Environmental Flow Assessment: Recent Examples from Sri Lanka

P. Dissanayake, N. Weragala and V. Smakhtin
International Water Management Institute, Colombo, Sri Lanka

Abstract

Assessment and provision of Environmental Flows (EF) is important for the protection of aquatic ecosystems. EF are a set of discharges of a particular magnitude, frequency and timing that are necessary to ensure a certain range of benefits from a river. Such flows need to be scientifically determined and economically justified. Limited exposure to the concept of EF exists in developing countries. This paper gives two recent relevant example studies, which were conducted by IWMI, with foci on EF Assessment (EFA) and valuation of EF benefits in the Walawe and Menik Ganga river basins located in a semi-arid zone of southern Sri Lanka. The Walawe example illustrates the simple method for estimation of EF. The EF are approximated at two sites along the main stream of the Walawe River, which are located below the two main reservoirs. A desktop method is used, which is based on simulated, unregulated daily flow time series and their flow duration curves. The study also illustrates how the required hydrological information can be generated for the locations where EF assessment is intended - quickly and in conditions of limited observed data. The second Menik Ganga example is used as a case study to evaluate the costs and benefits of environmental water allocations. The EF components evaluated include the water needs for religious festivals, and the requirements of the Yala National Park, the Pilinnawa coastal wetland and grasslands, and the Yala Fisheries Management Area (YFMA) off the coast. Almost all estimates are based on use values of EF such as marketed goods and recreation. The paper intends to stimulate discussion and further research in the fields of EF assessment and economic valuation.

Introduction

Many of the world's rivers have been modified through storage, diversion and control structures to provide water for urban and agricultural supplies, to generate electricity and control floods. In many rivers, almost all the flows have been diverted. Flows left in the river or flowing into the sea were often seen as wasted water. This attitude is changing worldwide. Ensuring environmental water allocations (normally referred to as Environmental Flows – EF), which are essential to sustain elements of natural aquatic ecosystems and maintain ecosystem services (such as fish, flood protection and wildlife), is becoming an important trend in water resources management (see www.maweb.org). EF are a set of discharges of a particular magnitude, frequency and timing that are necessary to ensure a certain range of benefits from a river. All components of the hydrological regime have certain ecological/social significance and have to be mimicked in a modified flow regime; the EF. High flows of different frequency are important for channel maintenance, bird breeding, algae control, wetland flooding and maintenance of riparian vegetation. Moderate flows may be critical for cycling of organic matter from river banks and for fish migration, while low flows of different magnitudes are necessary for fish spawning, water quality maintenance and the use of the river by local people. Many authors now suggest that social aspects, such as human well-being, should also feature in EF (e.g., Korsgaard 2006; Meijer 2007). Balancing the requirements of the aquatic environment and other uses is becoming critical in many of the world's river basins as population and associated water demands increase.

The assessment of water requirements of freshwater-dependent ecosystems represents a major challenge due to the complexity of physical processes and interactions between the components of the ecosystems. Only limited exposure to EFA and management exists in developing countries (Tharme and Smakhtin 2003). Some obstacles include the lack of relevant expertise and legislative support, and the reluctance on the part of water resource developers to move away from past practices. Another reason is that economic benefits of EF are more difficult to quantify as their values are generally not expressed in market terms. To promote environmental water allocations, it is important to create awareness about the existing EFA methodologies and processes that should be followed, examine the economic side of EF, and illustrate the applicability of these approaches through relevant case studies in individual countries, which to date have had limited exposure to EF. The Walawe and Menik river case studies, presented below, address these issues in the specific context of Sri Lanka.

Case Study 1: Environmental Flow Assessment - Walawe Ganga

Study Area and Objective

Walawe is the largest river basin (2,442 km^2) in southern Sri Lanka and one of the three main rivers (Walawe, Kirindi and Menik) flowing south in the area, which, together with a few smaller catchments, form a group of basins known as the Ruhuna drainage area (Figure 1). A characteristic feature of the basin is two wet seasons, from the northeast and southwest monsoons, with precipitation peaks in April and November. The mean annual precipitation (MAP) is 2,050 mm with uneven spatial distribution. Despite the high precipitation, parts of the basin experience water scarcity problems during February-March and July-October almost every year.

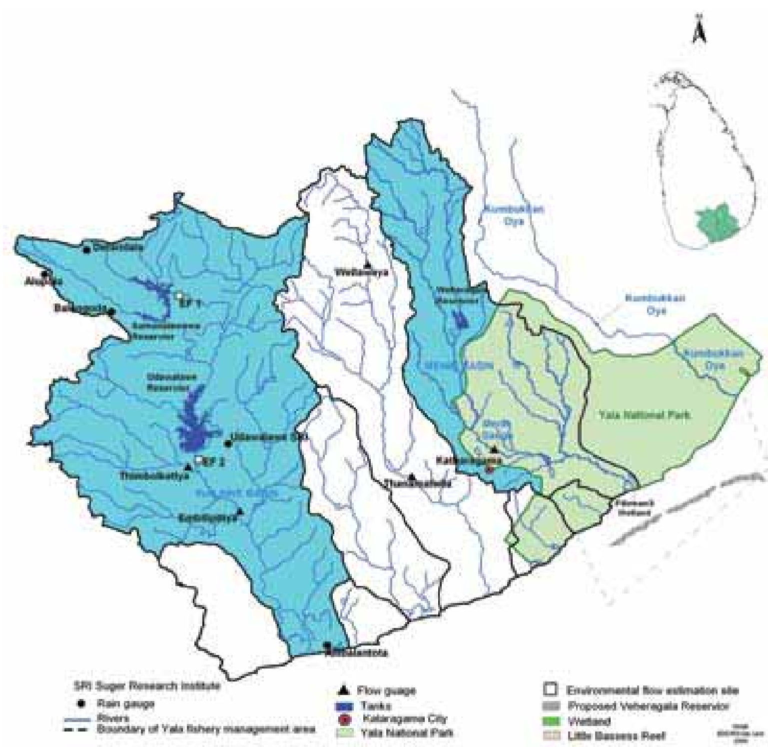
The Walawe Basin features a variety of water-related issues, from massive irrigation development to water quality and drinking water problems. Two major reservoirs for irrigation and hydropower generation are constructed on the main river (Figure1): Samanalawewa (upstream, in 1993) and Uda Walawe (middle reaches, in 1957), with a total capacity of 486 million cubic meters (MCM). Water is also transferred out of the Walawe Basin to develop irrigated agriculture in adjacent basins of the Ruhuna area. About 40 % of the catchment area is irrigated land and 20 % is under rain-fed agriculture. Expanding the irrigated area could lead to the loss of more than 5,000 ha of secondary forest, an important wildlife habitat. Human-elephant conflicts are being aggravated due to this loss of wildlife habitat, and irrigation development has had negative impacts on the aquatic environment.

There is only very limited quantitative knowledge of these impacts and no attempt has been made to quantify EF or their releases, or to ensure them. The study, therefore, aimed to undertake a quick, preliminary EFA, based primarily on hydrological information. Any EFA requires that, first, a hydrological reference condition is established, which in most of the cases means reconstructing the unregulated flow regime of a river. This reference condition may then be used to compare with and assess the impacts of land-use changes and water-resources development in a basin or to quantify the environmentally acceptable flow regime (EF).

Establishing the Hydrological Reference Conditions

The site selection for EFA was based primarily on the location of sites relative to the existing reservoirs. Site 1 (EF1) is located immediately downstream of the Samanalawewa Reservoir and Site 2 (EF2) is downstream of the Uda Walawe Reservoir (Figure 1). There are no flow observations at these sites and, hence the reference hydrological time series needs to be simulated. This simulation may be done using hydrological models or, as in this study, by observed flow data transfer techniques, known as hydrological regionalization.

Figure 1. A schematic map of Ruhuna drainage area highlighting Walawe and Menik River basins.



Only five gauges with daily and monthly unregulated flow data have been identified in the Ruhuna group of catchments. The preliminary screening and visual analyses of these time series showed that only three of these datasets are usable; as the others contain inaccurate values, have short records or other deficiencies. In addition to flow data, several observed daily rainfall datasets have been used for simulation, as described later in the paper. Although there are many rainfall stations in the basin, most of them have short records of 10 to 15 years or are located far from the sites where simulation is required and, therefore, are of little use. The rainfall stations used are shown in Figure 1.

The reference hydrology is simulated using a non-linear spatial interpolation technique based on observed rainfall and flow records (Hughes and Smakhtin 1996; Smakhtin and Masse 2000). This technique makes an intensive use of flow duration curves; a cumulative probability distribution function of flows. The components of this approach include: technique(s) to establish representative flow duration curves for different types of ungauged river catchments; and technique(s) by which the established flow duration curves may be transformed into actual continuous flow time series for any further analysis. The first part is accomplished by developing 'regional' flow duration curves. This is a relatively straightforward process of overlaying the actual flow, normalized by mean, daily discharge, 'observed' flow duration curves from available flow records (Smakhtin and Weragala 2005). Three usable observed flow datasets in the entire Ruhuna area were used to calculate regional flow duration curves. To estimate the actual (dimensional) flow duration at each EF site, it is necessary to have an estimate of the mean annual runoff (MAR) for unregulated conditions for each site. A long-term, mean daily discharge is then derived from the MAR for each site and the ordinates of the regional flow duration curve are multiplied by this discharge. The MAR values at EF1 and EF2 sites were estimated from the unregulated parts of available, monthly, time step, 'observed' flow records at the Samanalawewa gauge and Uda Walawe Reservoir, respectively (Smakhtin and Weragala 2005).

Once a flow duration curve at the EF site is established, it can be converted into actual continuous flow time series by a non-linear spatial interpolation algorithm, developed by Hughes and Smakhtin (1996). The method uses the data from one or more 'source' (gauged) sites and transfers these data through the flow duration curves to the 'destination' EF site. The main assumption of the algorithm is that flows occurring simultaneously at sites in reasonably close proximity to each other correspond to similar percentage points on their respective flow duration curves. If no suitable source flow gauge(s) with observed records can be identified in the vicinity of the destination site, more readily available rainfall records are used. In this case, both source flow time series and source flow duration curves are replaced by a rainfall-related function, reflecting the status of catchment wetness (Smakhtin and Masse 2000). The function is known as Current Precipitation Index (CPI).

$$CPIt = CPIt\text{-}1\ K + Rt \qquad (1)$$

where Rt is the catchment precipitation (mm) for day t and K is the recession coefficient, which varies in a small range and has limited impact on the resultant time series.

Since no suitable flow gauges with 'unregulated' daily data in the vicinity of the EF sites are available in the Walawe Basin, rainfall data from the nearest suitable rain gauges were used. For EF1, it was the Balangoda gauge. Unfortunately, its record is limited to only 10 years, so the simulated reference flow time series was eventually also limited to the same 10-year period

(1990-2000). (The observed time series of inflows to the Samanalawewa Reservoir, which in principle represents unregulated flow conditions at the EF1 site, was even shorter and, hence the simulation for even modest extension was deemed necessary). For EF2, the source sites were those at Uda Walawe Sugar Research Institute and at Ambalantota. Both have relatively long records and were found to have similar (although not identical) temporal variability patterns. The similarity between selected rain source sites suggests that they both reflect the pattern of catchment wetness dynamics reasonably well.

Assessment of Environmental Flows

The EFA method used in this study was based on the Range of Variability Approach (RVA) developed by Richter et al. (1997). In the RVA, 32 hydrological parameters, which jointly reflect different aspects of flow variability, are estimated from a natural daily flow time series at an EF site. The RVA method suggests that in a modified (ecologically acceptable) flow regime, all 32 parameters should be maintained within the limits of their natural variability. For each parameter, a threshold of 1 standard deviation (SD) from the mean is suggested for use as a default arbitrary limit for setting EF targets in the absence of other supporting ecological information. Smakhtin and Weragala (2005) suggested that the number of parameters may be reduced to six, without detrimental effect to the overall estimation. These parameters may then be expressed as flows on the flow duration curve and, following the RVA default threshold, it can be assumed that the attained value of each selected parameter should be:

$$(\text{mean} - 1\ \text{SD}) < \text{RVA parameter} < (\text{mean} + 1\ \text{SD}) \qquad (2)$$

In most of the impacted river basins, including Walawe, it is the overall reduction of flows that is the problem. It is, therefore, the first part of (2) above that is of primary importance. This is a low-threshold condition: (mean –1 SD) < parameter.

It has been assumed that the six selected flow parameters are each exceeded the same amount of time in the modified (target) flow time series as the six original parameters in the unregulated flow time series (Table 1). The resultant ‘high-limit’ and ‘low-limit’ flow duration curves for each EF site may be estimated and plotted, as shown in Figure 2 for EF2. These flow duration curves are the summaries of EF regimes in which the selected six flow parameters are at their highest ([mean+ 1 SD]) or lowest ([mean –1 SD]) acceptable limits.

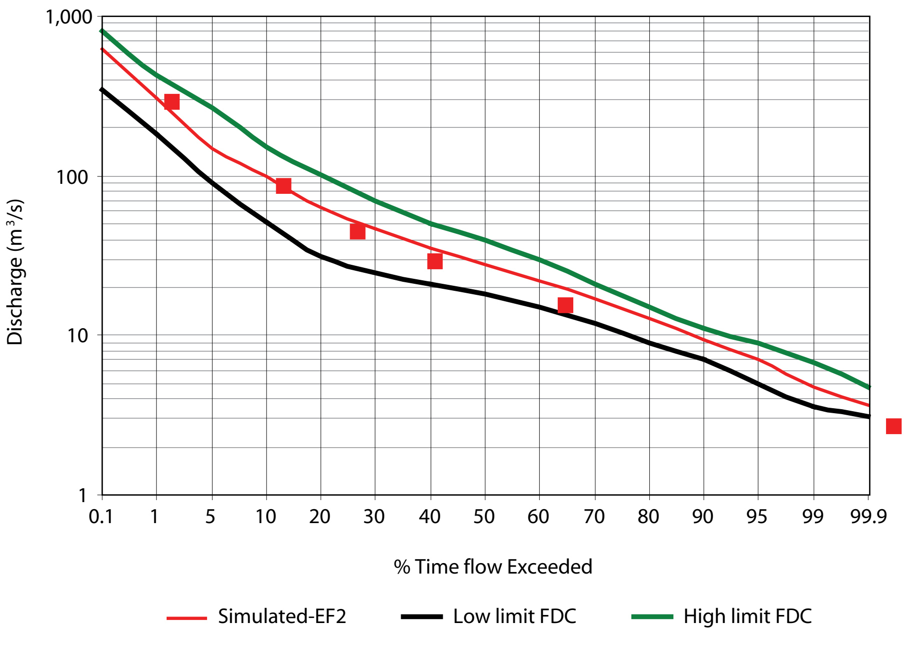
Each ‘environmental flow duration curve’ can also be converted into a complete time series of environmental flows using the same spatial interpolation approach described earlier (more details may be found in Smakhtin and Masse 2000). The interpretation of this approach needs only a minor change. The destination site now is an EF with a flow duration curve representing the environmental flow regime (e.g., Figure 2, lower curve). The source site is the same EF site but with a flow duration curve and the actual time series, representing an unregulated, originally generated flow regime. This conversion and simulation of an environmentally acceptable flow time series could be useful if the present-day flow time series downstream of the Uda Walawe reservoir was also available (they may then be compared and visualized). The authors could not locate such a time series during the course of the study. It is, however, possible to suggest that given the extensive water diversions from Uda Walawe, very little water is flowing at EF2 at all times. Therefore, it is unlikely that the established low-limit EF target is ever met.

Table 1. Selected RVA parameter analysis for site EF2.

N	Modified RVA parameter	Mean, $m^3 s^{-1}$	% time flow exceeded (for selected points only)	SD, $m^3 s^{-1}$	Low (Mean -1SD), $m^3 s^{-1}$	High (Mean + 1SD), $m^3 s^{-1}$
1	Mean: April	43.7	32.0	19.2	24.5	62.9
2	Mean: August	25.6	54.0	8.7	16.9	34.3
3	Mean: October	66.4	19.0	34.5	31.9	101.0
4	Mean: November	118.5	7.5	65.2	53.3	183.6
5	1-day minimum	5.14	98.3	1.5	3.6	6.7
6	1-day maximum	339.6	0.8	86.12	53.5	425.7

Source: Smakhtin and Weragala 2005

Figure 2. Flow duration curves illustrating unregulated flows and estimated high and low thresholds of ecologically acceptable flows for site EF2 (Uda Walawe).



Source: Smakhtin and Weragala 2005
Note: FDC: Flow duration curve
Markers show the location of the six flow parameters

Case Study 2: Costs and Benefits of Environmental Water Allocations – Menik Ganga

Study Area and Objective

The Menik Ganga Basin (1,272 km^2), is also located in the Ruhuna area (Figure 1). Its mean annual precipitation is around 1,500 mm and is received primarily during the northeast monsoon period from November to January; the dry season lasts from June to September. More than half of the catchment area is covered by forests, which extend into one of the main attractions of the area, Yala National Park (Ruhuna and Yala East), (Figure 1). The park covers 1,512 km^2, of which about 594 km^2 is within the Menik Basin. The area is rich in biodiversity and has the largest concentration of wild leopards in the world as well as supporting a significant population of elephants. The Yala coastal region has two Marine Protected Areas (MPAs) (www.mpaglobal.com): Ruhuna and Yala East. The YFMA of 450 km^2 is located within the Ruhuna MPA. In addition, the basin is known as the place of traditional religious festivals that attract a significant number of pilgrims and tourists. These features prompt the attempt to evaluate, in monetary terms, water allocations required to sustain them. The study was undertaken in the absence of any actual EF assessments, simply to explore ways of putting economic value on various, primarily non-consumptive, in-stream water uses. These uses include:

- water requirement for the Kataragama religious festival;
- requirement of the Yala National Park (primarily for the support of the large elephant population and other wildlife);
- requirement of the Pilinnawa Coastal Wetland
- requirement of the YFMA, including the needs of the Menik estuary.

Requirements for the Religious Festival at Kataragama

Each year, the 'Kataragama Festival' attracts about 100,000 people per day over a 15-day period during July and August. The main event of the festival is the water cutting ceremony held in gratitude to God Kataragama. The water cutting ceremony ideally requires about 1.2 to 1.5 meters (m) of water in the river (USAID 2005). The minimum water depth required for the festival around the Kataragama Temple has been estimated to be 0.6 m with the corresponding discharge at Kataragama gauging station of 2.0 m^3/s (Central Engineering Consultancy Bureau (CECB) 2004). However, over the past decade, the river did not carry this much flow at Kataragama during the months of the festival. Analysis of available flow records for the period of 1977-1998 shows that the long-term mean flow in the river during August, for example, is less than 0.6 m^3/s (Dissanayake and Smakhtin 2007).

Due to increasing levels of water pollution arising from low flows, water becomes unsuitable for bathing during this period and is satisfied by bowser water supply. During the 15-day festival, around 25 bowsers in total are used by the National Water Supply and Drainage Board (NWSDB), several NGOs, and the police to supply water to the migrant populations (M. G. Gunathilake, pers. comm. 2006). Therefore, the total expenditure to supply water by bowsers was used as a proxy for EF (Table 2). However, alternative bowser supplies are unlikely to provide the same satisfaction as that received from using the river.

Requirements of the Yala National Park

The Yala National Park requires water during the dry season to sustain its aquatic and terrestrial flora and fauna. However, according to the Department of Wildlife Conservation (DWLC), the stretches of the Menik Ganga that pass through the Yala National Park are completely dry throughout the months of July, August, and September (USAID 2005). Analysis of observed flow records at Kataragama suggests that, on average, the Menik Ganga is dry for about 20% of the year (Dissanayake and Smakhtin 2007). The additional allowance that the DWLC spends to cope with the water shortages (B. V. R. Jayaratne, pers. comm. 2006) during the three dry months can be taken as a proxy for the benefits of EF to the Yala National Park (Table 2). However, the actual benefits to the park are much greater than this proxy value.

The water and fodder requirements of elephants are treated as part of the EF in the Menik Ganga. The DWLC suggests a maximum of 200 elephants are living in the Menik Ganga portion of the Park (594 km^2). The maximum daily requirement for drinking and for the general hygiene for 200 elephants is relatively minor. However, the actual flow of water in a river has to be higher for an elephant to access it. To ensure the long-term survival of this elephant population, it is important to maintain the vegetation in the National Park during the rainless season, by ensuring some flow in the river and thus some healthy riparian vegetation around it.

The value of crop damage, compensation paid for damage and the value of the human elephant conflict (HEC) mitigation measures in Yala in the dry season (Table 2), could be used as proxy values for benefits derived from keeping the elephants in the park by maintaining EF in the river. During the dry season, the elephants in Yala migrate to other areas in search of fodder and water. The effects of these migrations are the destruction of property by elephants and the loss of human and elephant lives. However, data on the exact number of families affected by elephant migration, and whether they are affected by the Yala elephants specifically, are not available. These losses, therefore, cannot be quantified at present without introducing great uncertainty. Considering the attention given to elephant protection in Sri Lanka and the world, the expenditure for HEC mitigation used here is likely to be an underestimate of the benefits of EF.

An approximate value of benefits from environmental water allocation could be derived from the fact that the Yala National Park is closed from September to mid-October due to a lack of water. It is assumed that willingness to pay to visit the park depends on the condition that water is available and, hence the park is open. The loss in revenue from tourism over 1.5 months could be taken as a proxy for the value of the benefits of maintaining EF in the Menik Ganga during the rainless season (Table 2). However, the cost of entry to the park is only part of all costs associated with traveling to the park and, therefore, it underestimates the costs actually incurred. It has been estimated that the recreational value of the park in Sri Lankan Rupees is 250/ha/year (cited in CECB, 2004). The forgone recreational value in 1.5 months was estimated by inflating this average value to obtain the price from April 2006 to the time of the study, which was calculated to be US$4.35, and by multiplying this with the area of the park. The forgone recreational value in 1.5 months is, therefore, US$82,215 (Table 2).

Requirements of the Pilinnawa Wetland

The Pilinnawa Wetland (Figure 1) is considered an important site for waterfowl and a variety of other fauna, including elephants. Water required for wetland flooding was evaluated by the Central Engineering Consultancy Bureau (CECB 2004). A discharge of 250 m^3/s is required to ensure the stable inflow of water into the wetland. Hence, a release through the Weheragala Reservoir of 300 m^3/s for a period of 3 hours once every 2 years is deemed necessary to ensure a minimum flow rate of 250 m^3/s for at least 45 minutes at Pilinnawa and to flood the wetland. However, the flooding requirement of the grassland area had not been considered in this calculation. These estimates have not been verified through any EFA. Therefore, these estimates will need to be revised in the future, taking into account water requirements for breeding and feeding of birds and fish, and for the maintenance of wetland vegetation.

A Benefit Transfer (BT) done for the open water and marshy area of Pilinnawa (1.0 km^2), using the land cover as a proxy estimate, gave the total value of Pilinnawa as US$13,400 (Table 2). (A site-specific primary valuation in the future would give a more realistic estimate, which could be used as a proxy estimate of the benefits of EF).With the average value transfer from Millennium Ecosystem Assessment (MEA), the total value of Pilinnawa is US$315,100, which is likely to be a gross over-estimation. The CECB (2004) has mentioned that the grassland will be adversely affected by the proposed development at Weheragala. There are no value estimates to be found for grasslands in Sri Lanka. Using the global average unit value for grasslands and land cover as a proxy measure, the total economic value of the grassland is around US$134,560 per annum, which is probably an over-estimation. A future site-specific ecosystem valuation based on the grazing benefits would give a more realistic value of the grassland, which could be used as a proxy estimate of the EF benefits.

Table 2. A summary of EF components in the Menik Ganga and the estimates of their benefits.

EF Component	EF Estimate[1]	Volume	Evaluation method	EF Benefits (US$)	Comment
Kataragama Religious Festival	2 m^3/s	63 MCM	Total expenditure of bowser supply (Avoidance cost as a proxy)	12,375	Underestimate as satisfaction of pilgrims is not included
Yala National Park	2 m^3/s	63 MCM	Additional DWLC Expenditure in the dry season as a proxy (Avoidance Cost as a proxy)	1,470	Underestimate as this expenditure cannot eliminate the water shortage problem to the park completely
		51m^3/day (elephants' drinking water)	DWLC Expenditure for HEC mitigation in the dry season as a proxy	1,960	The EF estimate does not include the water need for fodder. The benefit estimate is much greater than HEC mitigation expenditure
		63 MCM	Foregone Tourism Revenue as a proxy	66,948	EF benefit estimate is an underestimate
		63 MCM	Foregone Recreational Value as a proxy	82,215	Based on estimate cited in CECB (2004)
Pilinnawa Wetland	250 (m^3/s) for 45 minutes every 2 years	3.7 MCM	BT land cover as a proxy	13,400	
			BT land cover as a proxy	315,100	
Pallassa (grassland)	NA	>3.7 MCM	BT land cover as a proxy	134,560	
YFMA	NA	NA	40 % of the Export value of lobster catch as a proxy (Market Price Method)	93,610	The relationship between the flow and the potential lobster catch is not established
			40 % of the Income of chank fishermen as a proxy (Market Price Method)	17,664	The relationship between the flow and the potential chank catch is not established

Source: Dissanayake and Smakhtin 2007

Notes: [1]CECB (2004) EF estimates are used; NA – Not Available; BT – Benefit Transfer; DWLC – Department of Wildlife Conservation

Requirements of the Yala Marine Protected Area and the Yala Fisheries Management Area

The YFMA is traditionally known as a good fishing ground for both edible and ornamental fish. Protected animals such as turtles, dolphins and whales are also frequently sighted. The Little Basses (coral) Reef has been identified as a highly environmentally sensitive area (NARA 2002). Freshwater has an important influence in the estuarine and in close offshore marine environments and the influence of river flow can extend into coral reef systems over 70 km offshore (Robins et al. 2005). Therefore, impact on coastal fish catches should be weighed against the economic benefits of water uses upstream. Saltwater intrusion, due to the tidal effects during the dry season in the Menik Ganga, extends approximately 7 km upstream from the mouth of the river (E. Wilson pers. comm. 2006), which could contaminate the groundwater. Reduced river flows and altered flow patterns may lead to deterioration of the water quality. The benefits of freshwater inflow from the Menik Ganga to the MPA and the river mouth should, therefore, be taken into account when assessing the costs and benefits of the EF.

There are about 40-50 fishing families who depend solely on the YFMA mainly targeting lobster, chank and skate. The estimates derived for the total export value of lobsters and the total income of the chank divers could be summed up and taken as a proxy measure for the benefits of EF to the MPA. It is assumed here that the current fish catch in the YFMA could be maintained by the total amount of EF that reaches the mouths of the main rivers flowing into the YFMA. Further research is necessary to quantify the relationships between freshwater inflow to the YFMA and fish catches. Another issue to consider is that, in addition to the water from the Menik Ganga, the Kumbukkan Oya, which is the neighboring river basin to the east of the Menik Ganga, bordering Ruhuna (Figure 1), also discharges a considerable quantity of freshwater (on average 472 MCM per annum) to the YFMA (Dharmasena 2005). Therefore, Menik Ganga freshwater flow (347 MCM) only contributes approximately 40 % of the benefits derived from the YFMA. Consequently, the benefits derived from EF in the Menik Ganga are estimated to be 40 % of the above values for lobster and chank fisheries, as given in Table 2.

Conclusions

The paper aimed to illustrate example tools and approaches which could: (i) provide hydrological data for EFA; (ii) perform quick preliminary EFA in conditions of limited data; and (iii) put an economic value on EF. All of these approaches are mostly ‘work in progress’, they have not been used in Sri Lanka before, and therefore are presented here primarily for the reasons of promoting the concepts of EF, creating awareness of the need to consider EF allocations as a legitimate use of water and stimulating discussion around these topics in the country.

Hydrological information (natural flow time series) is necessary regardless of the type of EFA method chosen and can also be used for different engineering applications. The hydrology-based desktop EFA method illustrated in this study and simplified without losing its major concept, which is the preservation of flow variability, is an example of the first step towards evaluating EF. Such hydrology-based desktop methods, developed elsewhere, need to be re-calibrated and tested in different physiographic environments (such as monsoon driven flow regimes of Sri Lanka) before they can be reliably applied. Hence, there is a need to further develop, modify and test existing methods in specific river basins.

The economic benefits valued in this study and attributed to environmental water allocations are significant when compared to the total value of the dry season paddy yield of US$567,000 (CECB 2004), which is a value likely to be exceeded by the total value of EF (if non-use values and other components of EF are included). The suggestions that were examined with regard to putting an economic value on various environmental water uses were also the 'first cut' and are quite simple approaches. They allow awareness to be raised regarding the potential and real damage that may be or is already occurring, due to neglecting the needs of the aquatic environment.

Acknowledgements

This study is part of the research project 'Environmental Flows: Theory and Practice', which is supported by the core funds of IWMI. We thank Mr. M. G. Gunathilake, District Engineer, National Water Supply and Drainage Board, Kataragama, Sri Lanka; Mr. Wasantha Ratnayake, Director, and Mr. Edmund Wilson, Deputy Director, Elephant Conservation, Department of Wildlife Conservation, Colombo, Sri Lanka; Mr. B. V. R. Jayaratne, Divisional Assistant Director, Department of Wildlife Conservation, Kataragama, Sri Lanka; Mr. Buddhika Vithana and Mr. Weragala, Department of Wildlife Conservation, Yala National Park, Sri Lanka; Ms. P. P. Dias, Head, Division of Hydrology, Department of Irrigation, Colombo, Sri Lanka; Dr. Champa Amarasiri, Head, Marine Biological Resources Division, National Aquatic Resources Research and Development Agency, Colombo, Sri Lanka; Mr. Anil Premaratne, Deputy Director-Planning, Coast Conservation Department, Colombo, Sri Lanka; Staff, Fisheries Statistics Division, Ministry of Fisheries and Aquatic Resources, Colombo, Sri Lanka, for the provision of useful information and insights during the course of this study.

References

CECB (Central Engineering Consultancy Bureau). 2002. Environmental Impact Assessment Report: Proposed Water Resources Development Works Across Menik Ganga at Kuda Gal Amuna. Kuda Gal Amuna Project, Sri Lanka, Department of Irrigation. p.137.

CECB (Central Engineering Consultancy Bureau). 2004. Environmental Impact Assessment Report: Quality Enhancement of Lunugamwehera National Park in the Menik Ganga and Kirindi Oya Basin by Harnessing the Development of Water Resources of Menik Ganga, Weheragala Reservoir Project, Sri Lanka Department of Irrigation. p. 290.

Dharmasena, G. T. 2005. Proposed Menik Ganga Reservoir: A Sensible Step. *Daily News*, April 28, 2005 (Sri Lanka).

Dissanayake, P.; Smakhtin, V. 2007. *Environmental and social values of river water: Examples from the Menik Ganga, Sri Lanka*. Working Paper 121. Colombo, Sri Lanka: International Water Management Institute. p.15.

Hughes, D. A.; Smakhtin, V. U. 1996. Daily Flow Time Series Patching or Extension: A Spatial Interpolation Approach Based on Flow Duration Curves. *Journal of Hydrological Sciences* 41 (6): 851 – 871.

Korsgaard, L. 2006. Environmental Flows in Integrated Water Resources Management: Linking Flows, Services and Values. Lyngby, Denmark: Institute of Environment and Resources, Technical University of Denmark. p. 60.

Meijer, K. S. 2007. Human Well-being Values of Environmental Flows: Enhancing Social Equity in Integrated Water Resources Management, Delft, the Netherlands: IOS Press. p.195.

NARA (National Aquatic Resources Research and Development Agency). 2002. Draft Report on Socioeconomic and Ecological Profile of the Fishery Management Area off Yala National Park. p. 35.

Richter, B. D.; Baumgartner, J. V.; Wigington, R.; Braun, D. P. 1997. How Much Water Does a River Need? *Freshwater Biology* 37: 231-249.

Robins, B. J.; Halliday, I. A.; Staunton-Smith, J.; Mayer, D. G.; Sellin, M. J. 2005. Freshwater-flow Requirements of Estuarine Fisheries in Tropical Australia: A Review of the State of Knowledge and Application of a Suggested Approach. *Marine and Freshwater Research* 56 (3): 343-360.

Smakhtin, V. U.; Masse, B. 2000. Continuous Daily Hydrograph Simulation Using Duration Curves of a Precipitation Index. *Hydrological Processes* 14: 1083-1100.

Smakhtin, V.; Weragala, N. 2005. *An assessment of hydrology and environmental flows in the Walawe river basin, Sri Lanka*. Working Paper 103. Colombo, Sri Lanka: International Water Management Institute (IWMI).

Tharme, R. E.; Smakhtin, V. U. 2003. Environmental Flow Assessment in Asia: Capitalizing on Existing Momentum. In: *Proceedings of the First Southeast Asia Water Forum, November (2003), Chiang Mai, Thailand*. Bangkok, Thailand: Thailand Water Resources Association. Volume 2: pp. 301-313.

USAID (United States Agency for International Development). 2005. Managing Conflict in Watersheds of Sri Lanka. Final Report. p. 58.