Hydrology in the Humid Tropic Environment (Proceedings of a symposium held at Kingston, Jamaica, November 1996). IAHS Publ. no. 253, 1998.

Development of a national water quality monitoring programme for Belize

J. D. STEDNICK, D. M. GILBERT
Department of Earth Resources, Colorado State University, Fort Collins, Colorado 80523, USA

M. D. LEE
Department of Natural Resources and Conservation Biology, Zamarano University, Tegucigalpa, Honduras

Abstract Belize has an area of 21 400 km^2 and a population of approximately 200 000. Although the average population density is low, concentrated land-use activities near populated areas have the potential to affect water quality. Land-use activities are shifting from small low impact traditional farming systems (milpa) to large slash and burn areas and commercial citrus production. An increasing population leads to increased development and increased industrial activity. Most major rivers drain into the Caribbean Sea and in most situations pose little known environmental consequences. However, Belize has the world's second largest barrier reef that is strongly promoted in their ecotourism industry and thus can ill afford any natural resource impact. The potential effects of land-use activities on water quality need to be evaluated. The Belize Environmental Protection Act of 1993 requires a comprehensive environmental monitoring programme. This paper discusses the development of a national surface water quality monitoring programme for Belize.

Desarrollo de un proyecto nacional para el monitoreo de la calidad del aqua en Belice

Resumen Belice se extiende sobre un area de 21 400 km^2 y tiene una población de aproximadamente 200 000 habitantes. Aunque la densidad media de la población es baja, el uso intensivo de la tierra en la cercanía de los centros poblados podría potencialmente afectar la calidad del agua. El uso de la tierra está cambiando de pequeños sistemas de agricultura tradicionales (milpas) a sistemas manyores de "corte y quema" y de producción comercial de cítricos. Una poblacíon en crecimiento conlleva a un mayor desarrollo y a un incremento en la actividad industrial. Lo mayor parte de los ríos principales desembocan en el Mar Caribe, y en la mayoría de los casos presentan pocas consecuencias ambientales conocidas. Sin embargo, Belice tiene la segunda barrera de coral más grande del mundo, la cual es una de las mayores atracciones turísticas y por lo tanto no se puede permitir cualquier tipo de impacto ambiental. Se necesita evaluar los efectos potenciales del uso de la tierra en la calidad del agua. El Acta de Protección de Calidad Ambiental de Belice de 1993 exige una programa nacional para Belice de monitoreo de calidad de las aguas superficiales.

INTRODUCTION

Water quality monitoring programmes often seek to determine what are naturally occurring concentrations of particular water quality constituents and how these constituents may be affected by land-use activities. Water quality concentrations result from the environmental interactions of water with soils, geology, vegetation and animals and their modification by land use to define a water with particular chemical, physical and biological properties. The ideal monitoring programme is linked to a hydrometeorological network and a land-use planning (and regulatory) framework.

One approach to establish a national water quality monitoring programme requires:

- knowledge of the hydrological system to be monitored;
- development of an index for prioritization of catchments by water quality risk;
- evaluation of analytical capability for water quality analyses.

Hydrological context

One of the most useful steps in the development of any water quality monitoring programme is the development of descriptive profiles for each catchment. Such profiles integrate the available knowledge of natural and anthropogenic factors that may affect water quality and quantity.

There are 16 major river catchments (Fig. 1) in Belize which drain to the coastal waters of the Caribbean Sea from the Mayan Mountain Range. Many of these rivers have a highly developed branching network of tributaries, several of which are significant rivers, including the Bladen and Swasey branches of the Monkey River, the Macal River tributary to the Belize River, and the Booths River and Rio Escondido (Lee *et al.*, 1995). Five of these catchments have watershed areas in Mexico and Guatemala. To prioritize sampling areas, a preliminary survey of the major catchments in Belize was conducted using the following descriptors (modified from Chapman, 1993):

- geographical features of the contributing area: topography, geology and soils, climate, land-use and area, and hydrology;
- water uses: drinking water, irrigation, or industrial input;
- pollution sources: non-point and point sources of domestic, industrial and agricultural contaminants;
- number and location of streamflow gauging sites, water quality monitoring sites and other hydrometeorological monitoring sites.

Major land-use activities with the potential to effect water quality were identified from diverse public and private sources including: land resources assessments (King *et al.*, 1986, 1992, 1993); pollution studies (Newell, 1993; Archer, 1994; Haskoning, 1994; Miller & Miller, 1994); environmental reviews (Hartshorne *et al.*, 1984); land-use records (LIC, 1994) hydrological databases; selected field visits; aerial reconnaissance; general literature sources; and best professional judgement (Lee *et al.*, 1996).

Establishing a risk index for Belize A contamination risk index is a way of understanding the expected catchment water quality dynamics, and to help prioritize monitoring efforts. Lacking detailed data on contaminant loading and runoff processes, the development of a risk index becomes a subjective process. However,

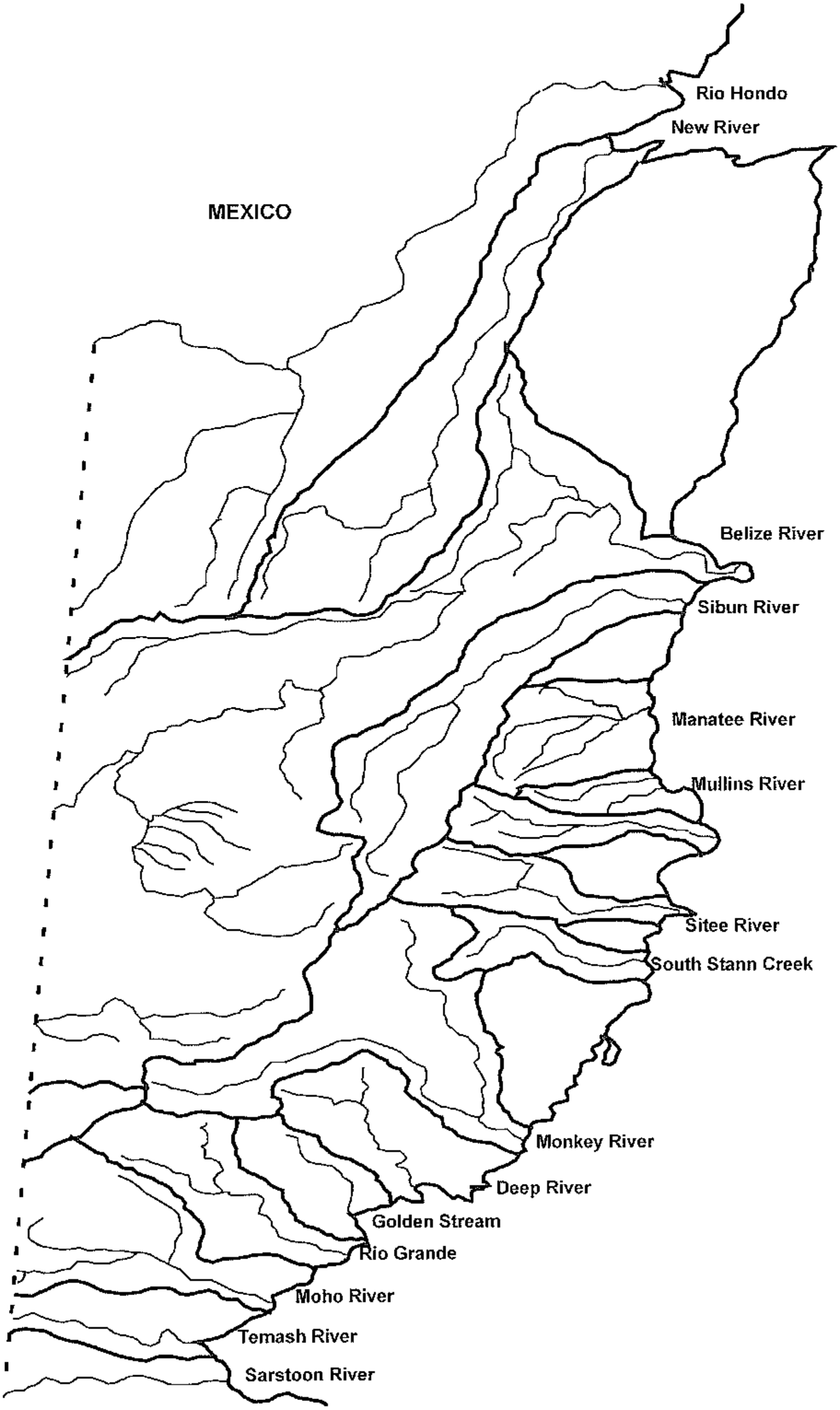

Fig. 1 Major catchments of Belize.

with assumptions, it is possible to approximate a relative risk index for Belize, one that may be improved over time as more data are collected. Evaluation categories included the relative amounts of agricultural land, urban land, orchard cover and industrial activity.

Agricultural land One would expect to see a relationship between agriculturally derived contaminants such as pesticides, fertilizers, suspended solids and the total area of agricultural land in a catchment, all things remaining equal. The actual risk of contamination from a given area of agricultural land depends on the type of soils and slope and its location relative to the streamflow generation mechanisms in the catchment, and the farming practices used (for example frequent use of chemicals, return-flows, and vegetation buffers). The small and widely spaced milpas are being replaced by large slash and burn areas for annual crop production. The area of agricultural land in a catchment is a good approximation of the agricultural land-use risk to water quality.

Urban land The number of hectares in urban land-use was the indicator for water quality risk from domestic wastewater and other urban-related water quality effects, such as stormwater drainage from streets and roads. The actual risk depends on the population density and the nature of sanitation and other drainage systems. These data were not readily available.

Orchard cover Forest cover is a useful indicator of the undisturbed catchment area. In Belize, primary and secondary forest covers are often being replaced by citrus. Given the capital investment of citrus tree crops, and the desire to recoup that investment over future years, there is a tendency for sustained use of agrochemicals. The establishment of many tree crops on steep hillslopes with poor soils means that there is considerable potential for off-site losses of applied chemicals to water bodies and soil loss associated with the clearing of vegetation and soil disturbance. Quantifying the number of hectares under citrus, bananas, mangos, cacao or cashew is therefore a useful risk indicator for pesticides, chemicals and suspended solids. The use of agrochemicals separates the orchard designation from agricultural land.

Industrial activity Industrial activity is often a source of river contamination in developing countries, because of the absence of waste treatment systems for pollution control or the advanced age of many installations and equipment. Contamination is usually of a point-source nature with recognizable discharge outlets from individual facilities to specific water bodies. Data on industrial activity and particularly discharge of combined waste streams to water bodies is not yet complete for Belize (Archer, 1994).

A river contamination risk index for Belize

Each category had a relative ranking from one to five based on the relative areal amount in each category (Table 1). Land-use activities were ranked comparably, for example, orchard area equals milpa area, recognizing that there may be greater and longer lasting impacts from one land use compared to another.

Table 1 Risk class values for each of the risk categories.

Class risk	Agriculture	Urban	Orchard	Industrial
5	>25 000 ha	>2500 ha	>2500 ha	> 10 sources
4	10 000–25 000 ha	1000–2500 ha	1000–2500 ha	5–10 sources
3	5000–10 000 ha	500–1000 ha	500–1000 ha	2–5 sources
2	1000–5000 ha	100–500 ha	100–500 ha	1–2 sources
1	0–1000 ha	0–100 ha	0–100 ha	0 sources

The range of risk went from very low scores of 4–6, which signify minimally modified catchments, to a high of 18, which signifies relatively extensive land-use activities that may lead to water quality impacts (Table 2).

Table 2 Risk assessment by land-use category for each catchment.

Catchment	Agricultural land use	Urban land use	Orchard land use	Industrial risk	Risk level
Rio Hondo	5	4	1	1	11
New River	5	3	1	5	14
Belize River	5	5	4	1	18
Sibun River	2	3	4	1	10
Manatee River	2	1	4	1	8
Mullins River	1	1	3	1	6
North Stann Creek	3	2	5	4	14
Sittee River	2	1	4	1	8
South Stann Creek	1	2	3	1	7
Monkey River	2	1	5	1	9
Deep River	1	1	2	1	5
Golden Stream	2	1	2	1	6
Rio Grande	4	2	2	1	9
Moho River	4	2	1	1	8
Temash River	3	2	1	1	7
Sarstoon River	1	1	1	1	4

Limitations of the risk index One of the limitations of the risk index is the lack of data on the land use and water quality of the catchments shared with Mexico and Guatemala. There is no mechanism currently in place to allow for data collection or data exchange between countries.

The risk index could be strengthened by the addition of other indicators. These include drainage density and average slope gradient. Average annual precipitation and total catchment area with drainage density and catchment slope could be used to estimate runoff. The index is based broadly on the concept of the mass (concentration and discharge) of possible water quality contaminants rather than the concentration alone. Streamflow volumes could be used to estimate concentrations, although streamflow-concentration relationships for many of these streams are unknown. The risk index does not consider proximity or connectivity of land-use activities to water bodies.

The transport processes that could carry water quality contaminants to the Belize barrier reef are not sufficiently understood to identify the critical catchments for nearshore water quality protection (King *et al.*, 1993). The closer the barrier islands to the shore and the shallower the water between the islands and the mainland, the greater the potential for contaminant plumes reaching the island corals. Since the movement of the plume will be affected by currents and cross-currents caused by tidal and other circulatory flows, it is difficult to develop a meaningful number for each of the catchments. Work planned by the Belize Coastal Zone Management Unit will identify the patterns of river-derived contamination in the offshore zone.

The risk assessment although subjective, is still a useful tool for focusing attention on contaminants and locations of key concern. The three major water quality parameters of importance to Belize are agrochemicals, suspended solids and faecal coliform bacteria (Stednick *et al.*, 1995). In the absence of primary water quality data, the index attempts to characterize these parameters through catchment characteristics and known cause-and-effect relationships for water quality from land-use activities in Belize.

Water quality variable selection Because of the complexity of influences within natural environments that determine concentrations of water quality variables, adoption of a single set of water quality variables to be monitored for all water bodies would be inefficient (Chapman, 1993). Water quality variables selected for the monitoring programme must reflect the range of concentrations expected in both background and land-use activity scenarios.

Analytical capabilities and equipment currently in Belize were evaluated and considered in the ranking of water quality variables for inclusion in the water quality monitoring programme. Not surprisingly, there was an assortment of equipment in different agencies in different locales. Our recommendation was to consolidate all analytical equipment in a nationally certified laboratory.

Land-use activities were evaluated for potential water quality effects. Such effects were based on a literature review of the cause-and-effect relations in land use and water quality in the humid tropic environment, and best professional judgement. Water quality monitoring parameters were ranked by the potential effects of specific land-use activities on water quality and available analytical capability (Table 3). They

Table 3 Ranking of parameters for the assessment of environmental water quality.

Land use/industry	Water quality variables						
	Discharge	TSS	Pesticides	Herbicides	NO_3-N	Metals	Bacteria
Sugar processing	1	2	4	4	3	3	3
Rum refining	1	2	4	4	3	3	3
Brewery	1	2	4	4	3	3	3
Soft drink bottling	1	3	4	4	3	3	3
Dairy processing	1	2	4	4	3	4	2
Poultry processing	1	3	4	4	3	3	2
Fish processing	1	2	4	4	2	4	2
Shrimp processing	1	3	4	4	3	3	3
Citrus processing	1	3	3	3	2	3	3
Garment processing	1	3	4	4	3	3	3
Battery manufacture	1	3	4	4	4	2	3
Timber harvest	1	2	4	4	2	3	3
Agriculture	1	2	2	2	2	3	3
Wastewater treatment	1	2	4	4	2	3	1

1 = highest importance; 2 = high importance; 3 = moderate importance; 4= little or no importance.

represent those variables most likely to indicate overall water quality conditions with and without land-use activities over time. For each constituent, a standard field sampling and analytical procedure was selected and documented in the form of a comprehensive protocol manual prepared for the Belize Department of Environment (Stednick & Gilbert, 1995).

Given the level of urbanization and industrialization in Belize and the largely rural nature of most catchments, heavy metals should not pose a significant problem. Water quality monitoring must keep an eye to the future, given the growing use of agrochemicals in Belize. The value of the unique offshore marine environment and the growing concern in Belize that concentrations of chemicals may affect the offshore ecosystems warrants water quality analyses for agrochemicals to define baseline conditions. National agrochemical imports are recorded, but the application of agrochemicals by catchment would improve the index.

SUMMARY

Following an evaluation of the environmental, institutional and technical situation of Belize, recommendations for a national water quality monitoring programme were made. The first major objective of the proposed water quality monitoring programme was to create baseline water quality conditions for each major catchment. Statistical comparisons with future water quality data will determine trends of the general state of the river health and influence land-use management decisions. A guiding principle for monitoring site selection was to use the existing streamflow gauging network as the basis for water quality sampling. A series of upstream–downstream water quality sampling locations should be established for those catchments with industrial facilities and land-use activities to evaluate possible changes over time.

Secondly, emphasis was placed on starting out relatively slowly, stressing the need to obtain representative samples that are properly collected, adequately documented in the field at the time of collection, with the exercising of proper care and custody practices. With regard to laboratory options, Belize had a relatively broad range of analytical capability at the time of the study, although equipment was located in different agencies in different locales. Our recommendation is that all equipment should be assembled into a national accredited water quality or pollution control laboratory. However, it was recognized that since this cuts across agency budgets and responsibilities, political consensus to re-allocate these physical and human resources would be needed.

REFERENCES

Archer, A. B. (1994) Land-based sources of marine pollution inventories: Belize & Cayman Islands. *UNEP Regional Coordinating Unit Report, May.*

Chapman, D. (ed.) (1993) *Water Quality Assessments: A Guide to the Use of Biota, Sediments and Water in Environmental Monitoring.* Chapman & Hall, London.

Hartshorne, G. *et al.* (1984) Belize: Country Environmental Profile. A Field Study. Nicolait and Assoc., Belize City, Belize.

Haskoning, J. (1994) Citrus waste stabilization. *Report to Government of Belize/United Nations Industrial Development Organisation (UNIDO).*

King, R. B., Baillie, I. C., Bissett, P. G., Grimble, R. J., Johnson, M. S. & Silva, G. L. (1986) *Land Resource Survey of Toledo District, Belize*, 177. Land Resources Development Centre.

King, R. B., Baillie, I. C., Abell, T. M. B., Dunsmore, J. R., Gray, D. A., Pratt, J. H., Versey, H. R., Wright, A. C. S. & Zisman, S. A. (1992) Land resources assessment of Northern Belize (vols 1 and 2). *Natural Resources Institute Bull. no. 43.*

King, R. B., Pratt, J. H., Warner, M. P. & Zisman, S. A. (1993) Agricultural development prospects in Belize. *Natural Resource Institute Bull. no. 48.*

Lee, M. D., Stednick, J. S. & Gilbert, D. M. (1995) Environmental water quality monitoring program. *Final Report to USAID-NARMAP, Government of Belize.*

Lee, M. D., Stednick, J. D. & Gilbert, D. M. (1996) Contamination assessment in the Belize National Environmental Water Quality Monitoring Program. In: *Integrated Management of Surface and Groundwater* (Proc. UCOWR Meeting, San Antonio, Texas).

LIC (Land Information Center) (1994) The land use of Belize 1989/92. *Preliminary Report, Land Information Centre.*

Miller & Miller, Ltd (1994) Recommendations on industrial effluent quality standards. *Draft Final Report to NARMAP* (Natural Resources Management and Protection project, Belize).

Newell, P. J. (1993) Industrial pollution management in the sugar cane, rum distilleries and other industries in Belize. *UNIDO Tech. Report SI/bze/92/801.*

Stednick, J. D. & Gilbert, D. M. (1995) Environmental Water Quality Monitoring Program water quality monitoring protocol. *Report to Government of Belize, Department of Environment.*

Stednick, J. D., Gilbert, D. M. & Lee, M. D. (1995) Development of a national water-quality monitoring program for Belize. In: *Water Resources at Risk* (American Institute of Hydrology, 14–18 May, Denver), RA16–22.