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A SURVEY OF METHODS FOR SETTING MINIMUM INSTREAM FLOW STANDARDS IN THE CARIBBEAN BASIN

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ABSTRACT

To evaluate the current status of instream flow practices in streams that drain into the Caribbean Basin, a voluntary survey of practising water resource managers was conducted. Responses were received from 70% of the potential continental countries, 100% of the islands in the Greater Antilles, and 56% of all the Caribbean island nations. Respondents identified 'effluent discharges', 'downstream water quality' and 'existing extraction permits' to be the most common sources of instream flow conflicts. In 75% of the countries, some type of 'formal procedures' exist for reviewing permit applications for freshwater extraction. In 82% of the countries, effluent discharge permits state the amount of effluent that can be discharged into a water body while only 69% require that surface water extraction permits explicitly state the quantity of water that can be extracted. In setting instream flow requirements, record low flow is used over 83% of the time. Freshwater fish were identified as the most important aquatic organism but no country 'always' considers the ecology or habitat requirements of aquatic species in their instream flow determinations and nearly 70% of the respondents indicated that multivariate, ecological-based methods are 'never' used in their country. Survey responses also indicate there is a notable lack of public involvement during the issuing of water permits. Moreover, over 80% of the countries do not provide public announcements or hearings during the permit process. In summary, this survey indicates that while there is a widespread recognition of the need for instream flows, there is a general lack of regionally based information and public involvement regarding stream flow determination. Published in 2003 by John Wiley & Sons, Ltd.

KEY WORDS: rivers; instream flow methodologies; Caribbean

INTRODUCTION

Although the legal right to divert stream water for off-site uses has been recognized for centuries, the notion that instream flows are valuable and protectable interests is more recent (Lamb and Doerksem, 1987). This protection is based on the recognition that many private and public interests require that water flows within stream channels. These instream flows are typically needed for hydropower, navigation, fisheries, waste treatment, recreation, and the maintenance of biodiversity. Consequently, the concept of maintaining some minimum instream flows to protect aquatic resources has become part of national and international customary law, pollution abatement treaties, and United Nation conventions (Utton and Utton, 1999).

Regardless of the legal, environmental, or economic merit of establishing instream flows, the tasks of objectively determining what flows are necessary to maintain a particular resource or ecosystem is a complex process (for reviews see Lamb and Doerksen, 1987; Reiser *et al.*, 1989; Beecher, 1990, King *et al.*, 1999). In practice, minimum instream flow standards are usually based on some combination of the following: historic discharge, channel morphology, water quality, the ecology of aquatic species, empirical evidence, modelling, and ultimately arbitration between user groups. Actual standards can range from simple statements regarding minimum water depth to comprehensive descriptions of flows that vary as functions of life cycles of critical species, environmental, and socioeconomic conditions. For a particular area, instream flow requirements will depend on local and downstream conditions and can vary considerably within areas of similar climate and hydrology (Beecher, 1990).

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Recent reviews indicate that the majority of instream flow research has originated in relatively dry areas of western North America, South Africa, and Australia (Dunbar *et al.*, 1998; King *et al.*, 1999). Moreover, there has been very little published research or accounts of instream flows in most of South and Central America and much of what has been recently published is limited to the Caribbean Islands (Sutton *et al.*, 1997; Gonzalez-Caban and Loomis, 1997; Fievet, 1999; Johnson and Covich, 2000; Scatena and Johnson, 2001). To evaluate the current status of instream flow practices in streams that drain into the Caribbean Basin, a voluntary survey of practising resource managers was conducted. This paper summarizes the responses to that survey and discusses the implication of current instream flow practices on the management of water resources in the region.

STUDY AREA

The survey area includes countries that drain into the Caribbean sea (Table I). A wide variety of climatic and hydrologic conditions exist within the region, including extremely wet cloud forests that have annual precipitation of more than 5000 mm/a, to extremely dry, streamless areas. Most watersheds are relatively small and experience a large portion of their annual precipitation and runoff in a few large events. Headwater channels typically have steep gradient and are boulder lined while meandering to braided alluvial channels traverse lowland areas. Compared to temperate areas where most instream flow research has been conducted, streams within the region have definable, but relatively minor, seasonal changes in water temperature and base flow. They are subject to catastrophic floods (Gupta, 1988; Ahmad *et al.*, 1993), frequent droughts (Larsen, 2001), and a variety of anthropogenic pressures (Pringle *et al.*, 2000). Water quality has also been declining rapidly because of increases in the discharge of untreated domestic and industrial wastewater, irrigation return flow, and non-point-source pollution (Pringle and Scatena, 1999).

Freshwater bodies in the study region support a wide variety of endemic, Pan-Caribbean and Pan-Tropical organisms including fish, eels, shrimp, snails, and crabs. Diversity and abundance of these aquatic organisms typically decrease inland and while many organisms spend most of their lives in freshwater, they originate or reside

Table I. Caribbean basin countries that responded to instream flow questionnaire

Caribbean islands countries
Anguilla
Cuba
Dominican Republic
Grenada
Guadeloupe
Haiti
Jamaica
Montserrate
Puerto Rico
St Georges
St Lucia
Trinidad and Tobago
Caribbean islands which responded that they lack surface water diversions and therefore the questionnaire was not applicable
Barbados
Cayman islands
Turk and Caicos islands
Continental Caribbean countries
Belize
Colombia
Costa Rica
Guatemala
Guyana
Mexico
Suriname

in coastal areas during their developmental stages (Covich and McDowell, 1996). Therefore maintaining migratory pathways to and from coastal areas is necessary to maintain the abundance and diversity of freshwater species. Recent studies in the region have demonstrated that both large and small dams can disrupt migratory patterns and populations of common aquatic organisms (Holmquist *et al.*, 1998; Fievet, 1999; Benstead *et al.*, 1999). Nevertheless, the number of water diversions and dams in the region is expected to increase dramatically in the next two decades and will double or triple in certain areas (Petts, 1990; Pringle *et al.*, 2000; World Commission on Dams, 2000).

A variety of instream uses of water are common within the region. Some of the most widely known and visited recreation sites are recognized for their freshwater resources (e.g. Ocho Rios in Jamaica, rafting in Costa Rica etc.). Subsistence, commercial, and recreational freshwater fishing also exist throughout the region. However, no large population is known to depend entirely on freshwater organisms for subsistence nor are there any large, well organized special interest groups that lobby to protect or enhance freshwater fisheries (e.g. Trout Unlimited in the United States). However, as several Central American countries have recently passed legislation to promote hydropower, there is increased interest in the timing and magnitude of instream flows upstream and downstream from hydropower projects (Petts, 1990; World Commission on Dams, 2000). Additionally, a large portion of the population does not have access to potable water and depends directly on instream flow for domestic use. Because of the lack of available water for both domestic and commercial uses, developing infrastructure to increase the availability of off-site water is a major goal of local, national and international organizations. Unfortunately, simulations of future water demand under various scenarios of climate and population change indicate that the existing level of water stress in the region will increase and large economic expenditures will be needed by 2025 to maintain present levels of off-site water use (Vorosmarty *et al.*, 2000). Most of the projected increases in demand are due to increases in population rather than climatically induced changes in water abundance.

METHODS

A five-page survey was developed in Spanish and English and was reviewed by three technical translators and five practising Caribbean water resource experts before being distributed. In June 2000, 136 survey instruments were mailed to individuals and organizations in 35 Caribbean countries. All the individuals and organizations that were sent the questionnaire were active professionals in the management of water resources in their country and were selected from the mailing lists of the International Institute of Tropical Forestry, the Meso-American AMIGO Program, and lists of attendees at recent conferences on regional water resource issues. Although the individuals were not necessarily experts in instream flow issues, their responses are considered indicative of the state-of-the-practice in their country.

The survey took approximately 15 minutes to complete and was divided into four sections: (1) instream flow conflicts; (2) granting surface water extraction permits; (3) methods for determining instream flow; and (4) critical species. The majority of the questions required a ‘yes/no’ response, or a four-category response: ‘never’, ‘rarely’, ‘usually’, or ‘always’. These questions were analysed according to the percentage of responses in each category. When multiple responses from the same country were received, only the responses from the senior official water authority were tallied.

RESULTS

Level of response

Of the 35 countries that were sent questionnaires, responses were received from 22 countries. Most of the responses were received within four months of when they were mailed. However, to obtain responses from several key countries, additional contacts and follow-ups had to be made. Ultimately, 70% of the potential continental countries, 100% of the Greater Antilles, and 56% of the island nations responded (Table I). Three island countries, Barbados, Turk and Caicos, and the Cayman Islands, responded that they could not answer the questionnaire because they do not have permanent freshwater streams and depend entirely on groundwater. Therefore these

countries were not included in the analysis and the results are based on the responses from the remaining 19 countries. Of these responses, 81% were from employees of local governments, and 53% were from water authorities All responses were from individuals in positions that require knowledge of the general regulations and conflicts regarding surface water in the country.

The comparison of multiple responses from the same country were generally consistent. For example, three questionnaires were received from Trinidad and Tobago. Two of the respondents were employees of the central water authority and one respondent was from a university research institute. All of these respondents were in agreement on questions regarding the frequency of techniques used, granting permits and critical species. However, the two government employees considered that 'existing extraction permits' and 'coastal resources' caused a greater source of conflict than was thought by the academic researcher. Similar consistency was also found between respondents from other countries. Considering the internal consistency within country, and the authority of the respondents, the questionnaire can be considered to provide a realistic representation of the situation in the region.

Instream flow conflicts

The first category of questions was designed to determine the common water uses that cause the most conflict or concern related to instream flows. Respondents identified 'effluent discharges', 'downstream water quality' and 'existing extraction permits' to be the most common sources of instream flow conflicts (Figure 1). Moreover, 69% of the respondents said that 'effluent discharges' were either 'usually' or 'always' a cause of instream flow conflicts. When asked to rank the relative importance of conflicts, 'downstream water quality' and 'effluent discharges' were also identified as the most important sources of instream flow conflicts (Table II). Conflicts caused by existing extraction permits were considered as either a first of second cause of instream flow conflicts in 25% of the responses. In the written comments that accompanied these questions, the most common conflicts related to existing permits in Central America were those associated with the development of new hydropower projects. In both continental and island areas, 'navigation' and 'coastal resources' were ranked as the lowest source of instream flow conflicts.

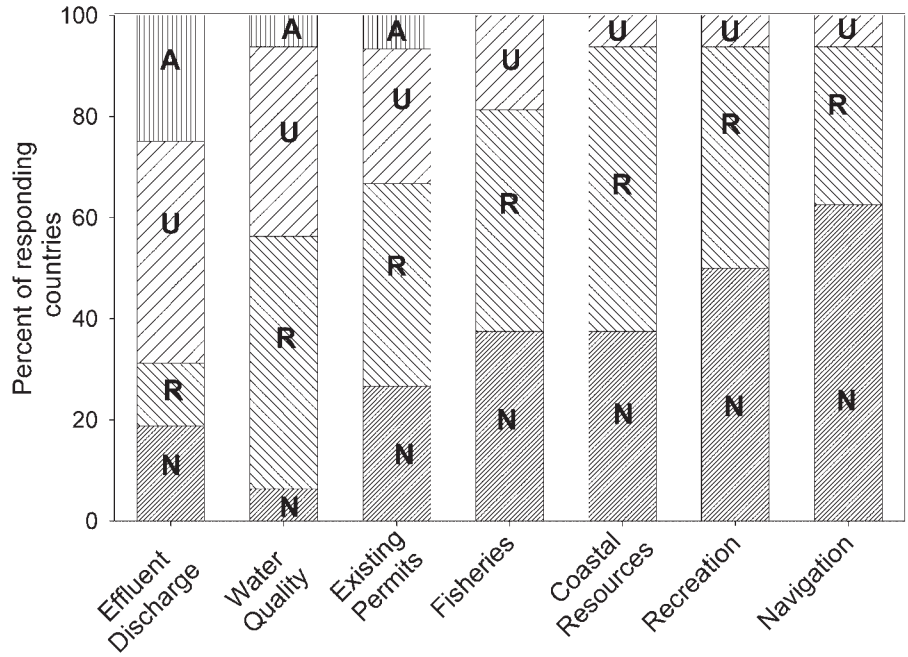

Figure 1. Percentage of response from all responding countries to the question 'What instream flow uses are currently causing the most conflict in your geographic area? Please check the level of conflict for each instream use' N = never causes conflict, R = rarely causes conflict, U = usually causes conflict, A = always causes conflict

Table II. Summary of the responses to the question 'Rank the common instream uses that cause the most conflict in your area, from 1 (causes least conflict) to 8 (causes most conflict)'

Instream use	Countries that ranked use as the greatest or second greatest cause of conflict (%)
Downstream water quality	66.7
Effluent discharges	50.0
Existing extraction permits	25.0
Freshwater fisheries	8.3
Recreation	8.3
Coastal resources	0.0
Navigation, boating, rafting	0.0

Granting surface water extraction permits

The second group of questions assessed how water extraction permits and effluent discharge permits are issued. The responses indicated that within the region a variety of government agencies are concerned with issuing and reviewing water use permits. These agencies include water authorities, departments of agriculture, departments of environmental and coastal protection, and hydrological and meteorological services.

In 75% of the countries, some type of 'formal procedures' exist for reviewing permit applications for freshwater extraction (Table III). In 56% of the countries, the agency that issues surface water extraction permits is the same organization that issues effluent discharge permits. Although multiple organizations are consulted during the permit process in 60% of the countries, only 17% of the countries post public announcements or have public hearings prior to issuing water extraction permits.

In 82% of the countries, effluent discharge permits state the amount of effluent that can be discharged into a water body (Table III). However, fewer countries (69%) require that surface water extraction permits explicitly state the quantity of water that can be extracted from a water body. Even fewer countries (56%) define extraction limits in groundwater permits. When asked how long water extraction permits are valid, only 21% of the respondents answered with explicit time limits. The majority of respondents answered with 'do not know'. This is apparently because extraction and discharge permits are typically issued to water authorities and are considered to be relatively permanent. For the countries that do have explicit time limits, permits are issued for up to ten years.

Table III. Percentage of 'yes' responses from all responding countries on questions related to granting water-related permits

	Yes (%)
Review process	
Are there formal procedures for reviewing permit applications?	75.0
Are different governmental and non-governmental organizations consulted during the permit process?	60.0
Does the same organization issue permits for surface water extraction and surface water pollution discharge?	55.6
Does the same organization issue permits for surface water extraction and groundwater extraction?	90.9
Are public announcements issued during the permit process?	16.7
Are public hearings held prior to issuing permits?	16.7
Permit specifications	
Do surface water extraction permits state the amount of water that can be extracted?	69.2
Do surface water discharge permits state the amount of effluent that can be discharged?	81.8
Do groundwater extraction permits state the amount of groundwater that can be extracted?	55.6
Related environmental regulations	
Are there standardized methods for estimating instream flow needs in your geographical area?	54.5
Are there standardized methods or guidelines for estimating stream flows in ungauged watersheds?	69.2
Are there water quality standards for streams and rivers?	86.7
Are their regulations regarding development in riparian buffer zones?	80.0

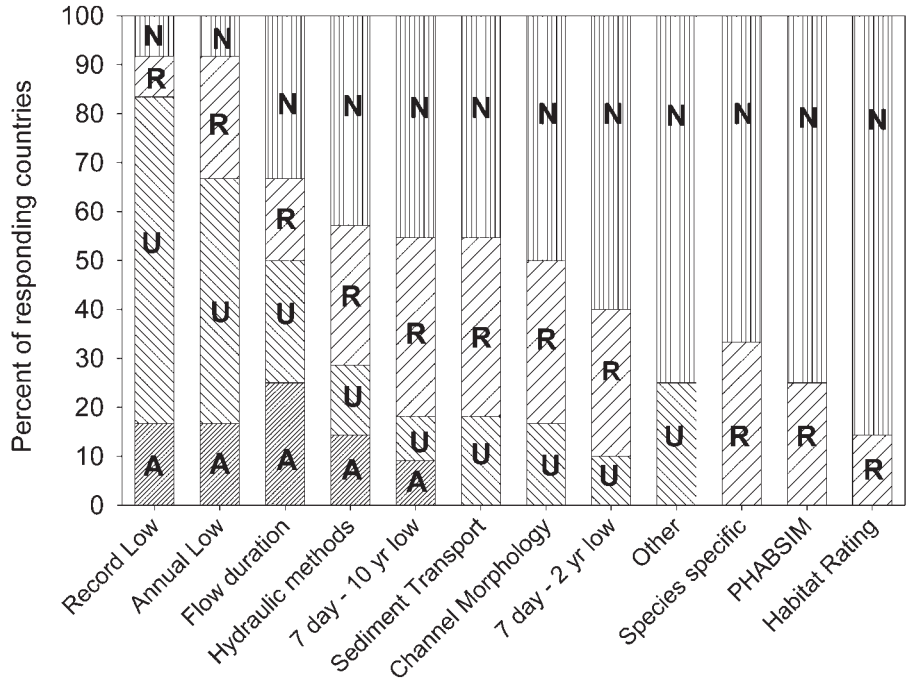

Figure 2. Percentage of response from all responding countries to the question 'Which of the following methods are used to define instream flows in your geographic area?' N = never used, R = rarely used, U = usually used, A = always used

Determining instream flow requirements

In 69% of the countries there are locally established methods for estimating stream flows in ungauged watersheds and 87% have defined some water quality standards for streams (Table III). The respondents also indicated that 55% of their countries had some type of standardized methods for determining instream flow requirements. The most widely used methods rely on historic low flows (Figure 2). In estimating instream flow requirements, record low flows were reported to be 'usually' or 'always' used over 83% of the time.

Determination of instream flow requirements using either hydraulic criteria (e.g. flow velocity, depth etc.) or channel geometry (e.g. wetted perimeter, pool depth etc.) is not widely practised in the region (Figure 2). Moreover, respondents indicated that some aspect of sediment transport and channel geometry are 'usually' considered in less than 20% of the countries, while hydraulic criteria are 'always' considered in 15% of the countries. Nevertheless, these approaches are more frequently used than techniques that require information on the ecology or habitat requirements of aquatic species. Furthermore, only two countries (Mexico and Puerto Rico) use the habitat-based PHABSIM model that is the most widely used model in North America (Reiser *et al.*, 1989; Beecher, 1990). Even in these countries, the PHABSIM model is used only 'rarely'. Only four countries (Mexico, Puerto Rico, Colombia and Guadeloupe) reported using 'species specific requirements' to determine instream flows requirements. No country 'always' considers the ecology or habitat requirements of aquatic species in their instream flow determinations.

Critical species

In this group of questions the respondents were asked to rate what common groups of aquatic organisms have been, or should be, considered when determining instream flow requirements (Table IV). Over 50% of the respondents indicated that the aquatic organism in question had been given some level of consideration. However, the most common response was that the organism in question 'had been considered without adequate information'. The second most common response was that the organism 'does not need to be considered'. Respondents indicated that 'fish' and 'coastal and estuarine organisms' need the most consideration when determining instream flows.

Table IV. Percentage of response from all responding countries to the question 'To the best of your knowledge, which of the following organisms have been or should be considered in instream flow determinations?'

Organisms	Has been considered using adequate information	Has been considered without adequate information	Should be considered in most water permits	Does not need to be considered
Fish	7.7	53.8	23.1	15.4
Coastal or estuarine	8.3	50.0	25.0	16.7
Other organisms	14.3	42.9	14.3	28.5
Freshwater shrimp	18.2	36.3	9.1	36.4
Manatee	11.2	44.4	0	44.4
Crabs	9.1	45.4	0	45.5

Region-wide, freshwater shrimp, manatees, and crabs received relatively low priorities. However, in the Caribbean islands where manatees are present and protected, 80% of the countries indicated that manatees should be considered when developing instream flow needs. Likewise, 75% of the Caribbean islands responded that shrimp should be considered. On all of these islands freshwater shrimp are harvested for local consumption. Freshwater crabs were not considered to be important enough to be considered in 38% of the Caribbean responses and in 67% of the continental responses. Nevertheless, freshwater crabs are also harvested throughout the region.

DISCUSSION AND CONCLUSION

Responses to the questionnaire indicate that water resource managers in the region acknowledge the importance of instream flows and are being confronted with complex instream flow-related conflicts. Nevertheless, the responses clearly indicate that water permits are vague and the procedures for granting permits and defining minimum instream flows are not well defined. For example, most permits apparently do not state the amount of water that can be extracted or the length of time for which a permit is valid. Overall, the more populated countries (e.g. Mexico, Cuba, Puerto Rico) and those that depend heavily on hydroelectric power (e.g. Costa Rica, Guatemala) have the most developed instream flow standards and permit process. However, even these areas rarely use the multivariate, ecologically based modelling techniques that are widely used elsewhere.

The respondents also indicated that instream flow considerations are driven by concerns related to water quality and effluent management, rather than fisheries, recreation, or navigation. Nevertheless, over 50% of the respondents indicated that aquatic organisms had been given some level of consideration when extraction permits were issued (Table IV). However, habitat-based models that consider the specific needs of important species are rarely used and the most common method for setting instream flows appears to be the historic low flow level. Basing instream flows solely on historic low flows is widely acknowledged to be inadequate to maintain aquatic abundance and diversity because it effectively maintains the river in otherwise rare drought conditions (Beecher, 1990). Likewise, in most situations historic low flows are also inadequate to dilute and process typical effluent discharges. Therefore, in most cases neither water quality nor aquatic populations will be maintained where instream flows are kept at historic low flow levels for extended periods. The relatively high percentage of responses indicating that species requirements had been considered 'without adequate information' underscores the need for additional research in defining the habitat and flow requirements of common species in the region. This is especially critical where migratory aquatic species are common and reproductive cycles and behaviour can be closely related to changes in stream flow. Therefore, research efforts to understand the basic life histories and environmental requirements of common aquatic species should be promoted.

Survey responses also indicate that there is a notable lack of public involvement during the issuing of water permits. Although permits play a central role in water allocation and both downstream water quality and existing permits are common causes of instream flow conflicts (Table II), over 80% of the countries do not provide public announcements or hearings during the permit process (Table III). Apparently, the current trends in community-based, participatory watershed management have not infiltrated into this basic component of water resource

allocation and management. Therefore, efforts to develop local capacity in reviewing, granting, and tracking water extraction permits should receive greater consideration by local and multinational organizations that are concerned with water resources.

In summary, this survey indicates that while there is a widespread recognition of the need for instream flows, there is a general lack of regionally based information and public involvement regarding stream flow determination. Assuming that 30% of the countries that did not respond to the survey do not have any established instream flow programmes, and that enforcement is often lacking even when regulations exist, the actual situation is probably worse than suggested here. The survey does indicate that there is considerable need and demand for further research and development in this field. Hopefully, the information provided here will be useful in clarifying and advancing instream flow analysis within the region.

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REFERENCES

Ahmad R, Scatena FN, Gupta A. 1993. Morphology and sedimentation in Caribbean Montane streams: examples from Jamaica and Puerto Rico. *Sedimentary Geology* **85**: 157–169.

Beecher HA. 1990. Standards for instream flows. *Rivers* **1**(2): 97–109.

Benstead JP, March JG, Pringle CM, Scatena FN. 1999. Effects of water abstraction and damming on migratory tropical stream biota. *Ecological Applications* **9**(2): 656–688.

Covich AP, McDowell WH. 1996. The stream community. In *The Food Web of a Tropical Rain Forest*, Reagan D, Waide RB (eds). University of Chicago Press: Chicago; 433–459.

Dunbar MJ, Gustard A, Cereman MC, Elliott CRN. 1998. *Overseas Approaches to Setting River Flow Objectives*. Institute of Hydrology, R&D Technical Report W6-161.

Fievet E. 1999. An experimental survey of freshwater shrimp upstream migration in an impounded stream of Guadeloupe Island, Lesser Antilles. *Archiv für Hydrobiologie* **144**(3): 339–355.

Gonzalez-Caban G, Loomis J. 1997. Economic benefits of maintaining ecological integrity of Rio Mameyes, in Puerto Rico. *Ecological Economics* **21**: 63–75.

Gupta A. 1988. Large floods as geomorphic events in the humid tropics. In *Flood Geomorphology*, Baker VR, Kochel RC, Patton PC (eds). John Wiley & Sons: New York; 301–315.

Holmquist JG, Schmidt-Gengenbach JM, Yoshioka BB. 1998. High dams and marine–freshwater linkages: effects on native and introduced fauna in the Caribbean. *Conservation Biology* **12**: 621–630.

Johnson SL, Covich AP. 2000. The importance of night-time observation for determining habitat preferences of stream biota. *Regulated Rivers: Research and Management* **16**: 91–99.

King J, Tharme R, Brown C. 1999. *Definition and Implementation of Instream Flows*. Contributing paper for Dams, Ecosystem Functions and Environmental restoration. http://www.dams.org [June 2001].

Lamb BL, Doerksem HR. 1987. Instream water use in the United States—water laws and methods for determining flow requirements. In *National Water Summary 1987*. Water Supply Paper 2350, US Geological Survey: Washington, DC; 109–116.

Larsen MC. 2001. Analysis of 20th century rainfall and streamflow to characterize drought and water resources in Puerto Rico. *Physical Geography* **22**: 494–521.

Petts GE. 1990. Regulation of large rivers: problems and possibilities for environmentally-sound river development in South America. *Intercencia* **15**(6): 388–395.

Pringle CM, Scatena FN. 1999. Aquatic ecosystem deterioration in Latin America and the Caribbean. In *Managed Ecosystems: The Mesoamerican Experience*, Hatch LU, Swisher ME (eds). Oxford University Press: New York; 104–114.

Pringle CM, Scatena FN, Paaby-Hansen P, Nunez-Ferrera M. 2000. River conservation in Latin America and the Caribbean. In *Global Perspectives on River Conservation: Science, Policy and Practice*, Boon PJ, Davies BR, Petts GE (eds). John Wiley & Sons: Chichester; 41–77.

Reiser D, Wesche TA, Estes C. 1989. Status of instream flow legislation and practices in North America. *Fisheries* **14**(2): 22–29.

Scatena FN, Johnson SL. 2001. *Instream-flow Analysis for the Luquillo Experimental Forest, Puerto Rico: Methods and Analysis*. USDA Forest Service General Technical Report IITF-GTR-11.

Sutton RJ, Miller WJ, Patti SJ. 1997. Application of the instream flow incremental methodology to a tropical river in Puerto Rico. *Rivers* **6**(1): 1–9.

Utton AE, Utton J. 1999. The international law of minimum stream flows. *Colorado Journal of International Environmental Law and Policy* **10**(1): 7–37.

Vorosmarty CJ, Green P, Salisbury J, Lammers RB. 2000. Global water resources: vulnerability from climate change and population growth. *Science* **289**: 284–288.

World Commission on Dams. 2000. *Dams and Development*. The Final Report of the World Commission of Dams. http://www.dams.org [June 2001].