RESEARCH REPORT

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Developing Procedures for Assessment of Ecological Status of Indian River Basins in the Context of Environmental Water Requirements

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International Water Management Institute
P O Box 2075, Colombo, Sri Lanka

IWMI receives its principal funding from 58 governments, private foundations, and international and regional organizations known as the Consultative Group on International Agricultural Research (CGIAR). Support is also given by the Governments of Ghana, Pakistan, South Africa, Sri Lanka and Thailand.

The authors: Vladimir Smakhtin is a Principal Scientist in Hydrology and Water Resources at International Water Management Institute (IWMI), Colombo, Sri Lanka; Muthukumarasamy Arunachalam is an Associate Professor at Sri Paramakalyani Centre for Environmental Sciences, Manonmaniam Sundaranar University, Alwarkurichi, Tamil Nadu, India; Sandeep Behera is a Senior Coordinator of the Freshwater and Wetlands Program, World Wide Fund for Nature (WWF)-India, New Delhi, India; Archana Chatterjee is a Senior Coordinator of the Freshwater and Wetlands Program, WWF-India, New Delhi, India; Srabani Das is a former Consultant of IWMI-India, New Delhi, India; Parikshit Gautam is a Director of Freshwater and Wetlands Program at WWF-India, New Delhi, India; Gaurav D. Joshi is an Independent Consultant, New Delhi, India; Kumbakonam G. Sivaramakrishnan is a Principal Investigator, University Grants Commission (UGC) Research Project, Sri Paramakalyani Centre for Environmental Sciences, Manonmaniam Sundaranar University, Alwarkurichi, Tamil Nadu, India; K. Sankaran Unni is a Guest Professor at School of Environmental Sciences, Mahatma Gandhi University, Kottayam, Kerala, India.

Acknowledgments: The study forms part of the research project on the assessment of the National River-Linking Project. The project is funded by the CGIAR Challenge Program on Water and Food (CPWF). Figures for this report have been produced by Mr. Nilantha Gamage (IWMI-HQ, Colombo). We gratefully acknowledge the detailed review of this report by Mr. V. V. Sugunan, Assistant Director General (Inland Fishery) of Indian Council of Agricultural Research (ICAR), and Ms. Rebecca Tharme (IWMI-HQ, Colombo).

Smakhtin, V.; Arunachalam, M.; Behera, S.; Chatterjee, A.; Das, S.; Gautam, P.; Joshi, G. D.; Sivaramakrishnan, K. G.; Unni, K. S. 2007. *Developing procedures for assessment of ecological status of Indian river basins in the context of environmental water requirements*. Colombo, Sri Lanka: International Water Management Institute. 40p. (IWMI Research Report 114)

/ river basins / ecology / habitats / ecosystems / India /

ISSN 1026-0862
ISBN 978-92-9090-668-1

Cover photograph by Vladimir Smakhtin shows the Godavari River, near Polavaram, India.

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Contents

Summary

This report attempts to introduce a prototype scoring system for the ecological status of rivers in India and illustrate the same through its applications in several major river basins. This system forms part of the desktop environmental flow assessment and is based on a number of indicators reflecting both the ecological condition and sensitivity of a river. The indicators include: presence of rare and unique aquatic biota; diversity of aquatic habitats; presence of protected areas; sensitivity of aquatic ecosystems to flow reduction; percentage of a watershed and floodplain remaining under natural vegetation cover types; percentage of exotic aquatic biota; overall richness of aquatic species; degree of flow regulation and fragmentation; human population density in a river basin; and the overall quality of water. Each indicator has its own estimation method using available data and expert knowledge. Each individual indicator value is then converted to a standard scoring system, which includes ratings from: 1 (none) to 5 (very high). The rationale of selecting each indicator is discussed including its relevance in the context of the estimation of environmental flow requirements. The scores for individual indicators are then summed up and the sum of indicator scores is expressed as a percentage of the maximum achievable score. The actual percentage shows the degree of the deviation of a basin from its natural condition and, therefore, the most probable 'environmental management class'. The latter, in turn, is related to the amount of water which needs to be allocated for environmental purposes in this basin, i.e., environmental flows. The approach is illustrated using several river basins in India, including Krishna, Cauvery, Narmada, Periya and part of Ganga. The study is influenced by already existing, and much more detailed approaches that are used in other countries, where more expertise and relevant data are available. It is presented here as an attempt to show one possible protocol for placing a river into a certain environmental management class, rather than to prescribe it for use in its current form. The method has rather general indicators, a number of assumptions and does not directly address the issues related to social importance of water use. It is anticipated, however, that these and other shortcomings can be addressed in the course of future work. The need for a specialist workshop in this regard is advocated. The study should be seen as a step towards the development of future national environmental flow tools and policies.

Developing Procedures for Assessment of Ecological Status of Indian River Basins in the Context of Environmental Water Requirements

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Introduction

Environmental water requirements, also referred to as 'Environmental Flows' (Dyson et al. 2003; Acreman and Dunbar 2004), are a compromise between water resources development and the maintenance of a river in some ecologically acceptable or agreed condition. The issue of environmental flows is relatively new in the world. Existing environmental flow assessment methods reflect the diversity of opinions on this subject and range from comprehensive expert panel approach to arbitrarily selected hydrological indices (e.g., Tharme 2003). In many developing countries, such as India, the issues of environmental water demand have not yet received the required attention. The first National Workshop on Environmental Flows, held in New Delhi, in March 2005, brought together over 60 participants from national agencies and research institutions. The workshop generated a significant interest to the concept of environmental flows in the country, and it also revealed the existing confusion in this field. Smakhtin and Anputhas (2006), attempted to further stimulate the debate on environmental water demand in India by suggesting a simple desktop assessment method and using it in several major river basins. The method, however, was designed in conditions with very limited hydrological, and no ecological, data. One of the major problems with developing environmental flow work in countries like India, is that despite existing significant knowledge on some aquatic ecosystem components (e.g., fish), it has never been interpreted in the context of environmental flow assessments. This means that it is not, as a rule, known how different ecosystem components in different biogeographical settings react to changes of flow caused by water resources or land developments. The impacts of reducing/increasing high or low flows on fish, invertebrates, riparian vegetation, or sediment regime (which is one determinant of aquatic habitat), for example, are not quantified. In some countries, the lack of such relationships and quantitative knowledge is addressed by expert panels and/or by certain scoring systems, which rank a condition of an ecosystem and/or its sensitivity to flow changes (Cottingham et al. 2002; DWAF 1999; Rogers and Bestbier 1997). Such scores are then fed into the determination of an environmental category or environmental management class (EMC). EMC, in turn, is used (together with measures of flow variability or analysis of hydrological time series) to determine the acceptable limits of flow reduction/increase in a river, i.e., actual environmental flows. It is assumed that the higher the EMC, the more water will need to be allocated for ecosystem maintenance or conservation and, more flow variability will need to be preserved. The existing scoring systems reflect the level of available expertise and ecological data. This report attempts, for the first time, to introduce a prototype scoring system for the ecological status of rivers in India and illustrate the same through its application in several major river basins. The attempt has been significantly inspired by the South African experience. However, it is a major simplification of the existing practice. It is presented here as an attempt to show one possible protocol for placing a river into a certain environmental management class, rather than to prescribe it for use in its current form.

Methodology

Ideally, the definition of the environmental management class (EMC) should be based on existing empirical relationships between flow changes and ecological status/conditions, which are associated with clearly identifiable thresholds. Despite some documented examples, limited evidence or knowledge is available of such thresholds (e.g., Beecher 1990; Puckridge et al. 1998). Therefore, EMC is a management concept that has been developed and used in the world because of a need to make decisions regardless of the limited lucid hydro-ecological knowledge available. In these conditions of uncertainty with regard to which EMC is required for a particular river, the EMCs may be used as default 'scenarios' of environmental protection and associated environmental flows—as 'scenarios' of environmental water demand (Smakhtin and Anputhas 2006). It is possible to estimate environmental demand corresponding to all or any of such default EMCs and then consider which one is the most feasible for a river in question, given the existing and future basin developments. Alternatively, it is also possible to use expert judgment in order to place a river into the most 'achievable' EMC. One can think of an 'ecological water passport' for a basin. Such a 'passport' could include answers to the following three, broad questions:

- *What is the ecological sensitivity and importance of a river basin?* The rationale for this is that the higher the ecological sensitivity and importance of aquatic ecosystems in a river basin is, the higher the EMC should be, ideally.
- *What is the current condition of aquatic ecosystems in a river basin?* The more natural the current condition of the basin is, the greater the incentive for its maintenance as such.
- *What is the trajectory of change?* This question aims to identify whether a river is still changing, and in what direction, how fast and due to what impacts. The rationale is that if the deterioration of aquatic environment continues, it will be more difficult to achieve a higher EMC, even if it is necessary, due to its high importance and sensitivity.

As this is the first time that such an approach is introduced in India, the focus should be on highlighting the *main* aquatic features and problems of each basin. This means that *aggregate environmental indicators*, which reflect different features or conditions of a river basin, could be used for scoring. The literature on environmental indicators is fairly extensive and its comprehensive review is beyond the scope of this report. Some of the relevant recent works include, for example, Galbraith (2001), who developed a set of indicators that could be used to assess the condition and coping capacity of freshwater ecosystems at the basin scale. These indicators include: percentage of the basin under natural vegetation; percentage of the floodplain under agricultural and urban land use; percentage of the lakes in eutrophic state; and several others. A similar indicator approach has been widely used in large-scale international water assessment programs such as Global International Waters Assessment (GIWA, http://www.giwa.net), Watersheds of the World (Revenga et al. 1998) or Land-Ocean Interactions in the Coastal Zone (LOICZ, http://www.loicz.org). However, the aggregate environmental indicators have never been previously used in the context of environmental flow assessment.

The first question above may be seen as an attempt to design a condensed measure of the ecological value of the basin, albeit in non-monetary terms. An arbitrarily selected set of semi-quantitative and quantitative indicators includes:

- Presence of rare and endangered aquatic biota
- Presence of unique (e.g., 'endemic') aquatic biota
- Diversity of aquatic habitats
- Presence of protected areas, areas of natural heritage and pristine areas, which are crossed by the main water course in the basin
- Sensitivity of aquatic ecosystems to flow reduction

Indicators from this group are calculated using national ecological surveys and databases. Considering that most of the 'ecological' attention in countries like India has so far been given to fish, such indicators as *rare and endangered biota and unique biota* are calculated here using available fish data. Rare and endangered fish species are first identified using IUCN (1994) categories such as CR (critically endangered) and EN (endangered). Their cumulative number is then expressed as the proportion of the total number of fish species found in a river basin. The assessment of *diversity of aquatic habitats* and *sensitivity of aquatic ecosystems to flow reduction* requires expert judgment and knowledge of a particular river. *Presence of protected or pristine areas* can be assessed against existing guidelines for protected area management, i.e., IUCN (1980), which sets the aim of 10 percent of the basin to be protected.

The second question above relates to what the river system looks like at present, compared to a reference condition in the past (e.g., prior to construction of major dams), or compared to some similar and relatively undisturbed subbasins in the same physiographic settings. The indicators used in this study include:

- percentage of the watershed remaining under natural vegetation cover types
- percentage of the floodplain areas remaining under natural cover types
- percentage of aquatic biota that are exotics
- overall richness of aquatic species
- the degree of flow regulation
- the degree of river fragmentation
- human population density in a river basin (percentage of population density in the main floodplains)
- overall water quality in the basin

The first two indicators are normally estimated from the GIS maps, remote sensing data, or already published literature sources. In some cases, a percentage of the floodplain areas actually remaining in a basin compared to some past reference condition may be used as an alternative to the second indicator. A *proportion of exotic species* (e.g., fish), can be calculated as a percentage of the number of total fish species recorded in the basin. *Overall species richness* may be assessed as a proportion of the total number of species in a country, or in a larger geographical region, whichever is more appropriate, or by an expert score on a scale from low to high. The most straightforward way of calculating the *degree of flow regulation* is as a ratio of total storage of all dams to the long-term mean annual natural flow volume of the basin. It is acknowledged though that this approach does not recognize timing or types of flow events that are altered—which may be more critical than change in volume *per se*. *A degree of river fragmentation* can be represented by a simple indicator of spatial changes to habitat—longitudinal and latitudinal (river-floodplain) connectivity of rivers. *Human population density in a river basin as a percentage of population density in the main floodplains* (which could be seen as an aggregate indicator of human pressure on aquatic ecosystems) may be calculated using Census data and GIS, where the floodplains are arbitrarily defined as areas within 2.5 kilometers (km) of either side of the main channel and the channels of the main tributaries (e.g., Revenga et al. 1998). (It is acknowledged that such a definition does not fully recognize the difference between the typical riparian zone and floodplains). An approximation of the overall water quality in a river is indexed using Indian national water quality categorization, which has several classes, from A to E —depending on the level of pollution—expressed by ranges of several constituents.

With regard to the *third question above*, no specific indicators are used and 'trend assessment' is left primarily to professional judgment. It may be seen as an attempt to foresee how the river will look like in the short-term (e.g., 5 years) and in the long-term (e.g., 20 years) in case of a 'do-nothing-to-protect-aquatic-environment' scenario.

Regardless of the original units and ways of estimation of every individual indicator, all indicator values in this study are then converted to a standard scoring system, which includes ratings: 1 (none), 2 (minor), 3 (moderate), 4 (high) and 5 (very high). Table 1 summarizes the indicators which have been used in this study, and explains why an indicator has been considered and how it is relevant in the context of the estimation of environmental water demand. The scores for individual indicators are then summed up and their sum is expressed as a percentage of the maximum achievable score. The actual percentage shows the degree of the deviation of a basin from its natural condition and, therefore, the most probable EMC. The latter, in turn, may be related to the amount of water that needs to be allocated for environmental purposes in this basin.

TABLE 1.
A preliminary set of basin indicators, their scoring systems and justification.

Indicator	Range	Score	Justification in the Context of Environmental Flow Assessment
	Indicators Related to Ecological Value (Importance and Sensitivity)		
Rare and endangered aquatic biota	Very High High Moderate Minor None	5 4 3 2 1	The total number of rare and endangered species can be expressed as a percentage of the total number of species in a country, region or basin—depending on the scale of analysis. These percentages may be related to the range and to the score. The more rare and endangered aquatic biota is present in the basin, the more sensitive the rivers generally are to flow changes (e.g., to reduction). Consequently the more effort is needed to maintain the flow in a river at least at existing levels.
Unique aquatic biota	Very High High Moderate Minor None	5 4 3 2 1	The number of unique (endemic) species can be expressed as a percentage of the total number of species in a country, region or basin—depending on the scale of analysis. These percentages may be related to the range and to the score. The assumption is that the more unique aquatic biota is present in the basin, the more important it is to ensure that they do not get affected by flow modifications. Therefore, more flow and more flow variability needs to be preserved in a river.

(Continued)

TABLE 1. (Continued)

A preliminary set of basin indicators, their scoring systems and justification.

Indicator	Range	Score	Justification in the Context of Environmental Flow Assessment
Indicators Related to Ecological Value (Importance and Sensitivity)			
Diversity of aquatic habitats	Very High High Moderate Minor None	5 4 3 2 1	Can be estimated either by professional judgment or a more quantitative approach, e.g., by identifying different habitat types in representative river reaches and then calculating the representative value for a basin. Example of habitats include runs (rapidly flowing water with a gradient over 4% with no surface turbulence), pools, glides (a shallow stream reach with a maximum depth of under 5% of the average, and without surface turbulence), pocket water (one or a series of small pools in a section of flowing water containing numerous obstructions), backwater (abandoned channel that remains connected to the active main river or secondary channel in which the inlet is blocked with deposition at low water velocities but the outlet remains connected with the active main channel), floodplains and marshes (including mangroves), etc. The assumption is that the more habitat types are present, the more incentives should exist to preserve them to ensure the aquatic biodiversity as well.
Presence of protected areas of natural heritage and pristine areas which are crossed by the main watercourse in the basin	>10 5–10% 3–5% 1–3% <1%	5 4 3 2 1	Based on the IUCN aim of 10% of the basin area to be protected. The more area that is protected, pristine or 'a must to be preserved,' the more flow is likely to be necessary to be left in rivers, or to be released into them for maintenance of aquatic life.
Sensitivity of aquatic ecosystems to flow reduction	Very High High Moderate Minor None	5 4 3 2 1	Can be evaluated using professional judgment and knowledge of a river. A limited decrease in flow in some rivers may result in particular habitat types (e.g., floodplains, riffles, brackish costal wetlands, estuaries) becoming unsuitable for biota, compared to other rivers, e.g., smaller rivers versus larger rivers, rivers in drier areas versus those in more humid ones, etc. The assumption is that highly sensitive ecosystems need more water to maintain them in the current or desired condition.
Indicators Related to Ecological Condition of Aquatic Ecosystems in the Basin			
Percentage of watershed remaining under natural vegetation cover types	70–100% 50–70% 30–50% 10–30% <10%	5 4 3 2 1	Can be estimated using RS images, from literature sources or based on field surveys. These are measures of the extent to which natural vegetation communities have persisted in a watershed or a floodplain. An area that retains a high proportion of natural cover types may be expected to also have many essential ecosystem services, such as flood control, still intact. Because it still contains 'natural capital' in the form of natural communities, the ecological structures and functions of such a watershed or floodplain would also be expected to be more sustainable, and their resilience and ability to cope with anthropogenic and natural stress would be greater. The assumption is that the higher the values of both indicators, the more biodiversity is likely to be preserved and the more the basin is insured against the functional degradation. If the natural capital is important to maintain at existing conditions, the higher EMC will be necessary and more environmental flows will be required.
Percentage of floodplain remaining under natural vegetation cover types	70–100% 50–70% 30–50% 10–30% <10%	5 4 3 2 1	
Degree of flow regulation	>100% 50–100% 20–50% 10–20% 0–10%	1 2 3 4 5	The first indicator is the total dam storage in a basin as a percentage of the mean flow, the second—the catchment area upstream of dams as a percentage of the total catchment area. These are important determinants of the habitat condition and aquatic biodiversity. Many riverine species move large distances through channel networks as part of their life history requirements. Dams and weirs disrupt longitudinal connectivity and fragment populations leading to decline in aquatic biodiversity. Migratory species often form the basis of productive fisheries and are typically the most affected by such barriers. A high density of impoundments prevents biota from migrating to preferred habitats such as upstream spawning beds. As these ecological processes are degraded, the sustainability and coping capacity of the system is reduced. Environmental flows should be allocated to cater for longitudinal and lateral connectivity. The more the river system is fragmented, the lower is the ecological status, hence a lower environmental management class is achievable.
Percentage of the watershed closed to movement of aquatic biota by anthropogenic structures	70–100% 50–70% 30–50% 10–30% <10%	1 2 3 4 5	

(Continued)

TABLE 1. (Continued)
A preliminary set of basin indicators, their scoring systems and justification.

Indicator	Range	Score	Justification in the Context of Environmental Flow Assessment
			Indicators Related to Ecological Condition of Aquatic Ecosystems in the Basin
Degree of flow fragmentation			This indicator is an alternative to the above one. The ranges are expressed in a number of structures per km of river length.
	0	5	Naturally flowing river without structures.
	0.001–0.01	4	* With/out upstream storage reservoirs and with possibilities of movement upstream—like fish ladders—for aquatic fauna.
	0.01–0.1	3	* With/out upstream storage reservoirs and with possibilities of movement upstream—like fish ladders—for aquatic fauna.
	0.1–1	2	* With/out storage reservoirs with/out possibility for movement upstream for aquatic fauna only during monsoon.
	>1	1	* With/out storage reservoirs with/out possibility for movement upstream for aquatic fauna only during monsoon.
Percentage aquatic biota that are exotics	0% <5% <10% <20% >20%	5 4 3 2 1	Successful invasion by exotic species often incurs losses and disruptions in ecosystem structures and functions (e.g., loss of biodiversity due to competitive exclusion and predation, disruption and modification of food webs, loss of habitat for fish and wildlife). Thus, the percentage of exotic species in a reach or a basin provides information on its likely sustainability and coping capacity. The higher the proportion of exotic species the lower the achievable EMC is.
Fish species relative richness, aquatic plant species relative richness, etc.	Very High High Moderate Minor None	5 4 3 2 1	These are measures of biodiversity remaining in a system and therefore—of its ecological capital and ability to self-organize and sustain itself and cope with stressors. It is important to address relative richness, rather than just species counts because the baseline biodiversity of an area is conditional on habitat types, geographical locations, etc. Thus, the number of species that inhabit a watershed should be expressed as a percentage of the number that would be expected to occur there in the absence of human interventions. Xenopoulos et al. (2005) have shown that fish species numbers are reducing with reducing discharge. The reference condition is, however, very often difficult to establish and consequently the quantification of ranges is also difficult. As a surrogate for the percentage of some 'natural' reference condition, the species richness may be quantified as a percentage of overall species in the country or geographical zone, or established by professional judgment.
Human population density in the entire river basin as a percentage of the population density in the main floodplains	<10% 10–20% 20–40% 40–60% >60%	1 2 3 4 5	Can be estimated using Census data. Districts located primarily in floodplain areas can be used to estimate population density in floodplains, other districts - to estimate population density in the rest of the basin. It is assumed that this measure may be seen as an aggregate indicator of human pressure on aquatic ecosystems and as an indicator of disruption of lateral connectivity in river basins.
Overall water quality in the basin	Class A Class B Class C Class D Class E	5 4 3 2 1	National Indian categorization of water quality is used, where each class is characterized by certain ranges of constituents. Water in Class A can be used for drinking after disinfection; water in class B is only for swimming and bathing; water in Class C requires conventional treatment and disinfection before drinking; water in Class D is suitable for propagation of wildlife and fisheries; and water in class E is only suitable for such uses as irrigation and industry cooling.

The Study Basins

The river basins which have been selected for this study include Krishna, Cauvery, Narmada, Periyar and part of Ganga. The selection has been based primarily on availability of expertise and data for each basin. The attempt, however, has been made to ensure the geographical spread of basins throughout the country, the range of catchment sizes, degrees of development and environmental issues. Most of the selected basins are earmarked for interbasin water transfers under the National River-Linking Project (NRLP).

The methods of estimation of individual indicators have varied slightly between the basins, due to varying degrees of data availability, differences in the specifics of the basin as well as in professional judgment. In some cases, attempts have been made to evaluate additional indicators, such as *aquatic plant species or phytoplankton richness* (e.g., Narmada). In some river basins, certain indicators could not be estimated (e.g., *degree of river fragmentation* in Krishna and Cauvery). These specifics are reflected in individual basin sections. However, every attempt was made to maintain the full spectrum of indicators for each river basin. In the light of many data uncertainties, the scoring system used here should be regarded as tentative and the entire approach, as still developing. In most of the cases, the indicators have been assessed at the basin-scale, which is obviously very coarse. But the same principles can be applied at smaller scales (subbasins or reaches), as illustrated with examples from Krishna and Cauvery rivers basins.

Krishna River Basin

The Krishna River originates in the Western Ghats at an altitude of 1,337 meters (m) above sea level, and flows to the Bay of Bengal through the peninsular states of Maharashtra, Karnataka and Andhra Pradesh. The total length of the river is approximately 1,400 km, and the total catchment area is 258,948 square kilometers (km^2). The interior of the basin is a plateau, which is at altitudes of 300–600 m above sea level. The river basin receives the major portion of its rainfall (up to 80% of the annual total) during the southwest monsoon period, which lasts from June to September.

Additional primary ecological data (Arunachalam 1999, 2004) exists for the Tungabhadra subbasin (one of the main tributaries of the Krishna River) and it has been evaluated separately. Each subbasin (Tungabhadra and the remaining part of the Krishna) has been additionally separated into three parts: 1) the headwater areas with a number of streams smaller than 10 km^2 (Arunachalam et al. 2005); 2) the middle reaches affected by reservoirs; and 3) the lower reaches (including delta), where development impacts are most pronounced (figure 1). Each of the aforementioned areas has been studied in several subbasins, where field data collection had been carried out earlier (Arunachalam 1999, 2004). The presence of rare, endangered and unique aquatic biota has been rated on the basis of fish catch data summarized in the assessment of 327 species of freshwater fishes found in India (CAMP 1997) using the IUCN (1994) categories. The diversity of aquatic habitats has been studied in the field by Armantrout (1990) and Arunachalam (1999, 2000a, 2000b, 2004) using selected 100-m reaches of Krishna, Bhima, Tunga, Bhadra and other rivers in the basin. The proportional abundance of habitat types in the three areas (headwaters, middle and lower) has been estimated using the mean value of available habitats in several streams studied in each area (Jayaram 1995). The scoring system for habitat diversity is based on Arunachalam (2000a, 2000b), who has studied aquatic habitats for peninsular rivers in India and has identified their main types. The degree of regulation was not possible to estimate at the accepted separation of the basin due to uncertainties with the flow estimates at required river points. The estimation of other indicators is explained in tables 1–3.

FIGURE 1.
A schematic map of the Krishna River Basin, showing the boundaries of the two main subbasins (Tungabhadra and the remainder of Krishna), separated into headwater, middle and lower areas for this study.

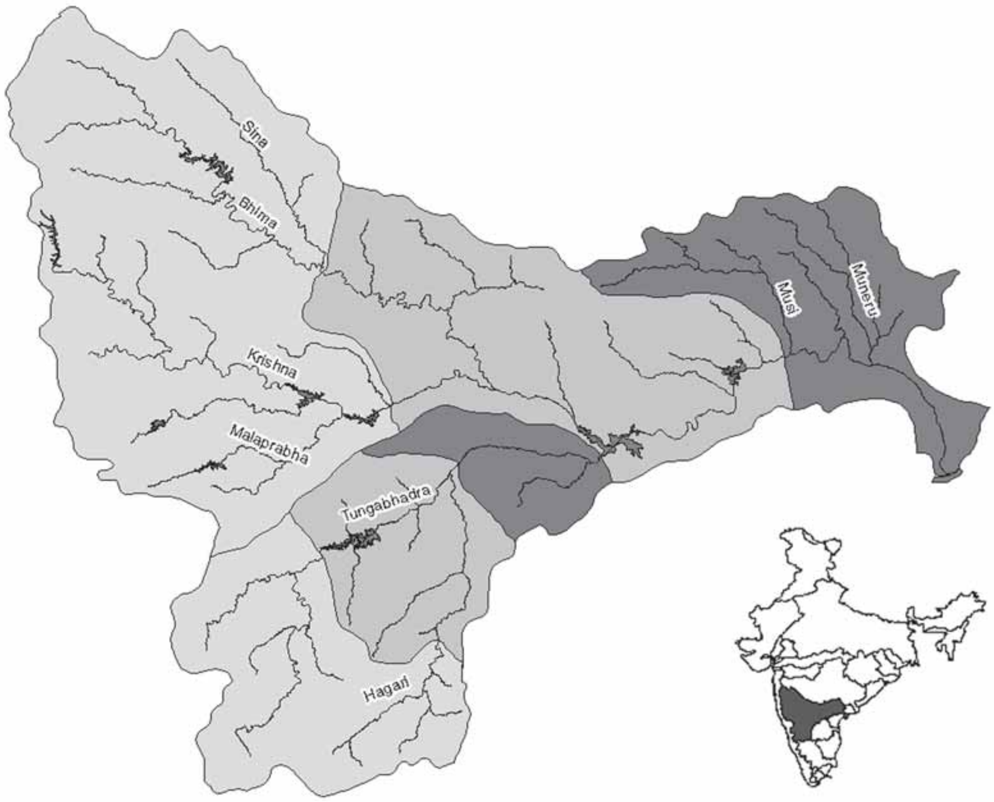


TABLE 2.
Indicators for the Tungabhadra subbasin of the Krishna River Basin.

Indicator	Value	Score	Justification and Comments	Data Sources
Rare and endangered aquatic biota			An arbitrary but quantitative scoring system is used based on the percentage of endangered fish species of the total species in the basin (>20% endangered species—very high, 10–20%—high, 5–10%—moderate, 2–5%—low and <2%—minor or none).	Arunachalam (2004) CAMP (1997)
	High	4	Of the total 118 species in the subbasin, 12 are endangered and critically endangered in the headwaters (10.1%).	Arunachalam et al. (2002)
	Moderate	3	In the middle reaches, 5 endangered species are represented (4.2%).	
	Low	2	In the lower reaches only 3 such species are represented (2.5%).	
Unique aquatic biota			A similar scoring system is used as for endangered species—based on a percentage of unique fish of the total fish species in the basin (>20% endangered species—very high, 10–20%–high, 5–10%—moderate, 2–5%—low and <2%—minor or none).	Arunachalam (2004) CAMP (1997)
	Moderate	3	Out of 118 fish species, 9 endemics (7.6%) are present in the headwaters.	Arunachalam et al. (2005)
	Minor	1	In the middle and lower reaches, 2 endemic species (1.7%) are present. Headwater reaches support more unique fauna because the streams in the Western Ghats are mostly bedrock valleys	

(Continued)

TABLE 2. (Continued)
Indicators for the Tungabhadra subbasin of the Krishna River Basin.

Indicator	Value	Score	Justification and Comments	Data Sources
			and are strongly confined. Out of 11 endemic species 5 species (*Barilius canarensis, Glyptothorax trewavsae, Botia straita, Longischistura bhimachari* and *Hypselobarbus dobsoni)* have narrow distribution.	
Diversity of aquatic habitats	High	4	In the upstream reaches of Tunga and Bhadra, falls, cascades, pools, riffles, glides, runs and 'pocketwater' are all present.	Arunachalam (2004)
	Moderate	3	In the middle reaches, reservoir habitat types are wetlands and deepwater, while downstream of reservoirs and the reaches in between—runs, deep pools and backwater habitats are present.	Jayaram (1995) Scott (1989)
	Minor	2	In the lower reaches, the only habitat types are runs with fine sand and occasional large pools.	Arunachalam et al. (2005)
Presence of protected and pristine areas	1–3%	2	The subbasin has 1.62% as protected area with two wildlife sanctuaries (Bard and Ghataprabha) and the Kudremukh National Park. More forests can be protected as buffer zones of the Kudremukh National Park and sanctuaries.	Arunachalam (2004) Manjrekar (2000) Jayaram (1995)
Percentage of watershed remaining under natural vegetation	70–00%	5	In the headwaters almost all the streams are under natural cover type (90%).	Arunachalam (2004)
	50–70%	3	In the reservoirs and the reaches 10–15 km downstream of them, the percentage of natural cover is under 65%, but in most of the middle reach the percentage is under 50%.	Jayaram (1995)
	10–30%	2	In the lower reach in the Karnataka part up to the confluence of Tungabhadra with Krishna river: 28–30%.	(for middle and lower reaches)
Percentage of floodplain remaining under natural vegetation			Floodplains are present in the middle and lower reaches only.	
	30–50%	3	Middle reaches before the Tungabhadra Reservoir.	
	10–30%	2	From the Tungabhadra Reservoir towards the AP boundary.	
Percentage of aquatic biota that are exotics	0%	5	In the headwater reach there are no exotic fish species.	Arunachalam (2004)
	<5%	4	In the middle reaches, particularly—in the reservoir sector—introduced species of *Cirrhinus mrigala, Labeo rohita* are present. But the proportion in rivers upstream and downstream of the reservoir is still small in spite of having introduced these species 40 years ago.	Sugunan (1995)
Fish species relative richness	50–70%	4	Upstream reach is represented by 68 species (57.6%) of the total 118 recorded in the subbasin.	Arunachalam (2004)
	70–100%	5	Middle reach is represented by 78 species (66.1%).	
	30–50%	3	Lower reaches are represented by 31 species (26.3%). A different scoring system should be designed, which is based on the total number of species present in India, or in the region. But the estimates of the total number of species nationally vary from 327 (CAMP 1997) to 577 (Arunachalam 2004). If the latter figure is used as a benchmark, the basin is estimated to support 20.4% of this total species.	Jayaram (1995) Ponniah and Gopalakrishnan (2000)
Human population density in the basin as a percentage of that in the main floodplains	<10%	1	Score is based on mean values from middle and lower reaches, which have an indicator value of 7%. Floodplains have been delineated using GIS.	District Planning Maps 2001, Karnataka. Census of India (2001)
Overall water quality in the basin	A	5	Headwaters are under relatively natural conditions with high levels of dissolved oxygen, low levels of TDS, very low alkalinity and no enrichment of nitrates and phosphates.	Arunachalam (2004)
	C	3	In the middle and lower reaches, non-point and point sources of pollution and nutrient enrichment from paddy fields contribute to the pollution.	Jayaram (1995) CPCB (1992)

TABLE 3.
Indicators for the Krishna River Subbasin (excluding Tungabhadra subbasin).

Indicator	Value	Score	Justification and Comments	Data Sources
Rare and endangered aquatic biota			An arbitrary but quantitative scoring system is used based on the percentage of endangered fish species of the total species in the basin (>20% endangered species—very high, 10–20%—high, 5–10%—moderate, 2–5%—low and <2%—minor or none).	Arunachalam (1999) Arunachalam et al. (2002)
	Low	2	In the headwater reaches, based on surveys of 15 streams, 5 endangered species (3.6%) are identified (out of the total 140 species in the subbasin).	Arunachalam (2004)
	Moderate	3	In the middle reaches downstream of the reservoirs in Maharashtra and Karnataka 11 endangered species present (7.9%).	Jayaram (1995)
	Moderate	3	In the lower reach below the Tungabhadra River confluence with Krishna River 10 endangered species (7.1%) are present.	CAMP (1997)
Unique aquatic biota			A similar scoring system is used as for endangered species—based on the percentage of unique fish of the total fish species in the basin (>20% endangered species—very high, 10–20%—high, 5–10%—moderate, 2–5%—low and <2%—minor or none).	Arunachalam (1999) Arunachalam et al. (2002) Arunachalam (2004)
	High	4	In the headwaters, 11 unique species out of the total 140 (7.9%) are present.	Jayaram (1995)
	Low	2	Middle and most of the lower reaches are represented by 4 species (2.8%).	CAMP (1997)
Diversity of aquatic habitats	Very high	5	In the headwaters a number of streams surveyed exhibit pools, riffles, glides, runs, alcoves/'pocketwater', etc.	Arunachalam (2004)
	High	4	Below the confluence with Tungabhadra, several streams were surveyed which have deep pools, falls cascades, riffles, rapids and glides.	Jayaram (1995)
	Low	2	In the lower reaches habitats are mostly riparian wetlands and wet hollows in delta.	
Presence of protected and pristine areas	<1%	1	In the headwaters, 0.97% of the area is protected with 5 wildlife sanctuaries (Koyna, Bhimsankar, Phansad, Radhnagiri and Chaprala).	Manjrekar (2000)
	3–5%	3	Nagarjunasagar Reserve is 4.7% of the area of the middle reaches.	Revenga et al. (1998)
	<1%	1	Mangrove ecosystem in the delta which needs to be protected has an area of 200 km^2. It could be considered for maintenance by means of environmental flow releases.	
Percentage of watershed remaining under natural vegetation	50–70%	4	Many headwater streams surveyed have the range of 55–68% of natural cover types.	Arunachalam (2004)
	30–50%	3	Middle reaches—below the Dhom Dam and Wai Town have the range of 38–47%.	Jayaram (1995)
	10–30%	2	Two streams surveyed in lower reaches had a range of 18–28% of natural cover types.	NSII (1991)
Percentage of floodplain remaining under natural vegetation			Floodplains are rare in the headwaters of Krishna and Bhima.	Arunachalam (2004)
	30–50%	3	In middle reaches in Maharashtra, most of the floodplains are flood hollows with natural cover types. In middle reaches in Karnataka below the impoundments, extensive cultivation of Bengal gram in the floodplain areas.	http://www.annauniv.edu
	10–30%	2	Below the confluence of Tungabhadra and Krishna and up to the Nagarjunasagar Reservoir. Overall, approximately 55% of the existing floodplains are under natural cover—mainly due to natural cover in protected areas and mangrove forests in the delta.	

(Continued)

TABLE 3. (Continued)
Indicators for the Krishna River Subbasin (excluding Tungabhadra subbasin).

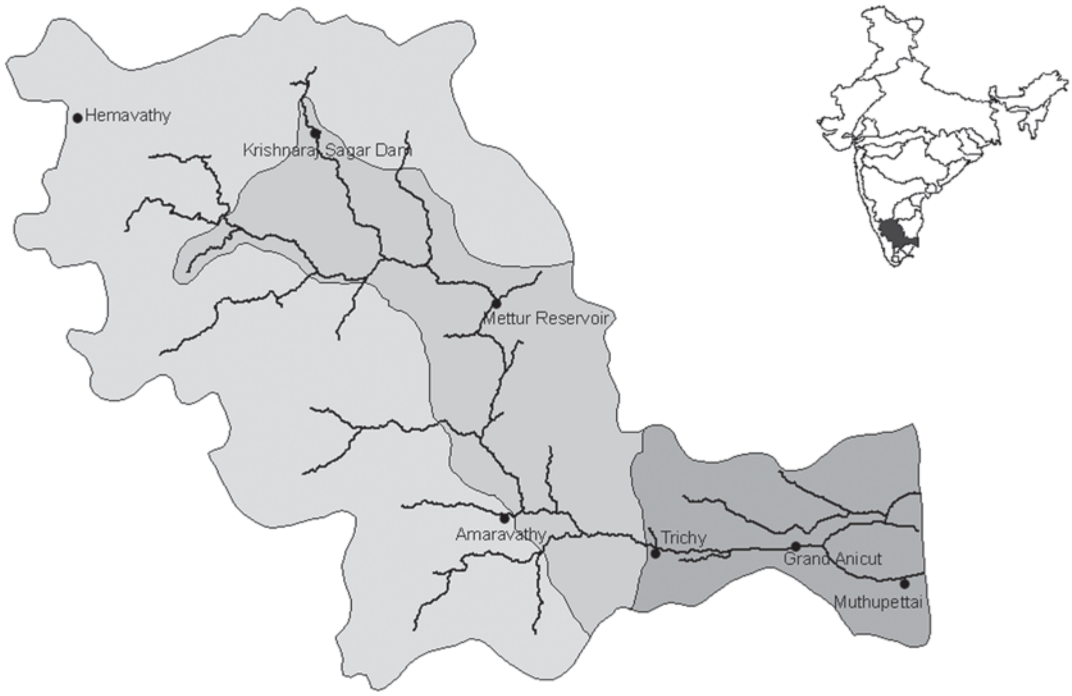
Indicator	Value	Score	Justification and Comments	Data Sources
Percentage of aquatic biota that are exotics	0%	5	In the headwaters there are no exotic fish species.	Sugunan (1995)
	<5%	4	In the middle reaches, including the reservoirs, the proportion of introduced species of *Catla catla*, *Cirrhinus mrigala, and Labeo rohita* is small. Native fish dominate the commercial fish catch.	Jayaram (1995)
	<10%	3	In the lower reach introduced species of Gangetic carps form 30% of the commercial catch. *Pangasius pangasius,* a native pangasid catfish, constitute the major catch. In the delta, native marine and estuarine species are the major faunal component.	
Fish species relative richness	30–50%	3	The headwaters have some 41% of the total species in the basin.	Arunachalam et al. (2002)
	70–100%	5	The middle reaches support 71.4% of the total.	
	30–50%	3	The lower reach has around 41% of the total species in the basin. In the delta no primary freshwater species are present, but 40 estuarine and coastal marine species are recorded. A different scoring system should be designed, which is based on the total number of species present in India, or in the region. But the estimates of the total number of species nationally vary from 327 (CAMP 1997) to 577 (Arunachalam 2004). If the latter figure is used as a benchmark, the basin is estimated to support 24.2% of total species.	Arunachalam (1999) Arunachalam (2004) Ponniah and Gopalakrishnan (2000)
Human population density in the basin as a percentage of that in the main floodplains			In the headwaters floodplains are rare.	NSII (1991)
	20–40%	3	In the middle reach this proportion is 25.9%.	
	40–60%	4	In the lower reach this proportion is 43.6%.	
Overall water quality in the basin.	A	5	In all the headwater streams, the water quality is close to natural conditions.	Department of Environment (2004)
	C	3	Upstream of impoundments at Yadgiri Town (Bhima River), Haripur Ghat (Krishna) and below the reservoirs, Krishna River at Wai are polluted by sewage. In the middle reaches point sources from industries and sewage from towns exist.	Andhra Pradesh CPCB (1992)
	E	1	In the lower reaches textile, sugar and manganese mixing industries are sources of pollution.	Jayaram (1995)

Cauvery River Basin

The Cauvery River, with a total basin area of 87,900 km^2, originates from the Western Ghats in Karnataka State and extends over parts of Tamil Nadu and Kerala. The river flows through small patches of upstream jungle and gorges, followed by predominantly vast monotonous plains—into a diverse delta with Pichavaram mangroves. As in the case of the Krishna River, for this study, the Cauvery River Basin too, is broadly categorized into headwater, middle and lower (delta) areas. Several experimental subbasins have been studied (figure 2) to determine the representative scores for each of the three areas.

The studies of the Cauvery River ecology mainly focused on fish (Hora 1942; Rajan 1963; Easa and Shaji 1995), and with more recent reports on the invertebrates (Jayaram 2000; Sivaramakrishnan et al. 1995). As in the Krishna Basin, CAMP (1997) data have been used, CR and EN and unique fish species (IUCN 1994) found in different experimental subbasins have been identified and their proportion of the total number of species has been calculated.

FIGURE 2.
A schematic map of the Cauvery River Basin, showing the boundaries of headwater, middle and lower areas and sites where field data were collected.

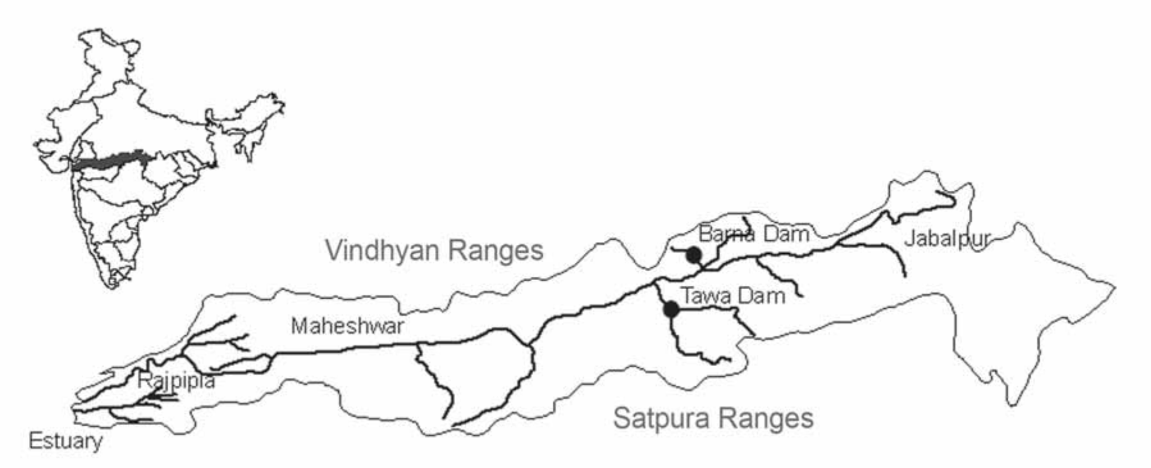


A number of fish species in more than 50 sites in the headwater subbasins and 30 sites in the middle and lower reaches have been used to evaluate the overall fish richness (Arunachalam 1999, 2004; Jayaram 2000) as a proportion of the overall species reported in India. The averages of these proportions have then been calculated for headwater, middle and lower areas, to produce the representative indicator values. The diversity of aquatic habitats has been evaluated by estimating the number of different habitat types present in the same reaches from all three areas, based on the scoring system proposed by Arunachalam (2000a). The percentage of watershed and floodplain remaining in natural cover types has been calculated as the mean value of this percentage in experimental subbasins of headwaters and middle areas, based on field surveys by Arunachalam (2004). For the lower area, these indicators are assessed from the literature of Jayaram (2000). The percentage of exotic fish species is calculated (as in the case of rare and endangered species) using the primary data by Arunchalam (2004), and the published literature of Sugunan (1995) and Sreenivasan (1989). Six districts in Karnataka, three districts in Kerala, seven districts in Tamil Nadu and one district in Pondicherry have been used to approximate the human population density in the floodplains of the main river and its tributaries (NSII 1991). Other indicators are estimated as explained in tables 1 and 4.

Narmada River Basin

The Narmada River, with a catchment area of 94,235 km^2 and total length of 1,312 km, is the largest west flowing river on the Indian Peninsula (figure 3), crossing three states—Madhya Pradesh (MP), Maharashtra (MS) and Gujarat (GS). The climate ranges from temperate at the source to subtropical at the outlet. The rainfall

FIGURE 3.
A schematic map of the Narmada River Basin.



varies from between 1,400–1,700 millimeters (mm) in the upstream parts to approximately 130 mm in the estuary. Narmada flows through the only rift valley of India, which is the alluvial tract between Jabalpur and Handia. It is over 320 km long and approximately 80 km wide, and is the most intensely cultivated part of the basin. In the estuarine part, the main river course divides into two branches before joining the sea. Although, the altitudes are generally under 1,000 m above mean sea level (amsl), Narmada is essentially a mountainous river tucked between the two ranges. The banks of Narmada are stable and the river lacks floodplains, which are extensive in other major Indian basins. Pools and waterfalls are the other characteristic features of Narmada.

Through most of its course, Narmada has prime quality forests that facilitate the maintenance of its flow throughout the year. These forests are unique for India and are rich in biodiversity, hosting panthers, sloth bears, sambars, barking and spotted deer, black bucks, wild boar, porcupines, foxes, hyenas, tigers, wildcats (including the endangered caracals), flying squirrels, jackals, blue bulls, the four-horned chinkara (the Indian gazelle) and many others. The prime forest area at Khandwa—the Chandragharh Forest—supports the endemic tree species of Anjan (*Hardwickia binata*), which attain considerable heights.

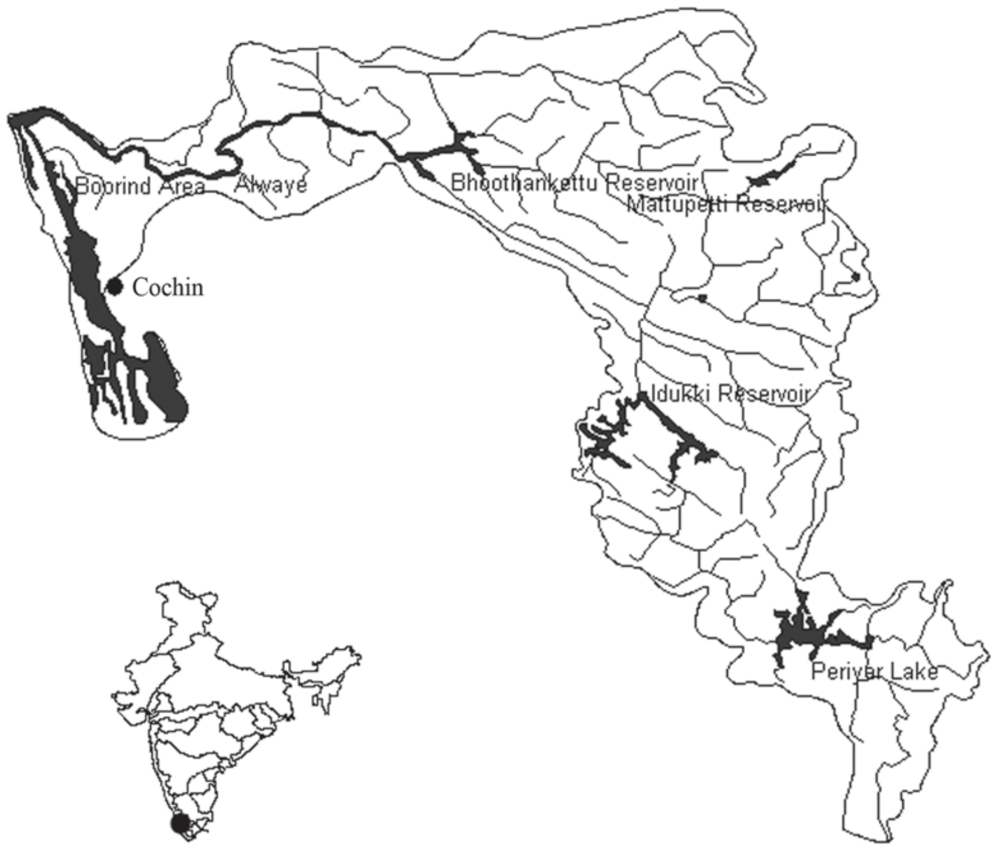
Narmada basin hosts some 20 million people, of which the majority is tribal people who depend entirely on the river and its forests for their livelihood. The population stress on the river is, however, low compared to other basins in India. Narmada has only three townships, and in two of these the population is less than 70,000 as per 1991 census. Only the major city of Jabalpur has a population of over 0.7 million.

This mean annual river flow of over 45.6 billion cubic meters (BCM) remains largely untapped at present, although heavily committed for development. Over the next few decades, the construction of 29 large, 450 medium and some 3,000 minor dams is planned (Alvares and Billorey 1988). At present, the major regulation structures in the basin are limited to the Barna and Tawa dams (on tributaries), constructed in the 1970s and the Bargi Dam on the main stream, completed in 1991. The estimation of indicators for Naramada basin in explained in tables 1 and 5.

Periyar River Basin

The Periyar River (figure 4) with a total catchment area of 5,243 km^2 and a length of under 300 km, originates at an altitude of

FIGURE 4.
A schematic map of the Periyar River Basin. The black areas near Cochin are backwaters.



1,830 m amsl in the Western Ghats. The annual rainfall ranges from 4,000 mm in the upstream parts to 200 mm in the coastal areas. The basin is located primarily in the Kerala State. Kerala has 41 west flowing rivers carrying a total annual discharge of 72.7 BCM—higher than the total flow of large rivers like Cauvery or Krishna (Sugunan 1995). The Periyar mean annual flow volume of 12.3 BCM is the largest among the river basins in the Western Ghats.

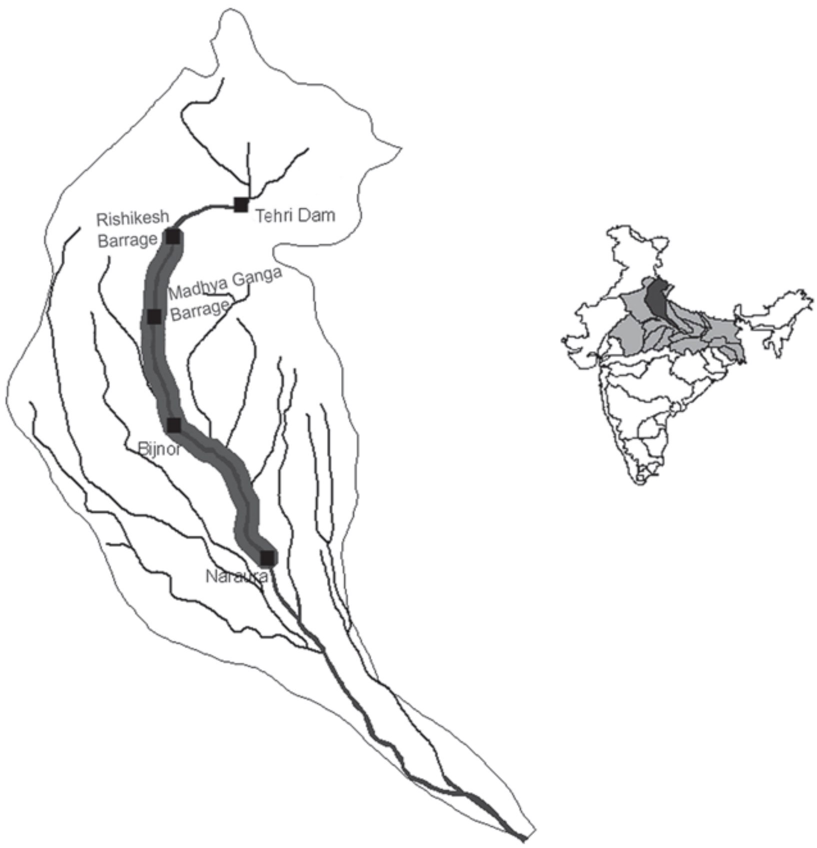
The characteristic feature of the basin is the Western Ghats' forests, where about 70 percent of the trees are endemic to the region (due to its geographic barriers), and where streams are home to a number of endemic fishes (Pascal 1996). The Periyar Lake in the upstream part of the basin is surrounded by such forests, renowned for sanctuaries like the Tiger Reserve—one of the 18 biodiversity hotspots of India (Pascal 1996), a home for several endangered species. More downstream, the river meanders through Malayattoor, Kalady and Alwaye—which are holy places of worship, attracting up to 50 million pilgrims annually. In its most downstream parts, the river flows through the 'Eloor industrial belt' into the Cochin estuary. The basin has 9 irrigation schemes and 16 hydroelectric projects. The total volume of all reservoirs in the basin is estimated to be 3.28 BCM (KSEB 2005). Of these, the Idukki Reservoir is the largest (around 2 BCM). Compared to other rivers in the Western Ghats, Periyar is relatively better studied ecologically. The estimation of indicators for Periyar is explained in tables 1 and 6.

Ganga River Basin (Rishikesh to Naraura Reach)

Ganga is the longest (2,525 km) river and the largest river basin in India. It supports over 300 million people across its 800,000 km^2 catchment area in India, and also extends into Bangladesh, China and Nepal. The mean long-term annual river flow is estimated to be 525.0 BCM. The live storage capacity in the basin has increased significantly over the past 50 years—from 4.2 to 37.8 BCM (http://wrmin.nic.in). In addition, a substantial storage capacity of over 17.0 BCM will be created on completion of the current projects, while an additional storage of over 29.6 BCM is planned (http://wrmin.nic.in) for the future. Therefore, after the construction of all currently proposed dams, about 30 percent of the annual utilizable flow (i.e., 250 BCM) could be stored.

The above developments will threaten the aquatic ecology of the basin. However, very few ecological studies have been conducted in the basin to date. While the entire basin should ideally be considered for ecology studies, it is not possible to do so in a limited study like this one. As an *imperfect* substitute for the basin-wide study, an attempt has been made here to describe the ecological value and condition of a 295 km stretch of the Ganga, between Rishikesh and Naraura, where WWF-India has been coordinating the Dolphin Conservation Program (figure 5). The area covered under the study is about 16,780 km^2 in the Uttar Pradesh and Uttaranchal States.

FIGURE 5.
A schematic map of the Ganga River Basin, showing the location and extent of the subbasin upstream of Naraura as well as the enlarged map of the Ganga reach between Rishikesh and Naraura reaches.



Some ecological information can be derived or inferred from sources like Behera (1995), Payne et al. (2003), and Rao (1995). These have been supplemented by other, more 'global' sources, like the World Resources Institute's Earth Trends database and its publications as well as Dudgeon (2000), Menon (1999, 2004), Kottelat and Whitten (1996), and Nilsson et al. (2005). In addition, the Census of India (2001) and maps from National Atlas and Thematic Mapping Organisation (NATMO) have been used. In the study reach itself (the 295 km stretch of the Ganga, between Rishikesh and Naraura), there are no major water storage dams, except for he Tehri Reservoir, which is located upstream.

Indicators and Trends in Study Basins

Krishna River Basin

Tables 2 and 3 summarize the results for Tungabhadra subbasin and the rest of Krishna River Basin, respectively. Both subbasins are more natural in the upstream areas, with diverse and relatively unfragmented habitat, limited or no exotics and a high percentage of natural cover types. Both subbasins are broadly similar in most of the indicator scores, which have a clear tendency to deteriorate downstream with the progressive increase of human pressure. The exception is the higher richness of fish in both subbasins in their middle reaches, which is partially due to the effects of tributaries that create more diverse and deeper habitats. In the lower reaches, however, species richness drops due to overfishing that occurs downstream of reservoirs and the impacts of urbanization. The practice of using trawl nets with a small mesh size (8–10 mm), for example, almost eliminates the entire fish population (Arunachalam, personal observations). In the Krishna subbasin, the middle reaches support more species than the headwater and lower reaches, primarily due to the increasing size of the streams that still remain in a more natural condition compared to the lower areas. The lower reach, including the delta (Jayaram 1995), has limited freshwater species, but is represented by 40 species of brackish and coastal marine fish.

Overall, the pressure in the upstream parts of the basin has been relatively limited compared to the lower reaches, where the deteriorating trends are alarming. River discharge, for example, has been decreasing at the outlet from 1968 onwards. In addition, water-sharing conflicts exist between the states of Karnataka and Andhra Pradesh. The major flow of water is obstructed by the increasing number of large- and medium-sized dams, which has completely changed the sediment regime of the river and fragmented its habitats in the middle and lower reaches. Krishna delta, with a mangrove forest area of some 200 km^2, faces threats of deforestation, overgrazing, harvesting of juvenile fauna and expansion of agriculture and shrimp aquaculture.

Cauvery River Basin

Field studies in the streams of the Cauvery River Basin, from the headwater reaches to their outlets, revealed significant habitat heterogeneity, which is exploited by guilds of fish species (table 4). Headwaters tend to support more endangered fishes and, as such, these streams can be used as 'reference sites' for the entire basin. These headwater streams have high gradients and predominantly bedrock substrates, and endangered fishes are confined to such rocky stream types. Similar sites are found in

TABLE 4.
Indicators for the Cauvery River Basin.

Indicator	Value	Score	Justification and Comments	Data Sources
Rare and endangered aquatic biota			A similar scoring system as in tables 2 and 3 above has been used.	CAMP (1997)
	High	4	Streams in headwaters have 16 endangered fish species (12%) out of a total of 135 species in the basin.	Arunachalam (1999, 2004)
	Moderate	3	The reservoirs Hemavathy, Kabini, Krishnarajasagar, Markonahalli and Harangi, and streams below them in the middle reaches, support 8 endangered species (6%).	
	Low	2	In the lower reaches, only 3 endangered species are found (2%). Common tolerant species such as *Pseudophromanus cupanus, Puntius filamentosus,* etc., occur in lower reaches. Near delta, no rare and endangered freshwater fish species are present.	
Unique aquatic biota			A similar scoring system as in tables 2 and 3 above has been used.	CAMP (1997)
	High	4	Headwater reaches host all 22 species that are endemic native fish (16% of total basin species).	Arunachalam (1999, 2004)
	Low	2	Middle reaches have 6 endemic species (4.5%).	
	None	1	Lower and coastal areas have no unique fauna.	
Diversity of aquatic habitats	Very high	5	In headwaters, habitats are diverse with falls, cascades, pools, riffles, glides, runs and 'pocketwater'. Bedrock and boulders and the leaf litter with woody debris contribute to fish habitat heterogeneity in headwaters (Western Ghats).	Arunachalam (1999, 2000b, 2004)
	Moderate	3	In the reservoirs, the habitat types are wetlands (limnetic zones) and deepwater (euphotic zone). In the middle reaches of the river, run, deep pools and backwaters are prevalent.	Arunachalam et al. (2005)
	Moderate	3	In lower reaches, most habitats are riparian wetlands and floodplains with runs, mangrove swamps and lagoons contribute to habitat heterogeneity.	
Presence of protected and pristine areas	5–10%	4	Compared to the overall watershed area, the headwaters have some 7.8% of the area protected with seven wildlife sanctuaries (Biligiri Rangaswamy, Brahmagiri, Cauvery, Nugu, Thalacauvery, Mudumalai and Wynaad) and four National Parks (Bandipur, Rajiv Gandhi (Nagarhole), Mukurthi and Silent Valley).	Manjrekar (2000) Dave (1957)
	<1%	1	Kaveri-Poompattinam—the ancient capital of the Chola Kingdom in the estuary. Pichavaram mangroves and the lagoon in the Vedaranyam Wildlife Sanctuary are the major protected spots or heritage sites. Vedaranyam Swamps and the Muthupet Lagoon can be declared as RAMSAR sites.	
Percentage of watershed remaining under natural vegetation	70–100%	5	In the headwater reaches almost all streams surveyed are under natural cover in the range of 74–85%. Only tea and coffee plantations reduce this proportion.	Arunachalam (2004)
	30–50%	3	In some streams surveyed in the middle reaches, this percentage is up to 53%, but the lowest part of the middle reaches—20 km from the reservoir towards coastal area—is under 50%.	Jayaram (2000)
	<10%	1	Estuarine area has a low natural cover proportion, only mangrove forest Pichavaram and distributaries raise it up.	
Percentage of floodplain remaining under natural vegetation			Floodplains are present only in middle and lower reaches.	Arunachalam (2004)
	30–50%	3	From Mayanoor to upper anicut, the floodplains are less than 50% under natural vegetation. This stretch forms about 30–40% of the overall floodplains in the basin.	Jayaram (2000)
	<10%	1	Below the Grand Anicut floodplains are impacted by rice and banana cultivation. In the delta region floodplains are mostly converted into shrimp farms.	

(Continued)

TABLE 4. (Continued)
Indicators for the Cauvery River Basin.

Indicator	Value	Score	Justification and Comments	Data Sources
Degree of flow regulation	10–20%	4	Taken from the cited source as is (19%). More detailed estimation was not possible due to uncertainties or absence of flow estimates at required points in the basin.	Nilsson et al. (2005)
Percentage of aquatic biota that are exotics	>0% <5%	5 4	In the headwaters there are no exotic fish species. In the middle and lower reaches, all channels below impoundments and the entire river from Bhavani Town, the proportion of exotic fishes are low (<5%). (Almost all reservoirs are dominated by introduced exotics and gangetic carps. Of 58 species recorded in reservoirs, the introduced species form some 41%. In the biomass of commercial catch the introduced species constitute 80–90% and the native species—less than 5%).	Arunachalam (2004) Sreenivasan (1989)
Fish species relative richness	50–70% 50–70% 10–30%	4 4 2	Headwaters host 68 species (50% of the total in a basin). The middle reaches host 72 species (53% of the total). Approximately 18% in the lower reaches (but in the delta—less than 5%). A different scoring system should be designed, which is based on the total number of species present in India, or in the region. But the estimates of the total number of species nationally vary from 327 (CAMP 1997) to 577 (Arunachalam 2004). If the latter figure is used as a benchmark, the basin is estimated to support 23.62% of total species.	Arunachalam (1999, 2004) Jayaram (2000) CAMP (1997) Ponniah and Gopalakrishnan (2000)
Human population density in the basin as a percentage of that in the main floodplains	40–60%	4	Estimated for middle and lower reaches only. In the lower reaches, the ratio is 42.4% and in middle—51%.	NSII (1991)
Overall water quality in the basin	A C D	5 3 2	Most of the headwater streams surveyed have high levels of dissolved oxygen, low levels of total dissolved solids, very low alkalinity and hardness and no enrichment of nitrates and phosphates. In the middle reaches, non-point and point sources of pollution increase. High pollution from industries in the stretch of delta except the Pichavaram mangroves and the Muthupet lagoon regions.	Arunachalam (2004) Jayaram (2000) CPCB (1992)

the middle areas, but to a lesser extent. In the lower reaches, however, fish diversity and their formerly abundant population are declining.

Most protected areas are found in the headwaters, less than one percent is found in the middle and lower reaches, while the mangrove swamps of Pichavaram and Muthupet lagoons—are protected by the State Forest Department. Some pristine areas may still be declared protected in the upstream areas (e.g., in the catchments of Moyar, Bhavani and Amaravathi streams). In the middle and lower reaches there are a few heritage sites such as the Vishnu Temples at Srirangapatnam, Sivasamudram and Srirangam; and Kaveri-Poompattinam (an ancient capital of the Cholas Kingdom in the first century AD). Most of the headwaters are still under natural vegetation cover, but the pressure from human settlements is increasing progressively downstream.

Perhaps the major basin-specific feature that is adversely affecting basin ecology is the expansion of coffee, tea and, to a limited extent, cardamom plantations. The high elevation in the upstream parts of Cauvery creates ideal conditions for these cultures. These developments, due to the removal of riparian forests, may lead to denudation. In addition, the associated population growth may lead to the abstraction of water from first and second order streams for domestic use, while the increased waste loads may eliminate the endemic fauna. Habitats in the headwaters are still up to 70 percent in an undisturbed condition. This is analogous to habitat intactness and can be regarded as wilderness (Mittemeier et al. 2003), hence needs protection.

Cauvery River at present is highly fragmented by various impoundments (Kathiresan 2000). While mangrove vegetation tends to be more luxuriant at lower salinities (Kathiresan et al. 1996), some areas in the delta are being degraded mainly due to high salinity levels, resulting from the reduced freshwater inflow (MSSRF 1998). A further reduction or a continuation of the current limited inflow will be detrimental to the coastal areas (Ittekkot et al. 2000).

Fishes upstream are affected directly by physical barriers (e.g., Lower Anicut, the Great Anicut and the Upper Anicut) to their migration, by the inundation or drying out of spawning grounds (upstream or downstream of dams), which is reflected by the poor species richness in the lower reaches. Some indigenous ichthyofauna (e.g., the anadromous fish, *Tenualosa ilisha,* or *Puntius* spp., which used to form 28% of the landings in 1943–1944) have completely disappeared from Cauvery after the construction of the Mettur Dam (Sugunan 1995). Population density in Cauvery is among the highest in the world (350 people/km^2 compared to the world's average of 42 people/km^2). The population growth is also 2.5 times the rate of the world's population growth as a whole, which is seen as a major threat to the vast native forests in the basin and a significant contributor to their disappearance in the not too distant future (Cincotta and Engelman 2000).

Narmada River Basin

Earlier studies of CIFRI (1993), NPA (1987), RRSL (1987), and Dubey (1993) did not identify any endangered, rare or unique species of fish in the basin. The only *rare* organism reported was the water monitor lizard, which lived in the estuary (Alvares and Billorey 1988). There is limited evidence, however, that up to 10 species in the basin may be classified as endangered and 8 of these as unique (Arunuchalam, unpublished data). Narmada and its main tributaries are rich in habitat types, which include pools, gorges, waterfalls, deep waters, etc. The river has a number of pristine and protected areas: it flows through Bandhavagarh National Park (430 km^2), Kanha Biosphere Reserve (940 km^2), Satpura National Park (524 km^2) and three forest reserves of Mandla, Seoni and Hoshangabad with areas of 110, 416 and 449 km^2, respectively. A number of protected areas and forest reserves on the one hand and the relatively low population density on the other hand, mean that the basin remains largely under natural cover. At present, Narmada has only a few structures and flow fragmentation is relatively low. However, the planned storage construction will increase flow fragmentation significantly. According to Rao et al. (1999), fishes of Narmada predominantly belong to the local endemic carp group (Mahseer, Hilsa and Catla) and Dubey (1993) reported that exotic fishes like grass or silver carp do not breed in the basin.

An attempt was made here to distinguish between fish, aquatic plants, phytoplankton and zooplankton species richness (table 5). The richness of *aquatic plants* is related to the degree of nutrients. Narmada has a relatively moderate aquatic flora (Unni 1996), reflected in a moderate score and range of 10–30 percent. This score, however, is based on observations at three sites in headwaters, while the data on other parts of the river are absent. The quantitative studies on *phytoplankton* (e.g., in Ganga) show high fluctuations and vary between thousands and millions of cells per liter, when correlated with the degree of pollution. The clear waters of Narmada have relatively lower numbers of phytoplankton. The distribution and composition of *zooplankton* indicate the status of water quality. The information on zooplankton is available for many Indian rivers. The

TABLE 5.
Indicators for the Narmada River Basin.

Indicator	Value	Score	Justification and Comments	Data Source
Rare and endangered aquatic biota	None	1	The CIFRI (1993) studies suggested that there are no endangered or threatened fishes. Some unpublished sources suggest that up to 10 species may be considered endangered.	Karamchandani et al. (1967) Dubey (1984) Rao et al. (1991)
Unique aquatic biota	None	1	There are no reports on unique aquatic fish biota in the Narmada Basin, though studies have been conducted over a 50-year period on distribution of fish species.	Chatterji et al. (1993) Nath and Shrivastava (1999) Dubey (1993)
Diversity of aquatic habitats	High	4	Narmada has diverse habitats, including pools, gorges, waterfalls and deep waters similar to other major river systems in India.	Rao et al. (1991, 1999) Unni (1996)
Presence of protected or pristine areas	>10%	5	The Narmada Basin includes many sanctuaries, and 38% of all forests are forest reserves.	Alvares and Billorey (1988)
Sensitivity of aquatic ecosystem to flow reduction	Moderate	3	The construction of the Tawa Dam resulted in a reduction of water depths and loss of carp breeding grounds, spawning and feeding in the central 240 km stretch of the Narmada Basin. Carp dominates Narmada fish and flow reduction is the reason for reduced carp fisheries.	Nath and Shrivastava (1999)
Percentage of watershed remaining under natural vegetation	10–30%	2	The National Remote Sensing Agency reported that 21% of the Narmada Basin has natural forest cover types. Others quote 38%. The likely average is around 30%.	Forest Department, Government of Madhya Pradesh Reconnaissance Survey. Alvares and Billory (1988)
The degree of flow regulation	0–10%	5	Calculated as the ratio of total storage to long-term mean annual flow at the outlet. The actual live storage capacity in 2006 is 2.07 BCM. Annual mean outflow is 45.6 BCM, and the ratio is around 4.5%.	CWC (2006)
Percentage of watershed closed to movement of aquatic biota by structures	10–30%	4	At present, this indicator is low and the score is thus high, but if the reservoir construction goes as planned, the entire river basin will be fragmented and the percentage of watershed closed could grow up to 100%.	Alvares and Billorey (1988)
Percentage of aquatic biota that are exotic	None	5	No exotic fish species have been reported.	Rao et al. (1991) Dubey (1993)
Species' relative richness, including fish, aquatic plants, phytoplankton and zooplankton	Moderate	3	Narmada has 76–84 fish species according to existing estimates, which is relatively low compared to the total number of species in India (<14%). It supports 19 species of aquatic vegetation, relatively low compared to other rivers. The total number of Phytoplankton species is 174 in the upstream and declines towards the middle stretches. Greater water current reduced the phytoplankton numbers to 34 species downstream. Zooplankton: maximum number of 72 rotifer species is reported only from Narmada and nowhere else in India. Four new species of zooplankton have recently been identified. The likely overall score of aquatic species richness in the basin is moderate.	Nath and Shrivastava (1999) Dubey (1984) Unni (1996) Sharma and Naik (1995) Dubey (1993)

(Continued)

TABLE 5. (Continued)
Indicators for the Narmada River Basin.

Indicator	Value	Score	Justification and Comments	Data Source
Overall water quality in the basin	Class B	4	Class A is from the source to Mandla (200 km), class C from Mandla to Jabalpur stretch (100 km), class B—the stretch up to the confluence with Kunti River (540 km), class C from confluence with Kunti River up to Bharuch, and class D—downstream of Bharuch (8 km). Overall water quality is class B (40% under class C, 40% under class B and about 20% under class A),	

characteristics of zooplankton for the Narmada reflect a good condition at present. The diversity of naturally occurring periphytic algae and diatoms as well as the diversity of naturally occurring zooplankton are, however, quite high in Narmada waters. Despite the limited data on actual constituents, the overall water quality is good (Unni 1996) and mostly free from pollution throughout its course, except for a small estuarine part of over 20 km.

Neither significant changes nor rapid developments are likely in the Narmada River Basin, since even basic infrastructure, like roads, is lacking. The hilly terrain of the basin is a major disadvantage for development. Agriculture is the main source of livelihood for the local ethnic groups. Fast urbanization is unlikely, and the negative impacts of existing towns on the river (e.g., on water quality) will be limited even in the next 25 years. At the same time, a large number of mainstream dams, if constructed without provisions of fish ladders and environmental flow releases, will definitely have adverse impacts on the river ecology. Lack of flow, decline in dominant fisheries, lentic conditions in dams and resultant eutrophication and waterborne diseases are some of the potential negative impacts in the long-term.

Periyar River Basin

For a relatively small basin, Periyar has a number of endemics and several threatened species (Kurup et al. 2001) as well as a range of various habitat types (table 6). Thirty percent of the basin area is covered with dense pristine forests, parts of which are crossed by the river, and include wildlife sanctuaries. Like other west flowing rivers, the Periyar has no floodplains. The introduction of exotic fishes into reservoirs has lead to a decline in the abundance of endemic fishes. However, in the Periyar River itself, the exotics have not been reported so far. Various sources have reported variable numbers of fish species in different parts of the basin, varying from 27 in the Periyar tributaries, to 150 in the downstream parts (Arun 1998; Arunachalam 2000b). The basin is rich in fish species, hosting approximately 70 percent of the species found in the Western Ghats and a significant proportion of the species found in India. In addition, CAMP (1997) identified a variety of endemic species found in the Periyar. As such, a proposition was made to declare the upper reaches of the Periyar, a fish sanctuary (Joseph 2004). However, no aquatic plants have been recorded in the basin.

A major negative trend in all the rivers in the Western Ghats is the construction of dams. The existing hydroelectric projects (e.g., Idukki) and the four proposed projects in the Periyar (additional fragmentation in the already significantly fragmented main river) pose threats of flooding to some of the primary forests. Another major impact is, sand mining, which has been fuelled by the construction boom in Kerala. Sand mining has affected the stability of river banks leading to loss of land and rendering large areas flood-prone. The quantity of sand that could be extracted safely is 19,178 tonnes annually, but the actual quantity removed is

TABLE 6.
Indicators for the Periyar Basin.

Indicator	Value	Score	Justification and Comments	Data Sources
Rare and endangered aquatic biota	Very high	5	Periyar basin has 5 critically endangered fishes and 14 threatened species. Fourteen species have become extinct. Some fish species disappeared over the past few years, including some cyprinids, goby, catfishes and eels.	Arun (1998) Kurup et al. (2001)
Unique aquatic biota	Very high	5	Fifty-six percent of the endemic fishes of Kerala are reported from Periyar (32 species), which makes it a unique ichthyfaunal basin of southern India.	Kurup et al. (2001) Arun (1998)
Diversity of aquatic habitats	Very high	5	Many threatened fish species inhabit pools, streams, runs, cascades—a diverse aquatic habitat types' system.	Arunachalam (2000a)
Presence of protected and pristine areas	Very high	5	The river flows through the famous Periyar Wildlife Sanctuary. Latest satellite imagery shows that around 30% of the basin is covered by dense pristine forests.	
Sensitivity of aquatic ecosystem to flow reduction	High	4	Multiple dams reduced flow which leads to decline in fish diversity, extinction of fish, prawns and shrimps—particularly in lower reaches. Large-scale fish mortality between Edamalayar and Eloor industrial sites are reported as well as algal bloom of *Oscillatoria sp.* Given the number of impacts and that Periyar is a relatively small river, the sensitivity to further flow reduction is high.	Joseph (2004)
Percentage of the watershed under natural vegetation	30–50%	3	National Remote Sensing data shows 30% of the watershed is covered by dense natural forests.	Joseph (2004)
Degree of flow regulation	20–50%	3	Calculated as the ratio of total storage capacity (3.27 BCM) to long-term mean annual flow volume at the outlet (12.3 BCM), which equals 25%.	KSEB (2005)
Percentage of the basin closed to movement of aquatic biota by structures	70–100%	1	The construction of 15 dams and wiers have almost closed the river system to movement of the biota through the basin.	
Percentage of aquatic biota that are exotic	<10%	3	Some species have been introduced in reservoirs (carp), which can be found in streams as well, at present.	Sugunan (1995)
Fish species relative richness	Very high	5	The basin is very rich in fish species having 208 species out of the total of 287 species in the Western Ghats (70%) or out of estimated total 577 in India (36%).	Joseph (2004)
Overall water quality in the basin	Class B	4	Water quality of the upstream and middle reaches is, as a rule, in class B. The water quality was rated as class C in the most downstream parts.	Singh and Anandh (1996) Joy and Balakrishnan (1990)

30 times more (Pratapan 1999). Indiscriminate sand mining deepens the river channel, which in turn promotes saline intrusion in the coastal area.

Another major threat in the basin is, water pollution. The physico-chemical analyses and reviews of the Periyar River water quality are available from 1976 onwards for a period of 25 years (Paul and Pillai 1976, 1981). These analyses show a consistent decline in: pH and oxygen levels; and an increase in: water temperature, radioactivity, pesticide pollution, and levels of heavy metals. Crabs and prawns that were found downstream have now become almost extinct due to water pollution (Joseph 2004). Greenpeace (2003) describes the 'Eloor industrial area', which is located in the downstream of the Periyar River, as one of the most vulnerable 'hotspots' of industrial pollution in the world. A parallel reduction in the flow of water will further increase algal blooms, resulting in occasional 'fish kills' as has already been experienced in the past.

Ganga River Basin (Rishikesh to Naraura reach)

The indicator values for this reach of the Ganga River are summarized in table 7. Ganga is the top basin in India with regard to fish species richness, but estimates of the total number of species vary significantly. The World Bank identified about 350 species (Kottelat and Whitten 1996), while Talwar (1991) reported 375 species. Of these, the estimates of freshwater species are between 104 and 161 (Menon 1999; Payne et al. 2003). In the study reach between Rishikesh and Naraura, Behera (1995) recorded 82 species of fish. Of these 4 to 10 are threatened or endangered according to different sources (Menon 1999; Behera 1995; Arunachalam, personal observations). These include the 'endangered' *Tor tor*, a Mahseer, *Bagarius bagarius*, *Pangasius pangasius*, and *Rita rita* (Behera 1995). In addition, 12 species of freshwater turtles are present, out of which 6 species are considered endangered in terms of Schedule I of the Indian Wildlife Protection Act, 1972 (Rao 1995). In the same stretch, two species of crocodile *Crocodylus palustris* and the *Gavialis gangeticus,* locally known as 'Gharial', are found. Both are considered *endangered* (IUCN 1994). The Common Indian Otter (*Lutra lutra*), and Smooth Indian Otter (*Lutra perspicillata*), have also been sighted in this stretch of the river. Both species are classified as threatened (IUCN 1994). More than 100 species of birds, both migratory and residential have been sighted (Behera 1995), of which several are endangered. The area around Naraura was proposed as a potential bird sanctuary in 1978 (Rao 1995); 51 species of aquatic insects and 15 species of mollusks have also been observed in this area.

TABLE 7.
Indicators for the Rishikesh–Naraura reach of the Ganga River Basin.

Indicator	Value	Score	Justification and Comments	Data Sources
Rare and endangered biota	High	4	There are at least 4 (and according to other estimates—up to 10) endangered freshwater fish in the reach. In addition, in the study reach there are: endangered Gangetic Dolphin, 6 endangered turtle species, 2 species of endangered crocodile, 2 species of threatened otter, and several endangered bird species.	Menon (1999) Dudgeon (2000) Rao (1995) Behera (1995)
Unique Aquatic Biota	High	4	Gangetic Dolphin is unique and 60 fish species of the study stretch are endemic.	Behera (1995) Menon (1999)
Diversity of aquatic habitats	Moderate	3	Presence of upstream reservoirs, muddy, sandy banks and fast flowing reaches as well as formation of islands during low flows offer relatively diverse habitats for wildlife.	Rao (1995)
Presence of protected and pristine areas	>10% of the reach	5	The Brijghat–Naraura stretch is a Ramsar site and the Hastinapur Wildlife Sanctuary is located close to Madhya Ganga barrage.	
Sensitivity of aquatic ecosystems to flow reduction	Moderate	3	With diversions from the Ganga ongoing for over 100 years, the ecosystem would have 're-adjusted' to the reduced flows. Rapid increases of summer flows (associated with glaciers melting in Himalaya) have been recorded leading to submergence of small islands used by turtles. Overall, given the river size, the sensitivity is still moderate.	

(Continued)

TABLE 7. (Continued)
Indicators for the Rishikesh–Naraura reach of the Ganga River Basin.

Indicator	Value	Score	Justification and Comments	Data Sources
Percentage of watershed under natural vegetation	10–30%	2	The historical destruction of forests is estimated to be over 80%. The trend seems to be reversing due to focus on plantation in Uttar Pradesh. It may, however, be misleading since the plantations may create monocultures.	Revenga et al. (1998)
Percentage of floodplains remaining	<10%	1	The current width of the floodplain is in the order of 2–3 km compared to anecdotal evidence of several tens of km width of flooding in the past.	R. Sinha (pers. comm.)
Degree of flow regulation	10–20%	4	While there has been little storage in the basin before, the recent construction and commissioning of Tehri Dam has started filling up a large 3.54 BCM reservoir. Four barrages in the study stretch also contribute to flow regulation, which remains relatively low—with a correspondingly high score.	Behera (1995)
Number of dams or other significant barriers per km of river channel	~0.01333	3	This is an indicator of fragmentation. Some newer structures have fish ladders that could 'reduce' fragmentation but their effectiveness is unknown. Four barrages exist over a stretch of approximately 300 km. However, since the river is not heavily regulated, and during monsoon upstream movement by aquatic biota is possible, a lower score is given.	
Percentage of aquatic biota that are exotic	>20%	1	Of about 80 fish species recorded in the study area, 60 are considered native and the rest as alien.	Behera (1995) Menon (1999)
Aquatic species richness	Very high	5	Ganga has the highest fish species richness compared to any other river in India—350–375 species (according to various estimates) out of estimated 577 total species (66%). This is partially determined by its mere size crossing many physiographic zones. The study stretch has around 82 fish species, which is about 22% of the basin's total number of fish species, but is much lower in the national context (14%).	Kottelat and Whitten (1996) Talwar (1991) Behera (1995)
Human population density as a percentage of that in the main floodplains	>60%	5	There is little difference between population density in 'floodplain' subdistricts compared to those further away from the river (532 persons/km^2 versus 577).	Census of India (2001)
Overall water quality in the basin	Class D	2	The water cannot be used for drinking or bathing, but is still suitable for propagation of wildlife and fisheries. Regular monitoring reveals substantial contamination by human waste as well as mixing of discharges from industrial effluent, mainly from sugar mills.	CPCB (http://www.cpcb.nic.in) Behera (1995)

By comparing the list of fish species from the stretch (Behera 1995) with the list of endemic fish species of India (Karmakar and Das 2004), it is inferred that *no endemic freshwater species of fish* have been reported from the stretch. However, one species of Crocodile, *Crocodylus palustris*, twelve species of turtles and one aquatic mammal species, *Platanista gangetica*—the Gangetic Dolphin, have been recorded (Rao 1995). Though the Gangetic Dolphin is also found in the Brahmaputra, it is considered *unique* to the entire Ganga-Brahmaputra-Meghna (GBM) basin, and its characteristics that separate it from the Irrawady and Indus Dolphins have been well documented (Behera 1995). Though the crocodile is not unique to the Ganga system, it is an 'endangered' animal as per IUCN classification (IUCN 1994), as such, it is protected under Schedule I of the Wildlife Act, 1972. Although these species are not unique in the strictest sense, their presence warrants the conservation of this reach.

The Ganga becomes a mature river after Haridwar, flowing over hundreds of meters of alluvium. In the upper part of the reach, the *aquatic habitats* include riffle areas, rocky, sandy and muddy river banks, while the lower part is dominated by sandy and muddy banks and deep pools (Rao 1995). The shallow parts of the river turn into islands during low flows and thereby become good nesting grounds for turtles and island breeding birds.

Protected areas include the Hastinapur Wildlife Sanctuary (2,073 km^2), which hosts the two-toed Barasingha (swamp deer), sambar, cheetal, blue bull, wolf, leopard, hyena and wildcat. Birds on the 'Red List' reported from the sanctuary area are: Greater Spotted Eagle, Swamp Francolin, Sarus Crane and Finn's Weaver. In 2005, the 85 km stretch of the Ganga between Naraura and Brijghat was declared a 'Ramsar Site' due to the WWF's ongoing Gangetic Dolphin Conservation Program. Considering the river reach only (without its catchment), the protected area proportion is, therefore, around 30 percent of the length, which is well above the IUCN norm of 10 percent. This approach has been used here to reiterate the importance of the reach for conservation.

Sensitivity of aquatic ecosystem to flow reduction is very difficult or even impossible to evaluate in the absence of direct relationships between ecosystem and flow changes. The diversion of the flow in the Ganga River has been ongoing since the early 1850s, and riverine ecosystems have gradually adjusted to such diversions with certain losses. However, there have been instances when parts of the river in this reach went dry in the past. This cannot be explained by natural flow variability only, but is rather the cause of diversions. Such events lead to increased stress on the ecosystem, especially on species like the dolphin that need deep pools of water and high flow velocities (Behera 1995). Das et al. (2005) has analyzed the impacts of irregular water flow from barrages on the river dolphin population and found that the reduced dolphin numbers correlated with the reduced downstream flow, in the study stretch. Other scientists have identified reduced river flows as one of the primary threats not only to the populations of dolphins, but also to Mahseer (a local endemic carp group), crocodiles and turtles (Rao 1995); although no quantitative data on this is available.

Since the Gangetic Plains have been inhabited for centuries, the dominant land-use has been agriculture, which has certainly affected the proportion of natural cover in the basin. According to some recent sources (Revenga et al. 1998), over 80 percent of the original forest cover in the entire Ganga basin has been lost. However, some areas in the subbasin of the study reach still remain under grasslands (e.g., protected areas like the Hastinapur Sanctuary). Forests have recently started to show a tendency of recovering some of its lost cover (a marginal increase in forest area of 2–5% has been reported in the past decade—Census of India 2001). However, most of the basin is now under agriculture. Similarly, almost the entire floodplain of the Ganga has been converted to agricultural land. The *remaining floodplain areas* range from 1.5 km (at both sides of the river in total) at Haridwar to some 20 km near the Naraura Barrage (estimated using images from http://www.earth.google.com). Less than approximately 10 percent of the original (i.e., 10,000 years ago) floodplains still remain (R. Sinha personal communication).

The degree of flow regulation in the basin is still relatively low. There were no storage reservoirs along the stretch or upstream of it, until the completion of the Tehri Dam in 2005. Nilsson et al. (2005) classify the entire basin, including the main channel and tributaries as 'moderately affected' by regulation. However, four major barrages have been constructed in the study reach from 1850s onwards. Some sources suggest that diversion and regulation in the reach remove approximately 50 percent of the discharge compared to 66 percent for the entire basin (Payne et al. 2003). This, however, is likely to be significantly overestimated as the data on observed historical flows in the Ganga are not readily available. The barrages fragment the main river into three reaches, resulting in 0.013 structures per km across the flow, which is used here as an estimate of the degree of river fragmentation (table 1 and 7). Some of the barrages constructed more recently, like the refurbished lower Ganga barrage at Naraura, have fish ladder arrangements that restore connectivity to a limited degree. However, these structures are based on designs for rivers in the temperate zone (Kottelat and Whitten 1996) and, as such, their effectiveness in the tropical rivers is unknown.

Behera (1995) reports over 80 species of fish in the study stretch. A comparison with Menon's (1999) description of freshwater fish in the Ganga basin reveals that about 60 of these species are native. Thus, slightly over 20 percent of the fish species recorded in the stretch may be seen as *exotic fish*—including carps and catfishes that may have been introduced for fisheries. At the same time, this may be an overestimation as exotic carp in India are few (V. V. Sugunan, ICAR, New Delhi, pers. comm.). Hence, the above figure needs to be verified in the future.

According to the Census of India (2001), there is little difference in the human population density between areas adjacent to the river and those further away from it (table 7). The water quality of the study reach is regularly monitored by the Central Pollution Control Board of India (CPCB - http://www.cpcb.nic.in) at Rishikesh, Haridwar, Garhmukteshwar, and Naraura; and occasionally—during research projects (Behera 1995). It varies in different parts of the reach from class B to D with most of it falling into class D, due to contamination of the river by human wastes that exceed the permissible thresholds and high Biochemical Oxygen Demand (BOD) values around Naraura (due to the presence of sugar industries in the area).

In the short-term, the flow downstream of the Tehri Dam is likely to decrease, while the increased use of groundwater for irrigation may reduce the baseflow, especially during summer months. The increasing diversion of river water for irrigation is the single most important consumptive use in the study reach. In addition, the power generation facility of the Tehri Dam will need its peaking power requirement met, which, in turn, will create a pulse discharge into the river downstream that can be felt as far as Rishikesh or even Haridwar. These factors adversely affect the single most important ecological issue in the reach—the protection of the Gangetic Dolphin. Although, due to recent conservation efforts its population has doubled (from 22 to 45) since 1995, the habitat for the dolphin in the Ganga is threatened by irrigation diversions and changes in flow variability. The overall prospects for the dolphins in the country remain a concern with their annual fatality rate nearing 10 percent.

Discussion and Conclusions

Once the scores for individual indicators have been estimated, it is possible to calculate their sum and express it as the percentage of the total *maximum possible* sum of all indicators. This percentage may then be converted into the most likely Environmental Management Class (EMC), which, in turn, determines how much water (*environmental flows*) needs to be allocated for environmental purposes in each river basin (Smakhtin and Anputhas 2006). These environmental flows are determined by the modification of the natural (reference) flow duration curves according to the class. Similar to the various number and types of ecological indicators used, various procedures and categories can be proposed on how to use the indicators to establish the EMC, or directly—the environmental flows themselves. In this study, the scores have been divided into six unequal categories, each representing one of the six EMCs described in table 8. The 'score ranges' in groups are arbitrary, with larger ranges in lower classes C and D.

TABLE 8.
Approximation of Environmental Management Classes (EMC) by total indicator scores.

A sum of actual indicator scores as a percentage of the maximum possible sum	EMC	Most likely ecological condition (adapted from DWAF 1999).	Management Perspective
91–100	A	Natural rivers with minor modification of in-stream and riparian habitat.	Protected rivers and basins. Reserves and national parks. No new water projects (dams, diversions, etc.) allowed.
75–90	B	Slightly modified and/or ecologically important rivers with largely intact biodiversity and habitats despite water resources development and/or basin modifications.	Water supply schemes or irrigation development present and/or allowed.
50–74	C	The habitats and dynamics of the biota have been disturbed, but basic ecosystem functions are still intact. Some sensitive species are lost and/or reduced in extent. Alien species present.	Multiple disturbances associated with the need for socioeconomic development, e.g., dams, diversions, habitat modification and reduced water quality.
30–49	D	Large changes in natural habitat, biota and basic ecosystem functions have occurred. A clearly lower than expected species richness. Much lowered presence of intolerant species. Alien species prevail.	Significant and clearly visible disturbances associated with basin and water resources development, including dams, diversions, transfers, habitat modification and water quality degradation.
15–29	E	Habitat diversity and availability have declined. A strikingly lower than expected species richness. Only tolerant species remain. Indigenous species can no longer breed. Alien species have invaded the ecosystem.	High human population density and extensive water resources exploitation. Generally, this status should not be acceptable as a management goal. Management interventions are necessary to restore flow pattern and to 'move' a river to a higher management category.
0–14	F	Modifications have reached a critical level and ecosystem has been completely modified with almost total loss of natural habitat and biota. In the worst case, the basic ecosystem functions have been destroyed and the changes are irreversible.	This status is assumed to be not acceptable from the management perspective. Management interventions are necessary to restore flow pattern, river habitats, etc. (if still possible/ feasible)—to 'move' a river to a higher management category.

The rule of thumb has been that rivers/ basins in the most natural category (A) are rare and, even if present, may not be assigned to this category due to development needs. The other extremes—classes E and F—should generally not be considered as feasible management options (which stem from the rules adopted in South Africa, e.g., DWAF 1999). Classes B, C and D together, thus cover most of the available range of percentage values (table 8). This system is clearly arbitrary at present, and a much more extensive research effort as well as further expert discussions are required to justify how to convert the indicator scores into different EMCs.

The final sum of all indicators and the estimation of EMCs for each basin or subbasin are given in table 9. Most of the basins examined in this study fall into class C, three—into class B and two—into class D. The basins/reaches in the highest class (B) are primarily headwater or 'smallish' basins located/originating in the Western Ghats, with high habitat diversity, species richness and, are relatively less developed compared to basins located further downstream. This combination of relatively natural conditions on the one hand, and higher sensitivity/importance due to greater species diversity, etc., on the other, places these basins in a high category.

TABLE 9.
Calculation of Environmental Management Categories (EMC) for selected study basins based on their indicator scores.

Basin/Reach	Ecological Indicators*																
	Rare and endangered aquatic biota	Unique aquatic biota	Diversity of aquatic habitats	Presence of protected or pristine areas	Sensitivity of aquatic ecosystem to flow reduction	Percentage of watershed remaining under natural vegetation	Percentage of floodplains remaining under natural vegetation (or % of floodplains remaining)	The degree of flow regulation	Percentage of watershed closed to movement of aquatic biota by structures or degree of flow fragmentation	Percentage of aquatic biota that are exotic	Aquatic species' relative richness	Human population density as % of that in the main floodplains	Overall water quality	Sum of Indicator Scores	Maximum Possible Sum of Scores	Percent of The Maximum	Probable EMC
Tungabhadra—headwaters	4	3	4	2		5				5	4		5	32	40	80	B
Tungabhadra—middle	3	1	3	2		3	3			4	5	1	3	28	50	56	C
Tungabhadra—lower	3	1	3	2		2	2			4	3	1	3	24	50	48	D
Krishna—headwaters	2	4	5	1		4				5	3		5	24	40	60	C
Krishna—middle	3	2	4	3		3	3			4	5	3	3	33	50	66	C
Krishna—lower	3	2	2	1		2	2			3	3	4	1	25	50	50	C
Cauvery—headwaters	4	4	5	4		5				5	4		5	36	40	90	B
Cauvery—middle	3	2	3			3	3			4	4	4	3	28	45	62	C
Cauvery—lower	2	1	3	1		1	1	4		4	2	4	2	25	55	45	D
Narmada	1	1	4	5	3	2		5	4	5	3		4	37	55	67	C
Periyar	5	5	5	5	4	3		3	1	3	5		4	43	55	78	B
Ganga (Rishikesh–Naraura reach)	4	4	3	5	3	2	1	4	3	1	5	5	2	42	65	65	C

Note: * Some indicators have not been calculated in individual river basins either because they were not applicable (e.g., there are no floodplains in most headwater areas and in the Narmada Basin) or due to data limitations

Two subbasins (in this study), placed in the lowest class D, are on the contrary, located in the most downstream parts of the basins. It can also be noted that Lower Krishna, although in class C, is at the lowest boundary of this class (tables 8 and 9). An interesting example is the Narmada basin: it falls into class C primarily due to its two low scores on rare and unique species (table 9). This reduces the importance of the basin and makes the otherwise relatively natural basin an 'attractive' candidate for development. But as table 5 indicates, there are unpublished sources suggesting that rare and unique species do exist in the Narmada basin, which may raise the scores of these indicators and increase the overall EMC of the Narmada. At the same time, the Periyar basin, which scores high on most of the sensitivity/importance indicators, is in the high class B category despite its low score, due to the presence of multiple dams in the basin. In general, high indicators of sensitivity/importance together with high indicators of the current ecological conditions place a river into a high management class, while any 'loss' of indicator scores—either in terms of current condition or importance/ sensitivity—leads to lower EMC and hence, a lower environmental allocation.

Smakhtin and Anputhas (2006) presented, among others, relationships between EMCs and the amount of natural long-term mean flow at the outlets of major river basins in India. If their relationships are used together with the procedure suggested herein, the environmental water requirements at the outlet of Krishna, for example, would be 18 percent of the long-term mean flow; Cauvery around 11 percent; Narmada 14 percent; and Periyar 28 percent of their long-term flows, respectively. It is important to understand that this report introduces the approach rather than the final method for setting EMCs for Indian rivers. Even if the existing EMC setting approach is retained for future management of Indian rivers in principle, it is necessary to be aware of its multiple limitations, including, but not confined to the following:

- The set of indicators used here is very preliminary and the selection of indicators needs to be revisited. Apart from the rather general nature of some indicators, no indicators relating to the social importance of rivers have been considered in the approach, at present. This is acknowledged as a serious limitation and one that needs to be addressed in future work.
- The existing information base for determining any ecological indicator in India is very limited. The authors of this report used their own knowledge of and judgment on specific rivers, but other specialists will need to be involved in estimating the scores to improve the level of confidence in the approach.
- The scale of the analysis was very coarse and a similar or a different set of indicators needs to be used at much smaller scales, e.g., for a particular reach of any river, rather than for arbitrarily selected, big areas of already very large river basins (with Periyar being the only exception).
- There seems to be a lack of agreement on such specifics as how many fish species there are in India as a whole, which, in turn, determines the estimation of several other indicators. There is little knowledge on the diversity of other aquatic species. Uncertainty and lack of information will, however, always be unavoidable factors, and it will be necessary to find ways to handle them generally, in such an approach.
- It is a challenge to bring into account coastal fish diversity to an EMC estimation for a river basin unless, of course, estuarine freshwater requirements are estimated using a protocol different from environmental flow assessment for inland rivers.
- The procedures used in this report to convert the indicator scores into EMC are very

arbitrary but illustrative. They are given here primarily to stimulate further development in this field.

- There is currently no system of rating the level of confidence for the indicators and/or overall score. This is typically done with similar approaches, and the one presented herein would benefit from attention to this aspect in future work.
- The estimation methods of individual indicators have varied slightly between the basins, due to varying data availability, specifics of the basin and professional judgment. These differences should be eliminated in the future, and be replaced with a more strict assessment protocol.
- Some indicators, like s*ensitivity of aquatic ecosystem to flow reduction,* are very difficult or even, impossible to evaluate in the absence of direct relationships between ecosystem and flow changes. The above appears to be the most weakly developed indicator and yet a critical one for the entire process. It may need to be replaced by a set of different and more specific indicators in the future. Such indicators may be defined through an expert workshop on indicators (see below).

It should also be noted that although useful, the scoring approach should not be used only for the estimation of EMCs. It may also be applied to estimate the permissible levels of reduction/increase of various flows—directly, as suggested by Smakhtin and Anputhas (2006).

As an immediate follow-up to this preliminary study on ecological scoring, the authors of this report propose to hold a national workshop, which would engage several aquatic ecologists, hydrologists, social scientists, etc. The objective of this exercise would be to design a more reliable assessment methodology of environmental importance and conditions of Indian water bodies.

The authors also consider it important to start the process of ecological status assessment of all Indian water resources—at the fine scale of spatial resolution. This new large-scale program should tap into the already existing ecological expertise in the country, and should redirect it from largely descriptive/inventory type work into the context of quantification of ecological water requirements of Indian rivers and wetlands.

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Postal Address
P O Box 2075
Colombo
Sri Lanka

Location
127, Sunil Mawatha
Pelawatta
Battaramulla
Sri Lanka

Telephone
+94-11-2880000

Fax
+94-11-2786854

E-mail
iwmi@cgiar.org

Website
http://www.iwmi.org

International Water Management Institute

FUTURE HARVEST
IWMI is a Future Harvest Center supported by the CGIAR

ISSN 1026-0862
ISBN 978-92-9090-668-1