Climate Variability and Change—Hydrological Impacts (Proceedings of the Fifth FRIEND World Conference held at Havana, Cuba, November 2006), IAHS Publ. 308, 2006.

Estimation of minimum acceptable (compensatory) flow for the rivers of Costa Rica

SADĹ LAPORTE, ALEXIA PACHECO & CARLOS R. RODRIGUEZ

C.S. Estudios Básicos de Ingeniería. Instituto Costarricense de Electricidad, PO Box 10032-1000, San José, Costa Rica
slaporte@ice.go.cr

Abstract A project for establishing minimum acceptable flow (MAF) is presented. The approach synthesizes knowledge about the natural river flow variability in space and time under low flow conditions in terms of probabilities and relates these to ecological demands, as well the demands of selected instream water uses. A hydraulic model linking discharges to the extent of usable area for biological indicator species and for socio-economic uses allows development of different hydropower regulation schemes in search for the optimal one. Testing different water regulation scenarios and their impact on natural runoff conditions, as well as ecological conditions and selected water uses offers a basis for sustainable solutions, preserving biodiversity and striving at equity in water use. The approach can be applied in any river basin of the humid tropics adjusting the chosen biological and socio-economic indicators to the characteristics of a particular basin.

Key words low flow; compensatory runoff; sustainability; humid tropics

INTRODUCTION

Availability of water is a natural constraint for all living organisms. However, in connection to human activities, water also becomes an invaluable natural resource of increasing importance and which is exploited more and more intensively. One severe negative impact on water resources is when too little water left in the river as a result of water use/withdrawals. This is not only a serious menace to the aquatic/riparian biota and basin environment as a whole, but is also a threat to many instream flow activities such as water supply, recreation, etc., and a factor that tends to aggravate eventual pollution problems. A sustainable development of water resources implies a policy balancing the interests of anthropogenic water uses and the requirements of the biotic environment. In response to this a new project has been started at the Instituto Costarricense de Electricidad (ICE) in Costa Rica with the aim of developing a methodology for determination of the compensatory[1] runoff based on the estimation of the minimum acceptable flow (MAF). The main aim is to optimize the use of water resources under low flow conditions, corresponding to the lowest boundary set up by the environment and various instream water uses; sustainability, balance and precaution being in focus. The demand for sustainability includes consideration of such aspects as biodiversity, equity, gender and poverty. This methodology will offer a reliable tool for water resources management and planning at the national level. The project, which will be finalized in 2007, consists of five interrelated parts (Fig. 1), and has six aims:

(1) Assessment of the natural low flow conditions for rivers in Costa Rica and their variability in space and time.
(2) Establishment of criteria (indicators) coupled to the maintenance of natural amenities, and identification of the minimum acceptable flow that satisfies the indicator species selected.
(3) Identification of the MAF requirements from the defined water uses.
(4) Combination of the information in 1-3 to determine MAF for two case studies.
(5) Establishment of a tool for testing different hydropower regulation scenarios under low flow conditions with respect to MAF in terms of usable parts of the river.
(6) Development of necessary software and databases.

As obvious from the aim formulation, the project is interdisciplinary, which is reflected in the project staff consisting of hydrologists, hydropower engineers, biologists and socio-economists. The project is carried out in co-operation with a multidisciplinary team of Swedish and Norwegian scientists. Below different parts of the project are presented in more detail.

[1] "Compensatory runoff" is a term commonly used in Costa Rica referring to the river runoff that can sustain the natural biological functioning of a river after hydropower regulation.

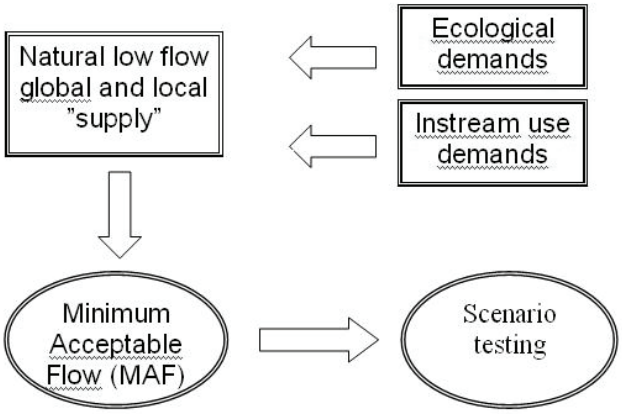

Fig. 1 Project blocks. "global" and "local" supply refers to the national and basin levels, respectively.

ASSESSMENT OF THE NATURAL LOW FLOW CONDITIONS

The first step when developing operational schemes for hydropower is correct description of the state of the runoff system in a historical perspective. Running water (lotic) ecosystems are extremely dynamic and reflect the natural variability of the water flow and the subsequent shifts in fluvial morphology. Before analysing the environmental impact of hydropower regulation schemes it is necessary to get a good idea of the regional runoff in terms of its temporal and spatial variation. This is usually done considering the **average** behaviour of runoff (assuming its stationarity), often described on the basis of a limited number of point observations and with no seasonal relevance. At the same time it is **extreme floods and droughts** that in combination with inappropriate water management may cause an irreversible deterioration of the water resources. The task is especially difficult if the observation records are short and scarce, since the credibility of the conclusions drawn on their basis must then be questioned. Regional approaches for the analyses of extreme low flow and dry spells (as well as floods) are generally preferred to an at-site analysis as it offers a more reliable ground for planning because the probability of observing an extreme event in a region is always bigger than the probability of observing such an event at one single station. A regional approach developed by Gottschalk *et al.* (2006b,c) and Sauquet *et al.* (2006) has been adopted in this study. This approach combines the theory of extreme events with an interpolation method considering basin support (i.e. development with area and time). It makes use of observed precipitation and runoff for the whole of Costa Rica, analysing dry spells jointly with the recession curves. Regionalization of flow duration curves (Krasovskaia *et al*., 2006), water balance elements (Gomez *et al*., 2006), low flow characteristics (Pacheco *et al*., 2006), and runoff moments has been accomplished. Regional curves and digital maps allow determining the above variables for any river basin in Costa Rica (see example in Fig.2).

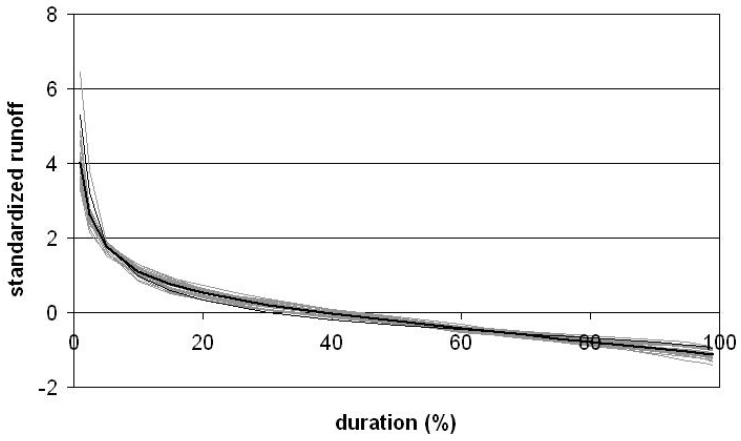

Fig. 2 Regional flow duration curve for basins of the Caribbean slope. Flow duration curves for individual basins are given as a background (from Krasovskaia *et al.*, 2006).

IDENTI FYING INDICATORS SPECIES AND THEIR DEMANDS TO MAF

Sustainability, balance and precaution represent the principle demands with respect to use of instream water, reflected in the directives for water resources development and management in many countries (e.g. Petts, 1996). Aquatic and riparian wildlife communities are dependent on instream flow that satisfies some basic ecological needs. During the last decade the environment has been recognised more and more as a legitimate user of water and some countries have even gone further claiming that "water belongs to the environment" (Dunbar *et al*., 1998).

This part of the project aims to identify biological demands to minimum flow with respect to useful biological indicators. Indicators are organisms or phenomena that have proven to be particularly sensitive to disturbance and which, in addition, are regarded as essential to sustain biodiversity. The maintenance of the natural biodiversity at some state is necessary for preventing the extermination of species. Some fish appear to be particularly useful as indicators, since they, by virtue of their food choice, integrate conditions on several trophic levels. In this study an Expert Panel approach (EPA) was utilized to identify first a ranked list of the indicator species to be used (Table 1) and then their habitat demands (Chavez *et al*., 2006). This approach proved to be very useful for humid tropical conditions with difficult access to the rivers. The expert opinions about the habitat demands of the indicator species were summarized using fuzzy logic into rules for tests of different scenarios (Gottschalk *et al.*, 2006a). In parallel, direct fish sampling was carried out in two study areas noting at the same time habitat conditions in terms of stream velocities, depth and substrate. The data were stored in a database attributing the information to pre-defined river stretches. This information was needed for the validation carried out for case studies.

Table 1 List of the selected indicator species.

Group	Family, genus or species	Common name
Mammalia	*Noctilio* sp	Bats
	Lutra longicaudus	River Otter
	Procyon sp	Racoon
Aves	Ardeidae	Egrets and herons
	Alcedinidae	Kingfisher
	Phalacrocoracidae	Cormorant
Amphibia	*Bufo* sp	Toads
	Smilisca sordida	Tree frog
	Centrolenidae	glass frogs
Reptilia	*Rhinochlemmys*	Fresh water turtle
	Basiliscus sp	Jesus Christ lizard
	Leptophis sp	snake
Osteichthyes	*Joturus pichardi*	Hog mullet
	Sicydium altum	Gobiid
	Parachromis dovii	Rainbow bass
	Agonostomus monticola	Mountain mullet
	Brycon sp	Tetra
	Poecilia gilli	Molly

IDENTIFYING THE DEMANDS TO MAF FROM WATER USES

Within the framework of the project, specific demands for MAF from different water uses (e.g. domestic, fishing, agriculture, tourism, etc.) in two study areas were quantified. The data were collected with the help of personal interviews with stake-holders, questionnaires and studies of concessions for water use. The data were stored in a database attributing information to each river stretch (Table 2). Together with purely quantitative estimates of requirements to MAF from the stake-holders, qualitative information related to gender, family size and composition, main income source and economic activity were also collected during personal interviews. This qualitative information provides an important background for testing regulation schemes with special foci on sustainability, equity, poverty and gender.

Table 2 An example of data collected on water uses.

GENERAL LOCATION			
Basin	Savegre	Sector	3 Silencio – Río Blanco
Place	Santo Domingo		
Informant	Alfredo Grajal Gambo. From small store 100 m to south. White house at right		
ACTIVITY DESCRIPTION			
Use	Watering		
Name	Alfredo's Farmer		
Code	02-01-1	Site type	Point
Period of use	Season	Dry	
	Months	January to April	
	Days	Every day	
	Comments	5 hours by day. 3 hours in the morning (6–9) and 2 in the afternoon (3–5).	
Activity description	Crops: Melon and water melon Extension: 1–2 ha $year^{-1}$ Consume 6–8 L s^{-1} when uses water in short distances (less than 100 m) and 3–4 L s^{-1} otherwise. He rents the equipments for watering.		
Estimated water discharge	Average: 5 L s^{-1} = 18 m^3 h^{-1} × 5 h day^{-1} = 90 m^3 day^{-1} × 30 days = 2700 m^3 $month^{-1}$ × 4 months = 10 800 m^3 total during period of use		
Coordinates (CRTM)	498 049.93 1 044 153.00		
Photography			
Point description	From small store in Santa Domingo, 200 m on the way to bridge. First gate on left hand side, crossing the small river		

DETERMINATION OF MAF FOR CASE STUDY AREAS

The approach for establishing MAF synthesizes the knowledge about the natural river flow variability in space and time under low flow conditions in terms of probabilities and relates these to ecological demands outlined on the basis of the selected indicator species, as well the demands from the selected instream water uses. A simple hydraulic model links discharges to the extent of usable area for indicator species and water uses in terms of depths and velocities (Gottschalk *et al.*, 2006a). It allows testing of different hydropower regulation scenarios and their impact to find the optimal one. The modelled results are validated on field data for fish presence in different sectors of the river. Figure 3 shows a validation case for the Savegre River.

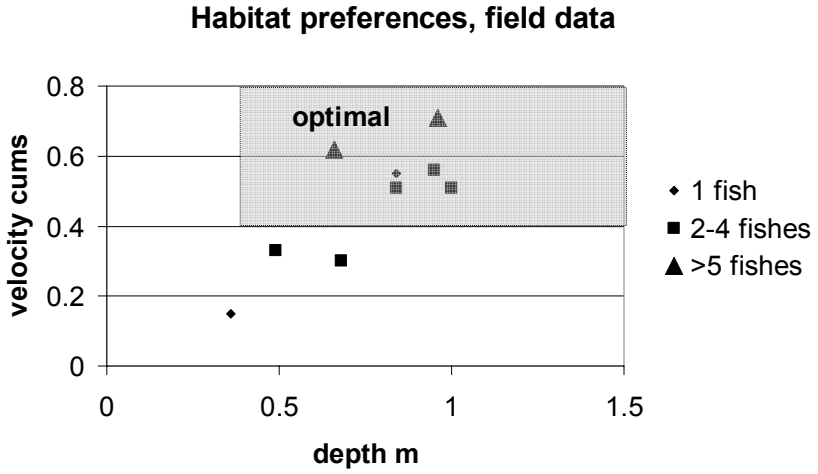

Fig. 3 Habitat preferences in terms of depth & velocity with optimal conditions shaded, field validation (from Gottschalk *et al.,* 2006a).

CONCLUSIONS

The approach described is now being introduced at Instituto Costarricense de Electricidad (ICE) and the project will be finished in spring 2007. When installed, the approach will make it possible to test different hydropower regulation scenarios for compensatory runoff in search of the optimal one. Consideration of environmental as well as socio-economic demands in such scenarios facilitates identification of the solutions that are sustainable, i.e. safeguarding biodiversity as well as equity of water use. Databases with biological and socio-economic data from the field, as well as information on identified biological and socio-economic indicators and their demands, offer well-structured reference materials for other environmental and socio-economic studies in the country and in the humid tropics. The approach can be applied in any river basin adjusting the chosen biological and socio-economic indicators to the characteristics of a particular basin.

Acknowledgements The project is being carried out with a financial support from the Swedish International Development Agency (SIDA) which help is gratefully acknowledged. Acknowledgements are also due to the University of Oslo, Norway, for granting a possibility to participate in the project to their scientists and supporting knowledge transference.

REFERENCES

Chavez, A., Krasovskaia, I. & Gottschalk, L. (2006) Environmental demands for sustainable regulation schemes in humid tropics. In: *Climate Variability and Change—Hydrological Impacts* (Proc. Fifth FRIEND World Conference held at Havana, Cuba, November 2006). IAHS Publ. 308. IAHS press, Wallingford, UK (this volume).

Dunbar, M. J., Gustard, A., Acreman, M. C. & Elliott, C. R. N. (1998) Overseas approaches to setting River Flow Objectives. Environment Agency and Institute of Hydrology, R&D *Technical Report W6-161*.

Gómez, F., Krasovskaia, I., Gottschalk, L. & Leblois, E. (2006) Interpolation of water balance components for Costa Rica. In: *Climate Variability and Change—Hydrological Impacts* (Proc. Fifth FRIEND World Conference held at Havana, Cuba, November 2006). IAHS Publ. 308. IAHS Press, Wallingford, UK (this volume).

Gottschalk, L., Gómez, F., Krasovskaia, I. & Chaves, A. (2006a) Estimation of the "minimum acceptable flow" for rivers of Costa Rica. Nordic Hydrological Conference NHK-2006, Denmark (accepted).

Gottschalk, L., Krasovskaia, I., Leblois, E. & Sauquet, E. (2006b) Mapping runoff characteristics in a river basin. In: *Climate Variability and Change—Hydrological Impacts* (Proc. Fifth FRIEND World Conference held at Havana, Cuba, November 2006). IAHS Publ. 308. IAHS Press, Wallingford, UK (this volume).

Gottschalk, L., Krasovskaia, I., Leblois, E. & Sauquet, E. (2006c) Mapping of mean and variance of runoff in a river basin. *HESS Discuss.* **3**, 1–35. http://www.hydrol-earth-syst-sci-discuss.net/3/1/2006/.

Krasovskaia, I., Gottschalk, L, Leblois, E. & Pacheco, A. (2006) Regionalization of flow duration curves. In: *Climate Variability and Change—Hydrological Impacts* (Proc. Fifth FRIEND World Conference held at Havana, Cuba, November 2006). IAHS Publ. 308. IAHS Press, Wallingford, UK (this volume).

Pacheco, A., Gottschalk, L. & Krasovskaia, I. (2006) Regionalization of low flow in Costa Rica. In: *Climate Variability and Change—Hydrological Impacts* (Proc. Fifth FRIEND World Conference held at Havana, Cuba, November 2006). IAHS Publ. 308. IAHS Press, Wallingford, UK (this volume).

Petts, G. E. (1996) Water allocation to protect river ecosystems. *Regulated Rivers: Research & Management* **12,** 353–365.

Sauquet, E., Gottschalk, L., Krasovskaia, I., Leblois, E. (2006) Predicting river flow statistics at ungauged locations—a hydrostochastic approach. In: *Large Sample Basin Experiments for Hydrological Model Parametization: Results of the Model Parameter Experiment–MOPEX* (Proceedings of the Paris (2004) and Foz de Iguaçu (2005) workshops). IAHS Publ. 307. IAHS Press, Wallingford, UK (in press).