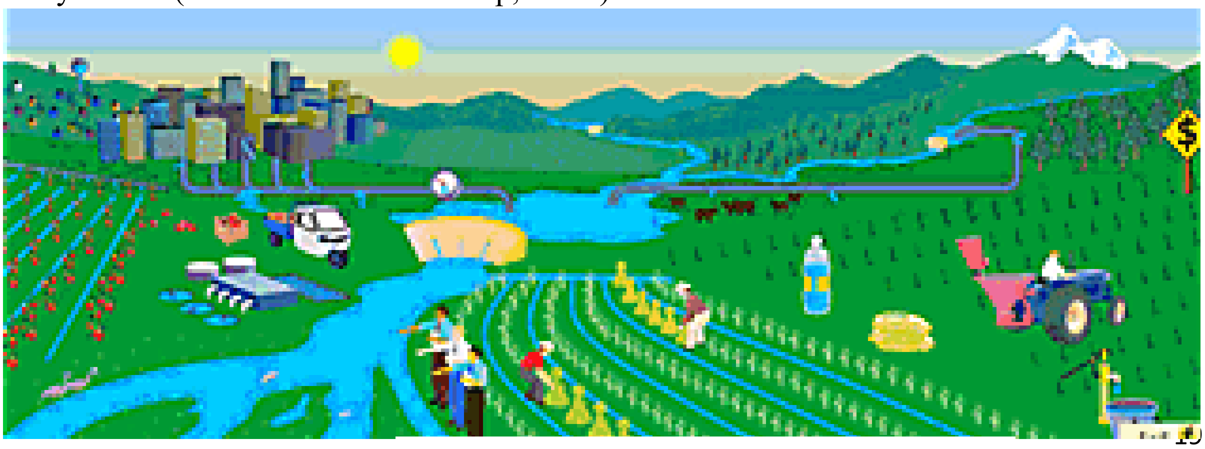

Fig 4: Integrated River Basin Management

Above approach of IRBM is mainly suitable for India and other developing countries as it envisages maximizing social & economic benefits in equitable manner ensuring sustainability of freshwater ecosystems. Aforementioned development is concerned with identifying structural and non-structural measures which will ensure availability of water overcoming its spatial & temporal variability to meet development objectives, subject to various technological, social and financial constraints.

The seven key elements to a successful IRBM initiative are:

i. A long-term vision for the river basin, agreed to by all the major stakeholders.

ii. Integration of policies, decisions and costs across sectoral interests such as industry, agriculture, urban development, navigation, fisheries management and conservation, including through poverty reduction strategies.

iii. Strategic decision-making at the river basin scale, which guides actions at sub-basin or local levels.

iv. Effective timing, taking advantage of opportunities as they arise while working within a strategic framework.

v. Active participation by all relevant stakeholders in well-informed and transparent planning and decision-making.

vi. Adequate investment by governments, the private sector, and civil society organisations in capacity for river basin planning and participation processes.

vii. A solid foundation of knowledge of the river basin and the natural and socio-economic forces that influence it.

3.0 IRBM: A multidisciplinary Approach

Historically, projects have been undertaken in fragmented manner such as management of individual reservoirs to meet local irrigation demand, abstraction of ground water for drinking water etc. Integration needed at river basin scale (conjunctive use etc) which may further call for integration at regional, national and possibly international scale. It enables a holistic approach for addressing issues related to water resources in a river basin. The major disciplines for IRBM are as under:

- HYDROLOGY - Concerned with quantifying natural distribution of water in time and space (assessment of water resources)
- HYDRAULIC ENGINEERING - Concerned with design and management of structural measures whereby water can be stored and distributed in time and space
- ENVIRONMENTAL ENGINEERING - Concerned with quantifying water quality in time and space, and with waste water treatment processes whereby this can be altered to accord with water quality standards for river water etc
- SOCIAL SCIENCES - Concerned with formulating objectives of development, with assessment of water demand and with water governance and public participation
- SYSTEMS ANALYSIS - Interacting roles of above disciplines can best be studied through the medium of systems analysis. Variables describing inputs to, components and states of, and outputs from a system can be defined and relationships between them can be represented through equations in a mathematical model. Constraints can

be introduced into the model and operation research techniques of simulation and optimization can be used to maximize objectives, evaluate risk etc

4.0 IRBM: Purposes

As envisioned in its definition, the main objective of IRBM is to maximise the economic and social benefits derived from water resources. This aspect can be further divided into following components as purposes of IRBM:

a. Domestic Water Supply
   - Drinking Water
   - Health and Sanitation
b. Industrial Activity
   - Sustain Industries
   - Attract Industries
c. Agricultural Activity
   - Irrigation
   - For Animals
d. Environmental Quality
   - Quality of Rivers
   - Reduce Adverse Impacts
e. Hydropower Generation
f. Navigation or Transport
g. Recreation
   - Lake Based
   - River Based
h. Flood Damage Reduction

Several engineering solutions may satisfy "purposes of development": choice between solutions based on how well they achieve the objectives. Following table enumerates the various purposes which enable achieving the different types of objectives:

Table 1 Purposes of IRBM for achieving Objectives

Type of Objective	Purposes
National Economic Development	b, c, e, f, h
Regional Economic Development	b, c, e, f, h
Social Development	a, c, g
Environmental Quality	d
International Trade	e, b, c

5.0 IRBM: A Sequence of Decisions

Success of IRBM depends on right decisions taken at the right time. There can be several kinds of decisions to be taken; some of them are as under:

- PLANNING DECISIONS - Involves deciding on feasibility of a project and further details regarding location and timing of construction of dams, transfer links, power stations, sewerage treatment works etc.

- DESIGN DECISIONS - Involves sizing individual components and setting target yields, consideration of risk etc.
- OPERATION DECISIONS - Long-Term Operating Policies; Short-Term Controls such as real-time monitoring of state of the system, quick decisions based on forecasts etc.

6.0 Trade-offs

Economic development can be measured in monetary terms, but environmental quality cannot always be measured in the same way. Planning involves the evaluation of several different options which can achieve objectives in varying degrees. A very careful consideration of various aspects is required for making decisions.

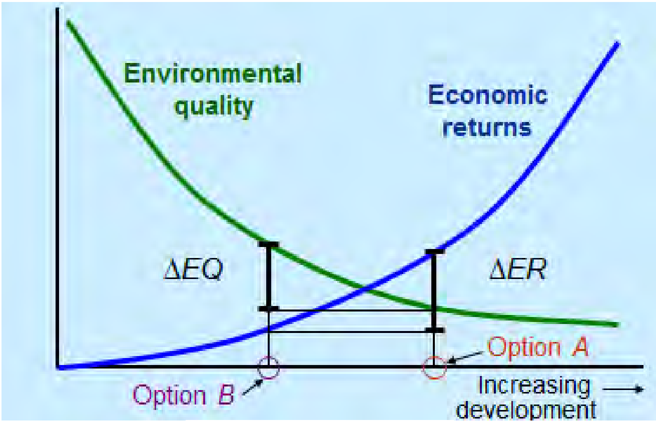

Fig 5: Trade-Offs

Suppose a decision maker has to choose between Plans A and B. If s/he is willing to choose Option B rather than A, then s/he is willing to forego ΔER to prevent a decrease in environmental quality ΔEQ. This is known as a tradeoff. Tradeoffs are functions of decision-maker.

If there are a large number of plans (options) and several objectives, a solution technique is required. Multi objective programming can be used for this purpose. Develop weights for each objective (trade-off functions). Use operational research technique to achieve optimum solution using weights eg

$$\max F = W_1X_1+W_2X_2$$

$$X_1 = NED$$

$$X_2 = EQ$$

$$W_1, W_2 = WEIGHTS$$

7.0 Multi-Criteria Analysis: UNESCO Methodology

For achieving objectives of Integrated River Basin Management, a Master Plan is envisaged which consists of several projects in the river basin. For a typical developing country, the objectives of the Master Plan are as follows:

- To attain food-sufficiency.
- To facilitate increase in cash crop.
- To broaden economic base & to facilitate growth of non-farm employment opportunities, etc.

During planning process, several projects are conceptualized and few of them are shortlisted as part of Master Plan. UNESCO's Multi-Criteria Analysis is widely used tool for evaluation of projects. For successful implementation of this analysis, various common indicators of projects need to be identified (base indicators) which represent the state of the project. Two of more base indicators are grouped together as second level indicator and further as third level indicator.

UNESCO's Multi-Criteria Analysis envisages following step-wise operations for multi-criteria project evaluation:

1. Selection of the base indicators which represent the actual state of the system. In the current scenario, thirteen basic indicators common to all master plan projects are provided.

2. Standardization of indicators between 0 and 1 using following empirical formula:

$$S_i = \frac{Z_i^+ - Z_i}{Z_i^+ - Z_i^-} \quad \text{or,} \quad S_i = \frac{Z_i - Z_i^-}{Z_i^+ - Z_i^-}$$

   Z_i^+ = ideal value, Z_i^- =worst value and, Z_i = the actual value.

3. Calculation of second level composite distances as under:

$$L_j = \left[\sum_{i=1}^{n_j} \alpha_{ij} S_{ij}^{p_j} \right]^{\frac{1}{p_j}};$$

   α_{ij} = weights to the indicators as per their importance
   p_j = a factor that penalizes deviation from ideal value.

   Similarly, the third level composite distance is calculated.

4. The calculated values for each indicator using above empirical formulae are represented graphically as in figure-6:

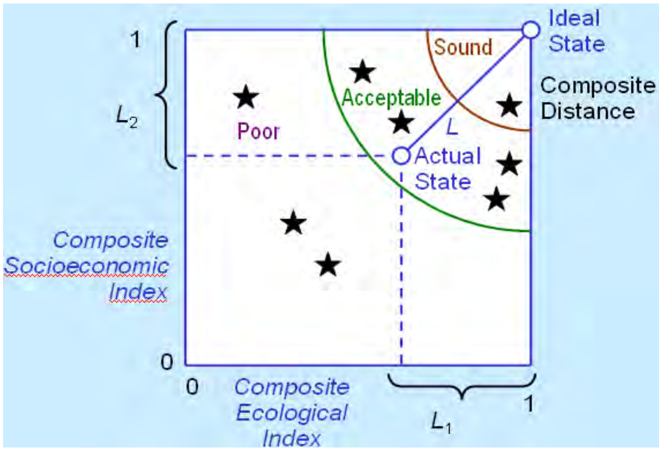

Fig-6

The indicators are grouped, assigned weight and balancing factor based on the Plan objectives

7.1 Grouping:

The basic indicators are grouped strategically into second level indicators. Generally, third level indicators are 'Social', 'Economic' and 'Environmental'. Basic indicators such as contribution to foreign exchange, revenue generation are grouped under 'economic' next level indicator. Increase in farmer / non-farmer income, increase in job etc are socially relevant matters, therefore, grouped next level 'social' indicators. Similarly base indicators such as water & land quality are purely environmental concerns and hence grouped under next level indicator 'Environmental'.

7.2 Ideal and Worst Value:

Several projects are shortlisted to fulfill the master plan, therefore, it may be assumed that all projects are meeting some basic requirement. As explained in the step-1 on pre-page, standardization of projects are done between 0 and 1 on the basis of ideal & worst value. For eg, if maximum and minimum revenue generations (a base indicator) of a particular project comparing to other are Rs. 50 lakh and 10 lakh respectively; then ideal value is Rs. 50 lakh and worst value is Rs. 10 lakh.

7.3 Weight:

Weight is assigned as per the importance of the particular indicator from the Master plan's objective and priorities point of view. As per the importance of the basic indicators, weight is assigned between 0 and 1 (shown as α_{ij} on pre page).

7.4 Balancing factor (BF):

This is a crucial parameter of the UNESCO analysis and used to penalise the project deviating from the ideal value of an indicators. The indicators linked to the master plan's objective directly and critical from priorities point of view, are assigned higher values of BF. Based on information furnished, the value of balancing factor is taken either 1 or 2.

7.5 Sensitivity Analysis

Versatility of a project of Master Plan is derived from its performance in various conditions. To enable this aspect in UNESCO Multi-Criteria Analysis, assigned weights of indicators are changed and performance of the project is analysed. This ascertains the sensitivity of a project in varying conditions and uniformly performing projects under varying conditions are considered advantageous.

7.6 Advantages of UNESCO Multi-Criteria Analysis

- Output is numerical value characterizing system state from joint ecological/ social/ economic perspective;
- Method is adaptable to different scales of system (local river basin to regional/national);
- Allows comparison across systems;

- Can reflect changing importance in time/space between development and conservation;
- Simple to use: interactive computer program available with numerical/graphical output;
- Final L (i.e. deviation from the idea value) values can be used to help choose between development options.

7.6 Disadvantages of UNESCO Multi-Criteria Analysis

- Always conflicting opinions about what is best for society: impossible to determine objectively what is best;
- Method should not be viewed as optimization procedure giving definite answers. Mathematical sophistication is not a measure of appropriateness;
- Possibility of assigning values to indicators which are subjective rather than quantitative.

8.0 R&D for IRBM

Water sector in India has been traditionally challenging yet fascinating. With the onset of the 21st century, the plummeting per capita water availability and rising water demand coupled with uneven distribution of resources, low water use efficiency, steady gap between irrigation potential created & utilized and the possible impact of the predicted climate change have rendered multi-hued complexity to the water sector in India. Concerns about the need to increase domestic food production to satisfy the needs of ever burgeoning population prompt to increase Water Use Efficiency (WUE) particularly in irrigation sector which uses about 80% of India's water resources. In this changing scenario, it is urgently needed to adopt an emerging paradigm of integrated, affordable, less complex and inclusive research and innovation to promote development at river basin level. Such focused R&D will definitely enable an informed policy making and consequently informed planning and management of water resources.

Keeping in view the present as well as future scenario, the R&D Challenges in water sector in respect of IRBM can be classified into three broad categories namely:

- To develop the unutilized water resources – In areas where utilisable water is available but are not being utilised due to non-development;
- To improve the efficiency of present utilization and bridge the gap between the demand and supply – In areas where present utilisation has outstripped availability; and
- To enhance the level of utilizable resource from the present estimate of 1123 BCM towards a higher potential – To meet the future requirement.

9.0 Participatory approach for IRBM

As explained, IRBM is a multi-disciplinary approach. Previous approaches couldn't yield desired results as the project or engineering centric methods have been followed. Scientists are good problem analysts; Engineers are good problem solvers but the affected people have the best knowledge of the problem which helps in formulating solution. Similarly other stakeholders of the river basin are also potentially capable of contributing towards the ideal solution. Water issues are getting complex day-by-day and proper & sufficient participation of stakeholders may only lead to a widely accepted solutions.

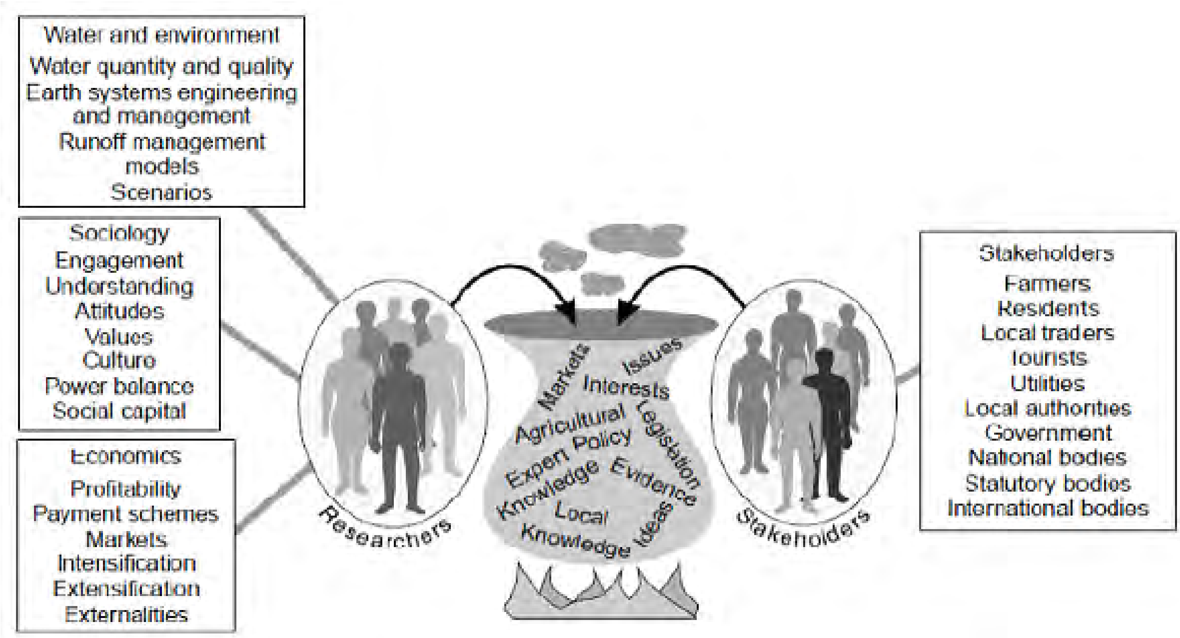

Fig 7: Participatory Approach

10.0 Conclusion

Addressing the river basin issues in integrated manner to develop adequate and state-of-the-art water policy can be the best way to address water challenges and ensure sustainable and efficient use of water resources. Solutions emerged through participatory approach at river basin level undertakes the problems holistically and therefore, widely acceptable. This constitutes the most scientific and pragmatic way of reconciling the conflicting interests of the stakeholders in water sector. In order to fully adopt the paradigm of IRBM, following objective need to be fulfilled:

- To create a collaborative, multi-disciplinary culture focused on water policy and management in river basins.
- To re-build the institutional processes and relationships, within and between, the water research community and the public water management sector.