Journal of Indian Geomorphology
Volume 2, 2013 • ISSN 2320-0731
Indian Institute of Geomorphologists (IGI)

The Second Prof. S.R. Basu Memorial Lecture,
2012 delivered at 25th IGI Conference, Allahabad

Ensuring Sustainability of Fluvial Systems: A Review of Key Tools

Dulal C. Goswami
Formerly in Department of Environmental Science, Gauhati University, Guwahati 781014
dulalg@yahoo.com

Introduction

Fluvial geomorphology is currently emerging as an effective and adaptable tool in various river conservation and management activities because of its larger space and time perspectives connecting the local-level scenario to the catchment scale and the contemporary processes to the historic ones, occasionally making projections into the future. Like arteries in the body, the rivers transport water and nutrients across the earth surface to sustain life and to maintain the ecological integrity of the planet. Also, they scrub and chisel it to shape the variegated landforms around us. However, a majority of these prime components of the earth's surface are presently under increasing threat due to rising population, land use and development pressures leading to their overall decay and degeneration. The situation invariably results in deprivation of many of their vital services to human society as well as ecology. Keeping the above perspectives in mind, a select set of currently evolving paradigms that seem to have considerable relevance and applicability in our context today are discussed in this article.

Environmental flow

The term environmental flow denotes the quantity, quality, duration and timing of flow needed to sustain riverine ecosystems and safeguard peoples' livelihood and wellbeing that depend on these ecosystems. In other words, it is the volume of water needed in a river to maintain healthy ecosystems. Environmental flow is determined by identifying important ecological attributes and their need to function normally. The term is generally applied to the flows released from dams which are meant for environmental benefit. In the case of managed rivers, environmental flow constitutes an essential element needed for ensuring sustenance of riverine ecosystems and human needs in the areas downstream of intervention. Although this part of the river flow represents the demand made by nature on the water course, this water use is not consumptive.

Environmental flow provides a wider set of benefits compared to other water uses like water supply, energy, flood control or recreation. Dams and others structures built on rivers change the downstream flow pattern affecting water quantity, quality, sediment transport, deposition, fish and wildlife and the livelihood of people depended on the river system.

Since the beginning of the 20th century through the 1960s, water management in developed nations was focused mainly on flood protection, water supply and hydropower generation. During the 1970s, the ecological and economic aspects of these project made scientists to seek ways to modify dam operations to maintain important fish species. Initially the focus was on determining the minimum flow necessary to preserve an individual species, such as trout, in a river. Subsequently, the concept of environmental flow evolved from the concept of 'minimum flow' and later on into 'in-stream flow' which emphasised the need to keep water within the channel.

Since 1990, restoring and maintaining more comprehensive environmental flow has gained greater support. More sophisticated techniques have been developed in different countries. Furthermore, the implementation has evolved from dam operation to an integration of all aspects of water management including groundwater and surface water diversion, return flows and storm water management. In most countries of the world today perception of environmental flow is quite widespread as an essential concept for sustainably managing water resources and meeting the long term needs of people.

The Brisbane Declaration on environmental flow was endorsed by more than 50 countries across the world. The declaration announced an official pledge to work together to protect and restore the world's rivers and lakes. By 2010, many countries throughout the world had adopted environmental flow policies although their implementation still remains a challenge.

One major effort presently undertaken to restore environmental flows is the Sustainable River Project, a collaborative initiative between The Nature Conservancy (TNC) and U.S. Army Corps of Engineers (USACE). Since 2002, TNC and USACE have been undertaking works to define and implement environmental flows by altering operations of several USACE dams across the country.

Environmental flows, also called e-flows, are at various stages of planning, assessment, designing and implementation in countries like Australia, US, Europe, Africa etc. Countries like South Africa and Australia have formulated laws and guiding principles for e-flows. The Cumulative Impact Assessment (CIA) being carried out in some Indian rivers like Lohit, Alaknanda-Bhagirathi and Bichom includes exercises on environmental flow assessment. However, these are done without giving adequate considerations to community needs on ecological requirements.

Currently more than 200 methods are used worldwide to prescribe river flows needed to maintain healthy rivers. However, only a few of them are comprehensive and holistic in nature. Among the more comprehensive approaches include DRIFT (Downstream Response to Imposed Flow Transformation), BBM (Building Block Methodology) and the 'Savanna Process' for site-specific environmental flow assessment. Several computer models and tools have also been developed in countries like USA and Australia (e.g. HEC-RPT, HEC-ResSim, HEC-RAS and HEC-EFM). The BBM is considered as a suitable methodology for our country. E-flows largely remain a purely technical exercise of assigning quantitative values based on average of the seasonal flows.

In India, although assessment of environmental flow is considered a necessary component in the planning and management of controlled rivers, especially in the case of determining downstream release of flows from hydropower and river-valley dams, there exists considerable laxity and under preparedness in this regard. The environment ministry does not have a prescribed methodology or a sound framework of policy in this vital aspect of public life and ecological significance. On thumb rule estimation, it is considered to be approximately 20 percent of average minimum flow for the four leanest months (during the non-monsoon season) at 90 percent dependability.

Ecological health of river

The term ecological health of river is defined as 'the ability of the aquatic ecosystem to support and maintain key ecological processes and community of organisms with a species composition, diversity and functional organisation as comparable as possible to that of undisturbed habitats within the region'. It relates to ecosystem productivity, its biological productivity and its resilience to the negative impact of various interventions. Ecological health of river indicates the degree of similarity to an unaffected natural river of the same type particularly in regard to biological diversity and ecological functioning. It is analogous to general assessment of human health that ranges differently between derelict to sound conditions. Although widely used at present, it is difficult to describe the concept in precise scientific terms. A river which is ecologically healthy will have flow regimes, water quality and channel morphology where the plants and animals of different species are indigenous, its natural ecosystem processes are intact, natural habitat parameters are mostly represented, native fish and fauna can migrate up and down the rivers and the natural linkages maintain ecological processes between the river and its floodplain and associated wetlands.

Over the past century, humans have drastically changed rivers posing threat to their health. As a result there has been considerable depletion of goods and services of rivers that are critical to human life and living.

The application of the concept of health to rivers is a rational outgrowth of various scientific principles, legal provisions as well as changing societal value systems. Assessment of health of river depends on realistic paradigms or models that can explain the interactions of the physical landscape, rivers and human activities. Ecological health of a river is a key issue in water and land management. For assessment of the ecological health of rivers, naturally consistent and scientifically valid methodologies based on standardised sampling of physical and biological processes and communities are needed. An ecologically healthy river has the advantage of a verifiable and regionally relevant scale against which its health can be measured. In reality, its underlying idea is analogous to a general assessment of human health.

Important stresses on river health include nutrient enrichment, sediment loading, pesticide concentration, erosion and aggradation, increasing water extraction, flow controls, riparian vegetation loss and effluent discharge. Assessment of physical health of a river system is a comprehensive exercise involving different aspects of its geophysical, bio-ecological and economic-environmental conditions. It helps to understand the overall status of the bio-geo-chemical processes and the various linkages with the life and activity of the communities that depend on them.

Cumulative Impact Assessment of river basin

The term Cumulative Impact Assessment (CIA) of river basins denotes assessment of cumulative effects from multiple activities in different locations of a basin over time. Cumulative effects can also result from a combination of effects from a single activity. In either case, whether singular or multiple activities, the cumulative effects can be synergistic, more intense, larger in magnitude, more long lasting and having greater spatial coverage than is the case with individual effect. It may generally cut across political or administrative boundaries.

The data management in case of CIA is generally more involved, complex and expensive in terms of time and cost effectiveness. The uncertainty level that normally exists in identification and prediction of environmental effects increases further in case of cumulative effects. The complex synergistic scenarios need to be considered in such cases.

The first-order cost-effect analysis used in case of single activity projects can no longer be valid in case of multiple activity projects. Rather, separate methods need to be developed for use in cumulative assessment analysis. Similarly, these assessments may cut across potential boundaries (e.g. district and regional).

In case of areas like the northeast India, where interstate and international transboundary basins predominate, such operational problems need to be carefully addressed in case of management of its prime water resources. The complexity further multiplies in view of the extremely varied and dynamic geoenvironmental and hydrometeorological setting and the equally diverse ecological and human landscapes.

Although assessment of cumulative impacts at the basin level is getting better attention and higher priority in all water resource development projects especially for hydropower generation, the policy framework and institutional arrangements in regard to these interventions are yet to be properly evolved and organised. It is high time to replace the conventional Environmental Impact Assessment (EIA) with basin-level CIA to maximise the benefits derived by both man and nature from these projects. In this regard, the state governments should be made to furnish the available details of projects in the pipeline at least for the next 10 or 15 years which should form a basis of any currently undertaken cumulative impact assessment. EIA of all new project formulations should be considered from a basin-level perspective instead of looking at stand-alone individual mode as at present.

Carrying capacity of a river basin

Carrying capacity can be defined in more general terms as the amount of activity or use that can be handled by a river system before it begins to deteriorate. It suggests how much use a given setting can absorb before undesirable impacts occur. The report on the existing conditions helps to identify current factors that will assist the determination of capacity thresholds for the study. The parameters that should be considered while determining carrying capacity are: (i) natural resources factors (physical and biological habitat characteristics), (ii) social factors that consider needs and wants of the local community and (iii) managerial factors which include legal directives and stakeholder missions.

The term carrying capacity includes the hydrological, environmental and social carrying capacity of the river basin. The estimation of carrying capacity of a river basin should precede any new project. Such a study can become a decisive factor in the free-flowing stretches to be left between two dams and the number of dams a river can hold. It needs to be properly initiated in our country using an independent expert body. The expert body should look into the prevailing catchment conditions as a necessary prerequisite before entertaining any new project in the same basin in the cascade.

Life span of most dams in the country are getting reduced. Hence restoring catchments should become the responsibility of the dam proponent instead of just proposing more and more new projects. For already dammed rivers, the reservoir operations should be managed so as to release enough water to meet the environmental needs of the river below the impounded stretch including livelihood, cultural and downstream needs. The environmental needs have to be assessed for the river basin and the dam operations have to be jointly monitored by river basin communities.

In ecologically fragile and biodiversity rich areas like the northeast India at least some rivers should be left in their natural pristine state for the future generations. The Environment Ministry has made it mandatory for state governments to conduct carrying capacity studies of river basins before any green clearances are granted to hydropower and river valley projects.

The carrying capacity study is important to plan the optimum number of power projects which can be based in a river basin. The study of the current status of the basin and plan for its future growth is therefore a prerequisite for future initiatives. In recent times, a GIS technique based carrying capacity study of the Damodar river basin has been done by the government.

Free flow distance

Free flow distance refers to the minimum distance (stretch) required by a river in between two successive interventions for maintaining its ecological health and sustainability of flow regime. It is also denoted by the minimum riparian distance that must be maintained between the tail race of one project and the intake of the next in order to enable the river to recharge itself and to continue to sustain life along its length. Based on the factors like topography, climate, biodiversity, human occupation etc., the free flow distance may vary from one river to another and from one stretch to another in the river.

Given the haphazard growth of dams along most of the rivers in recent years, it is necessary that any new intervention in the river needs to be weighed very carefully in order not to upset the already degraded river system, its ecology and dependent population.

There is considerable variation in river flow, geology, topography, soil, climate, catchment status and floral and faunal diversity across river landscapes in the country. For example, the character of the tropical Western Ghat rivers is quite different from that of the Himalayan snow-fed rivers. As a river gathers water from all the tributaries along with sediments and nutrients in its lower reaches, it will need more space to flow and more free-flow distance. For the Western Himalayan region, the free flowing distance is suggested to be 10–15 km according to some recent estimates. In some stretches of rivers in the northeast Indian region as the gradient is too steep, topography extremely variable and biodiversity exceptionally high, even a stretch of 5 km cannot be safely taken as a standard free-flow distance between successive interventions for the region. The free flow distance under these conditions needs to be evaluated in a case to case basis. With numerous dams being planned closely spaced to one another in cascading mode, the eastern Himalayan region presents an awesome sight of flagrant disregard to the sustainability norms and conditions for river conservation and flow management posing serious threat to public life and ecological integrity.

Integrated River Basin Management

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 resource in an equitable manner while preserving and, where necessary, restoring freshwater ecosystems (GWP–TAC, 2000).

It is a practical operating approach that implies management of water in a river alongside the management of co-dependent natural resources viz. soil, forest, air, biota etc. taking the river basin as the basic planning and development unit. It entails a system approach that recognises the individual components as well as the linkages between them. A management paradigm like this, based on regional framework of planning with adequate interstate and international cooperation and coordination, appears to be the prime need of the hour in harnessing the untapped water resources of areas like the northeastern region. Only such a strategy will help evolve a much-needed 'shared vision' based on equity in respect of costs and benefits of water-related development initiatives among different levels of stakeholders within and across the local, regional and national boundaries. Unfortunately, in real practice not even an iota of the above type of considerations has gone into the planning and development initiatives undertaken so far in case of the northeastern rivers, where the current scenario is dominated by a discrete array of localised, ad hoc and piecemeal works of largely unsustainable nature. The sooner a holistic and integrated paradigm is brought into practice, the better it is for both man and nature in this part of the country.

IRBM centres around the principle that naturally functioning river basin ecosystems, including associated wetland and groundwater systems, are the prime source of freshwater on the planet. Therefore, management of river basins must include maintaining ecosystem function as a paramount goal. River basins are dynamic entities over space and time and any single management intervention has implication for the system as a whole.

The seven key elements contributing to a successful IRBM initiative are identified by the GWP–TAC (2000) mentioned earlier. These include: (i) A long-term vision for the river basin, agreed upon 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 etc. (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, private sector, and civil society organisations in river basin planning and participation processes, (vii) A solid foundation of knowledge of the river basin and the natural and socioeconomic forces that influence it.

Fluvial Information System

Fluvial Information System (FIS) is a new raster based GIS-type system designed to manage fluvial remote sensing data that is capable of automatically extracting meaningful information. It is based on a river coordinate system generated automatically by detecting and digitising successive channel mid points from classified georeferenced imagery. The adaptation of GIS to fluvial system is a significant innovation contributing positively to fundamental river science and management. The system offers a unique tool that carries promise to modernise our understanding of aquatic ecology and ability to manage rivers. The FIS has been able to effectively cater to the need of fluvial scientists for a method that is applicable to catchment scale processes. The meaningful use of high resolution remotely sensed data are capable of yielding unprecedented amount of information over large areas, thereby producing vast amount of raster data that are useful in the management of water resources. The information gathered through FIS can allow us to quantify the available habitat for important species to support river management decisions. The FIS offers a unique tool to help us understand our water systems much better than before, besides increasing our knowledge base on aquatic systems and capability to manage the rivers.

Conclusion

The above review of existing and emerging concepts and methods regarding assessment of health of rivers and their long term sustainability indicates the intricacies involved in addressing these issues in precise scientific terms. However, these ideas and efforts seem to be theoretically rational and practically relevant with ample potential for application.

Presently, there exist numerous examples of meaningful and effective use of these techniques in river basins across the globe. However, in the case of south Asian countries including India, these concepts and techniques have by far received very little, if any, attention and applicability. Nor these have become part of any serious academic discourse and scrutiny. Assessment of physical and ecological health of a river system is a comprehensive exercise involving various geoenvironmental, hydrometeorological, eco-biological and socioeconomic characteristics of the basin. These are assessed through naturally consistent and scientifically valid methods of standardised sampling that are components of a practical operating approach for management. In these aspects the government needs to create suitable policy frameworks and organisational arrangements.

The current scenario in the country especially in regard to east Himalayan rivers is marked by a discrete array of unsustainable interventions without much heed towards safeguarding the hydrological, ecological and socio-cultural integrity of rivers and their basins. Under these circumstances, integrated and holistic approaches towards management of rivers are considered the crying need of the hour. The situation becomes much more crucial in view the increasing challenges from the possible scourge of climate change and the mounting pressures from escalating population growth, unsustainable development pattern and damaging land use practices.

Suggested readings

*A*PEM Environmental Consultancy: *Fluvial Information System*. http://www.apemltd.co.uk/remote-sensing/fluvial-information-system

Centre for Inter-disciplinary Studies of Mountain & Hill Environment (CISHME), University of Delhi (2007) *Carrying Capacity Study of Teesta Basin in Sikkim,* 1 (Introductory Volume): 267p.

Cullet, P., Paranjape, S., Thakkar, H., Vani, M.S., Joy, K.J. and Ramesh, M.K. (2012) *Water Conflicts In India: Towards a New Legal and Institutional Framework*. Forum for Policy Dialogue on Water Conflicts in India, Pune: 107p.

Davies, P.E. Harris, J.H., Hillman, T.J. and Walker, K.F. (2010) The sustainable Rivers Audit assessing River ecosystem health in the Murray- Darling Basin, Australia. *Marine and Freshwater Research* 61: 767–777.

Dyson, M., Bergkamp, G.J.J. and Scanlon, J. (eds) (2003) *Flow: The Essentials of Environmental Flows*. International Union for Conservation of Nature and Natural Resources (IUCN), Gland: 118p.

Goswami, D.C. (2006) Towards sustainable use of the Brahmaputra river. In: Jianchu, X. (ed.) *Sustainable Mountain Development in the Greater Himalayan Region*, International Centre for Integrated Mountain Development (ICIMOD) Publication, 50: 20–22.

Goswami, D.C. (2010) Integrated Basin Approach: Management paradigm for Harnessing North-East Rivers, *Proceedings, International Geographical Union Seminar* (11-13 Dec. 2010), Dept. of Geography, Cotton College, Guwahati: 5–19.

GWP–TAC: Global Water Partnership–Technical Advisory Committee (2000) *Integrated Water Resources Management*, Background Paper, 4: 67p.

Lenin Babu, K. and Harish Kumara, B.K. (2009) Environmental flows in river basins: A case study of river Bhadra, *Current Science*. 96(4): 475–479.

Smakhtin,V., Anputhas, M. (2006) *An Assessment of Environmental Flow Requirements of Indian River Basins*, International Water Management Institute (IWMI) Research Report 107: 42p.