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In addition to those mentioned here, several scientists, educators and public officials provided key materials, opinions and assessments to the consultants concerning the current state and future directions of environmental water quality monitoring in Belize. All people consulted are listed in the Annex 4 to this report and the consultants would like to thank them for their time and efforts.

Executive Summary

The Government of Belize contracted with the Escuela Agrícola Panamericana (Honduras) and Colorado State University (U.S.A.) to establish an environmental water quality monitoring program to meet the requirements of the Environmental Protection Act of 1992. These consultants, working with various representatives from the different Government of Belize ministries prepared two documents: this Environmental Water Quality Monitoring Program and the accompanying Environmental Water Quality Monitoring Protocol (Stednick and Gilbert, 1995).

Environmental profiles are presented for the 16 major catchments in Belize. These profiles include environmental characteristics as well as current land uses and represent a comprehensive summary of the current state of knowledge about each major river system. They indicate that there is considerable heterogeneity between different catchments that give rise to different hydrological and water quality conditions. These characteristics and conditions are used to develop a catchment risk index. The index is used to prioritize, or rank, the catchments for water quality monitoring purposes. As suggested by the risk index, the rivers potentially most affected by industrial, urban and agricultural land uses are in the northern and central catchments of the country, the top ranking being the Belize River followed by the New River, and North Stann Creek. These three show particularly high risk due to the presence of both agriculture and agro-industry in close proximity to river stretches. The lowest risk of water quality change from land use effects is associated with the more pristine forested catchments, especially the Deep and Sarstoon Rivers.

The existing Belize water quantity (stream discharge) and water quality monitoring programs and data bases are reviewed. The stream gauging network operated by the National Hydrological Service provides an excellent structure for a water quality monitoring program. Water quality issues have been identified for non-point and point sources as related to Belize industries and land uses. Specific industries and land uses are reviewed for water quality concerns, of major importance being the sugar processing, citrus processing, and to a lesser extent, other food industry facilities. These data and information can be used by Belize ministries to develop a coordinated water quality monitoring program.

The existing laboratory facilities in Belize are reviewed and no single laboratory is adequate to conduct and coordinate the full range of analyses necessary to fulfil an environmental water quality monitoring program, although Belize is relatively well endowed with equipment and trained personnel. Because of the dispersed and duplicate nature of facilities, it is recommended that a single laboratory be formulated in which human and financial resources can be best invested to meet national needs.

An assessment is made of national priorities related to water quality data and an emphasis is placed in the short-term on quantifying the overall characteristics of the Belize river systems by sampling at lower gauging stations closest to the coastline and downstream of river border crossings within

shared catchments with Guatemala and Mexico. This will allow the program to meet the needs of at least three agencies concerned with water quality and quantity at the land-sea interface: the Department of Environment, the National Hydrological Service and the Coastal Zone Management Unit, and will provide a basis for regional collaboration to control water quality. This program will allow the Government of Belize to inventory their natural resources and provide guidance in their management and economic development. More detailed analysis of water quality from different geographical elements of the catchments can be added at a later date based on future resources.

Specific recommendations within this report include:

1. To pursue funding from the Government of Belize to support a coordinated water quality monitoring program for the benefit of the Belize people and its resources.

2. To use selected National Hydrological Service stream gauging network sites as a starting point for the coordinated Belize environmental water quality monitoring program and to empower the service to assume a leadership role in the program.

3. To adopt a suggested prioritization of sampling locations throughout Belize based on assessed risk and short to medium-term institutional capabilities.

4. To foster the institutional flexibility that will allow water quality samples to be efficiently analyzed by one laboratory for a range of ministries, non-governmental organizations and other interested parties. A mechanism for inter-agency billing and collection will help increase the Belize analytical capability.

5. To develop a Central Laboratory for Belize water quality analyses. This independent laboratory would be officially approved and certified as to its quality assurance and quality control procedures and its data management, and would be supported by laboratory users according to their use, through budgetary allocations by individual ministries and departments and sample fees.

6. To upgrade existing analytical capability for pesticides. Increased pesticide use in Belize is recognized as potentially affecting all water resources.

7. To develop a memorandum of understanding between all Belize ministries to identify individual and collective roles with respect to water quality monitoring. This will require discussions at the level of Permanent Secretary and above.

8. To initiate high-level and technical dialogues with Guatemalan and Mexican government institutions concerning a coordinated monitoring program and data exchange on shared river water quality.

Specific recommendations from the consultants concerning follow-up activities include:

a. the preparation of a detailed report for the siting, equipping and operation of a centralized laboratory. The report should maximize the use of already committed capital investments (equipment and physical plant) and personnel, while minimizing impacts on the near-term ability of existing individual laboratory facilities to perform needed analyses. The report should clearly identify in which cases equipment should be redistributed within the national system and which additional purchases are necessary.

b. the preparation of an appropriate personal computer-based data management component for water quality and quantity information, geared to specific user needs and compatible with the nascent CEDS and existing National Hydrological Service discharge data management program HOMS.

c. a program to provide training to environmental water quality monitoring personnel on data management and statistics. An outside consultant could both train personnel and take initial steps to introduce existing water quality and quantity data into the selected data management system.

d. a technical review of the current capability for pesticide analysis in Belize, including gas chromatograph equipment and accessories, and the feasibility and cost-effectiveness of upgrading this equipment for national monitoring use compared to sending samples to regional laboratories.

e. the development of specific procedures and tests for accrediting the centralized laboratory, its operating procedures and personnel. This could ideally be carried out by staff from an existing, recognized laboratory already engaged in legislation-related monitoring such as the West Indies Public Health Institute or CEPIS, or by other outside consultants.

f. an evaluation of how the water quality monitoring laboratory will be integrated into the industrial effluent monitoring procedures required by the Environmental Protection Act and how this relates to the accrediting process from a legal perspective.

g. a review of medium and long-term training needs and opportunities associated with the operation of the central laboratory and field sampling program, and the potential for additional training, education and periodic reviews, for example through PAHO and CEPIS or through the American Universities International Program (AUIP) .

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1.0 Introduction

The Government of Belize, through the USAID-financed NARMAP project, has contracted with the Escuela Agrícola Panamericana (Honduras), more commonly known as Zamorano, and sub-contractor Colorado State University (U.S.A.) to establish an environmental water quality monitoring program in order to meet the requirements of the Environmental Protection Act of 1992. Specific sections of the Act that require address in the proposed program are:

Part II §4(a) - (b):	"The powers, duties and functions of the Department shall be to: be responsible for the continuous and long term assessment of natural resources and of pollution"; and "ensure the protection and rational use of natural resources for the benefit of the present and future generations."
Part II §4(f) - (h)	"undertake surveys and investigations into the causes, nature, extent and prevention of pollution and to assist and co-operate with other persons or bodies carrying out similar surveys or investigations"; "conduct, promote and co-ordinate research in relation to any aspect of environmental pollution or prevention thereof, and to develop criteria for the protection and improvement of the environment"; and "specify methods to be adopted in taking samples and making tests for the purposes of this Act;"
Part II §4(j)	"undertake investigations and inspections to ensure compliance with this Act other regulations made thereunder and to investigate complaints relating to breaches of this act or the regulations made thereunder;"
Part III §7(1)(a)-(b)	"The Minister may after consultation with the Department, make regulations for - recognizing one or more laboratories or institutes as laboratories to carry out the functions entrusted to a laboratory under this Act or any regulations made thereunder;"; and "specifying the procedure for the submission to the said laboratory of samples of air, water, soil or other substances for analysis or tests, the form of the laboratory report thereon and the fees payable for such report;"

1.1 Program Objectives

One objective of water quality monitoring is to establish baseline water quality conditions including normal ranges of seasonal variation and periodic fluctuations. Another objective of water quality monitoring is to identify and explain cause and effect relationships between water quality characteristics and land use activities such as road construction or pesticide use. Finally, trends can be determined from water quality measurements over time and space with sufficiently long records. Water quality monitoring programs seek to determine what are naturally occurring concentrations of particular indicators and what levels result from specific catchment activities. Background water quality concentrations result from the environmental dynamics by which water interacts with soils, geology, vegetation, and animals to define a water with particular chemical, physical and biological properties. Some of these are beneficial, some have little consequence while others are detrimental to particular water uses. Water quality concentrations may change as a result of various interventions in the natural system, including construction, agriculture and industry. The ideal objective for any monitoring program is for it to be combined in a comprehensive total integrated catchment management program, linked to a hydrometeorological network and a land/water use planning and regulatory framework.

Establishing an effective water quality monitoring program requires:

- knowledge of the hydrological system to be monitored;
- an understanding of the temporal and spatial distribution of water quality indicators being monitored, and their causes;
- clear objectives concerning how and why the data will subsequently be used, for example in regulatory enforcement and the design of corrective actions;

Water quality monitoring is usually conducted with three applied issues in mind:

- water quality objectives - water quality characteristics that a country hopes to achieve or maintain over a period of time in a given water body. Monitoring is geared to assessing whether these objectives could be or are being met;

- water quality criteria - specific numerical values that a given water body needs to possess in order to be used for a specific purpose or support a particular environmental condition. Monitoring determines whether this is so;

- water quality standards - regulatory requirements concerning water quality, particularly the discharge of point and non-point pollutants into natural water bodies. Monitoring is designed to identify where these standards are being violated and to enforce restrictions or penalties. This requires that monitoring be coupled with legislation and enforcement and requires a particular type of sampling designed to identify the impacts of distinct causal factors.

A water quality monitoring program may fail to provide sufficient information to meet national needs for several reasons including (Chapman, 1993):

1. Objectives of the monitoring program were not properly defined.
2. The monitoring system was implemented based on insufficient knowledge of the water body.
3. Inadequate planning of sample collection, handling, storage and analysis.
4. Data was poorly managed and stored.
5. Data was improperly interpreted and reported to decision makers.

The program presented in this document concentrates primarily on the surface water systems of Belize. It includes environmental profiles of each of the major catchments and the range of water quality issues known to be important for each catchment.

At this time, the program does not include water quality monitoring plans for groundwater resources or marine waters. Nor does it discuss in detail the limnological issues associated with determining time and space water quality variations in lacustrine environments. While the techniques and variables discussed in the report can be applied in large part to the study of these aquatic environments, the program concentrates short and medium-term resources into better quantifying the ambient conditions of Belize surface waters. In this way, the broad spirit and substance of the Environmental Protection Act (EPA) can be satisfied given the available resources and parallel initiatives already in progress in Belize. These parallel initiatives with respect to water quality include:

- Groundwater monitoring: groundwater resources are currently monitored and analyzed by the Public Health Bureau (PHB), Rural Water Supply Program (RWSP) and Water and Sewerage Authority (WASA) with assistance from the Pan-American Health Organization (PAHO).

- Marine water monitoring: marine waters are the focus of increasing monitoring efforts by the Coastal Zone Management Unit (CZMU) which has assumed a unifying role in the area of barrier reef and coastal ecosystem protection. The objective is to use data to shape and implement environmental management policy for the coastal zone.

Specific objectives of the Environmental Water Quality Monitoring Program include:

- define background water quality
- define potential water quality effects from land use
- define long term water quality effects associated with land use practices within Belize
- provide information useful in the planning of future development/industrial growth in Belize

1.2 Hydrological Context

1.2.1 Belize

There are 16 major catchments in Belize which drain to the coastal waters of Belize from the Mayan Mountain Range which forms the topographic and geological backbone of the country. Many of these rivers have a highly developed branching network of tributaries, several of which are significant rivers in their own right, specifically the Bladen and Swasey branches of the Monkey River, the Macal River tributary to the Belize River and the Booths River and Rio Escondido (Mexico) tributaries to the Rio Hondo. There are perhaps 15 additional definable catchments within Belize but because of the low-lying nature of the landscape and presence of multiple channels, creeks, swamps and lagoons these catchments are difficult to categorize. These have been identified on the Land Information Centre (LIC) Geographical Information System (GIS) base map digitization. The catchments and their approximate planar land area in km^2, as calculated using digitized boundary data in the LIC GIS and areas calculated or taken from topographic and thematic maps from Mexico and Guatemala, are listed in the following tables. Note that five of these catchments extend into the neighboring countries of Mexico and Guatemala.

Note that these numbers do not necessarily match with figures produced by the Hydrological Service in their 1981/82 yearbook. However, this report will use the numbers produced by the LIC as the best available data.

In terms of the shared catchments with Mexico and Guatemala, a number of maps are available, both thematic and topographic, from which the size of contributing area can be calculated or obtained.

Table 1.1 Major Catchments and Areas for Water Quality Monitoring

MAJOR CATCHMENT	AREA (km^2)
Rio Hondo *	15,075.5
Belize River *	9,434.2
Sarstoon River *	2,217.5
New River	1,864.0
Monkey River	1,275.4
Moho River *	1,188.5
Sibun River	967.8
Rio Grande	718.5
Manatee River	484.0
Temash River *	474.6
Sittee River	451.2
Deep River	347.9
North Stann Creek	281.4
South Stann Creek	258.0
Golden Stream	204.1
Mullins River	156.9

*** rivers with portion of catchment extending outside Belize.**

Table 1.2 Other Catchments and Areas

OTHER CATCHMENTS	AREA (km²)
Freshwater Creek (1)	1,181.8
Northern River	642.2
Mango Creek	247.1
Freshwater Creek (3)	222.7
Freshwater Creek (2)	166.8
Potts Creek	156.4
Santana Creek	150.3
Santa Maria Creek	149.1
Freshwater Creek (4)	136.6
Cabbage Haul Creek	103.2
Black Creek	89.0
Sennis River	75.0
Big Creek	58.3
Middle River	50.9
Pine Ridge Creek	39.5

1.2.2 Guatemala

A useful source of information for Guatemala is the Inventario del Recurso Agua en Guatemala, the Atlas Hidrológico Primer Edición (no date). The boundaries of the five shared catchments with Belize: the Rio Azul tributary of the Rio Hondo, the Belize River (Mopan Branch), the Moho, Temash and Sarstoon, are each marked on the map "Morfometría e Hidrografia" at a scale of 1:1,000,000" in the Atlas Hidrológico. They provide a good approximation of the total area of each catchment, since no previously tabulated data for shared catchments was located.

More detailed map coverage is available in 1:50,000 and 1:250,000 for the border areas of Belize and

Guatemala. The 1:250,000 topographic maps were examined during this project and date from 1967. They do not mark catchment boundaries. The relevant sheets that encompass the shared catchments are from Edition 1-IGN-DGC Series E503:

NE 16-4: No name
NE 16-5: Orange Walk
NE 16-9: Tikal
NE 16-13: Flores
ND 16-1: Puerto Barrios
NE 16-10: Belice
NE 16-14: Punta Gorda

The total area of the portions of Belize river catchments in Guatemala are calculated to be:

CATCHMENT	**AREA (km^2)**	**% IN GUATEMALA**
Rio Hondo	4,790	31.8
Belize River	2,891	30.6
Moho River	376	31.6
Temash River	115	24.2
Sarstoon River	2,023	91.2

1.2.3 Mexico

The shared catchment between Mexico and Belize, the Rio Hondo, is contained in the Mexican 1:250,000 map sheet of Chetumal E16-4-7 available as both a topographic coverage and as a surface water hydrology map. The "Carta Hidrológica de Aguas Superficiales" 1988 series was consulted (1:250,000). Sheet E16-4-7 lists the surface area in km^2 for each catchment and sub-catchment and the locations of catchment and sub-catchment divides are clearly marked. This map is available from the Instituto Nacional de Estadisticas, Geografia e Informática.

In the case of the Rio Hondo, both the main river contributing area and the sub-catchment of the Rio Escondido, which is wholly contained within Mexico, are annotated. The map indicates that the Rio Escondido sub-catchment comprises a total area of 4,582 km^2, with the portion of the Rio Hondo and Rio Azul catchments in Mexico comprising 3,032 km^2. Thus the total area contributing to the outflow of the Rio Hondo from Mexico is 7,614 km^2, or 50.5% of the entire catchment.

1.3 Existing gauging stations and their characteristics

1.3.1 Hydrological Stations and Locations in Belize

From discussions with the Belize National Hydrological Service (Mr. Frank Panton, Chief Hydrologist) the following table lists the currently operating river gauging sites in Belize. The table does not include lake or tidal level gages

Table 1.3 Existing Hydrological Network Sites

NAME	LOCATION	OBSERVATIONS
Tower Hill	New River. Northern Highway. Toll Bridge Site.	Tidal influence. Low velocity. Difficulties experienced in establishing useful rating curve and measuring Q. Only station on river.
Rio On, Belize River, Macal Sub-Basin.	Old logging road off Western Highway and Chiquibul Rd. Wading Site.	Difficult access. Small river with low discharge (normal 1 m^3/s or less). Possible value as comparative quality indicator. Rating curve established.
Cristo Rey	Belize River, Macal sub-Basin. Turn-off road SE from San Ignacio. Wading or boat site.	Easy access but enormous flow-range (+15m). Requires boat for profiling or construction of walk or cable-way at high flows. Quantifies Macal sub-basin. Rating curve established.
Benque Viejo	Belize River, Western Branch (from Guatemala). Western Highway. Bridge site.	Accessible site. No special conditions. Quantifies flow from major Guatemala sub-basin. Rating curve established.
Banana Bank	Belize River, Main Channel. Dirt road north off Western Highway near Belmopan. Ferry (boat) site.	Accessible site. Boat and cable but inadequate for peak flows. Downstream of Roaring creek and Spanish Lookout tributaries and main agricultural belt. Rating curve established.
Big Falls	Belize River, Main Channel. Road north off Western Highway. Ferry site.	Close to Bermudian Landing site. Few expected changes in between. Can eliminate one or other. Perhaps eliminate both in favor of Double Run. Rating curve established.
Bermudian Landing	Belize River, Main Channel. Reached via Burrell Boom (connections from Northern or Western Highways). Ferry site.	See above. No rating curve established as yet. Data sufficient to do so.

NAME	LOCATION	OBSERVATIONS
Double Run	Belize River, Main Channel. Access via Treatment Plant road from Northern Highway. Bridge/gantry site.	Located at treatment plant intake. Last free-flowing station before sea. Important quality site. Rating curve established.
Freetown Sibun	Sibun River, Main Channel. South from Western Highway at Hattieville. Boat site.	Quantifies most of basin prior to lagoons. Only station. Rating curve established.
Kendall Bridge	Sittee River, Main Branch. Southern Highway. Bridge site.	Excellent access. Captures agricultural activity inland of highway. No rating curve established as yet.
South Stann Creek Bridge	South Stann Creek, Main Channel. Southern Highway. Bridge site.	Excellent access. Captures agricultural activity inland of highway. Rating curve established.
Swasey Bridge (near Logans Bank)	Monkey River, Swasey Branch. Southern Highway. Bridge site.	Excellent access. Captures agricultural activity inland of highway. No rating curve established as yet.
Bladen Bridge (near Melvins Bank)	Monkey River, Bladen Branch. Southern Highway. Bridge Site.	Excellent access. Captures agricultural activity inland of highway. No rating curve established as yet.
Medina Bank	Deep River, Main Branch. Southern Highway. Bridge Site.	Excellent Access. Captures hill basin runoff but not conditions after the significant coastal portion. No rating curve established as yet.
Hellgate Village	Golden Stream, Main Branch. Southern Highway. Bridge Site.	Excellent Access. Captures runoff from hilly zone. No rating curve established as yet.
San Pedro	Rio Grande, Columbia River Branch. Road north at Southern Highway turn to Punta Gorda. Bridge Site.	Good access. Captures broad interior basin runoff from major tributary system. Rating curve established.
Big Fall	Rio Grande, Main Branch. Southern Highway. Bridge site.	Good access. Captures hillside runoff but is upstream from sizeable coastal section. Few expected differences to San Pedro. Rating curve established.
Blue Creek	Moho River, Blue Creek. Minor roads connecting to Southern Highway. Bridge site.	Captures interior sub-basin runoff. Rating curve established.
Jordan Village	Moho River, Main Branch. Minor road west from Southern Highway. Bridge site.	Measures most of basin runoff just before main coastal section. Probably no feasible site closer to sea. Rating curve but doubts about suitability.

To the best of the consultants knowledge, the above table reflects the state of the existing gauging stations as of September, 1994. Note that hydrological data has also been collected periodically over the last three years from three tributaries on the coastal plain section of the Belize River, at: Mexico Creek, Mussel Creek and Black Creek (Panton, personal communication). All three drain the marshy, lagoonal sections north and south of the main river just upstream of Double Run as part of attempts to monitor flood risk and peak development in the catchment. No rating curve has been developed for any of these sites.

Also note that a number of the southern catchments currently have sampling sites dictated by access, in other words, associated with the points at which the Southern Highway crosses the stream channel. Since the highway was constructed on the edge of the Maya Mountain complex maintaining a higher elevation to avoid saturated ground conditions and flooding, the gauging sites tend to reflect the water quality conditions of discharge leaving the upper catchments. Where the coastal plain is relatively narrow, for example in the region of Dangriga, this comprises most of the catchment, but further south, a considerable portion of the catchment, including sections converted to agricultural use in the form of citrus and bananas, lie to the seaward side of the highway.

Moreover, the highway often marks the downstream boundary of a zone in which a considerable break-in-slope for the catchment has occurred in which converging, fast-moving flow meets a shallowing, meandering "mature" river with subsequent general lessening of velocities, increases of average depth, sedimentation and greater in-channel retention times with less mixing. This may well give rise to significant water quality variations especially in total suspended solids (TSS), dissolved oxygen content, turbidity and related constituents. Data from sampling points such as the Swasey and Bladen bridges of the Monkey River, therefore, may be misleading indicators of final estuarine discharge characteristics.

1.3.2 Hydrological Stations and Sampling Locations in Shared Catchments with Guatemala

From an analysis of the Inventario del Recurso Agua en Guatemala, the Atlas Hidrológico Primer Edición (no date), the following hydrological stations were identified for shared river basins with Belize from the map "Localización de Estaciones Hidrométricas y Limnimétricas, 1:1,000,000".

Belize River catchment, Mopan River

CODE	NAME
II.4.1.H	El Arenal
II.4.2.H	El Cruzadero

Both stations are administered by the Instituto Nacional de Electrificación (INDE) and located a short distance inside the Guatemala-Belize border.

Sarstoon River catchment

CODE	NAME
II.9.1.H	San Pedro Cardenas
II.9.3.H	Modesto Méndez

Both stations are administered by the Instituto Nacional de Electrificación (INDE) and located on the main highway north from Lago de Izabal to Flores.

1.3.3 Hydrological Stations and Sampling Locations in Shared Catchments with Mexico

According to the 1:250,000 surface water hydrology map of 1988, there are four sampling sites in the main catchment comprising one hydrological station (station 1) at the border bridge crossing west of Chetumal, and three sampling locations at surface water intakes on the Rio Hondo downstream of the Rio Escondido confluence (sampling point 9), on a small channel close to the Caseta de Migración (sampling point 6) near Lago Milagros and at La Unión near the main channel of the Rio Hondo (sampling point 12). There is also a fourth water sampling point on Lago Milagros near Huay-Pix (sampling point 7). There also appear to be three sampling points in the Rio Escondido sub-catchment of the Rio Hondo at Xpujil (sampling point 5), at Veinte de Noviembre (sampling point 10) and Ucum (sampling point 8), the latter just upstream of the confluence with the Rio Hondo. It is not clear whether these three are for surface or groundwater intakes but they are located on or near marked stream or river channels.

1.4 Existing Water Quality Data in Belize

Water quality data in Belize consists of six main sources:

1. water quality data collected as part of routine monitoring of intake water quality at WASA facilities - water quality does not represent true ambient river quality conditions since it is not sampled in-situ, instead in a manner determined by the nature of the intake structure and the mixing and modifying impacts of the intake process. Variables have been selected based on

their importance to water users or to the water treatment process. Samples are collected and transported to the Double Run laboratory by its technicians, who also perform the analysis.

2. water quality data collected on an ad-hoc basis at selected discharge gauging stations established by the National Hydrological Service - water quality data is limited, one sample or less per year over a period from 1982-1987. A core of variables (pH, alkalinity, hardness), have been measured with an ancillary group of variables occasionally measured (turbidity, sulfates, chlorides- see following table). The methods by which data were collected are not documented.

3. water quality data collected on an as-needed basis by Public Health or Department of Environment staff and subjected to selected analysis to determine the nature or causes of observed environmental contamination - limited to one or two instances associated with public health complaints, factory discharges or environmental red flags such as fish-kills or unusual algal blooms, water discoloration, etc. Variables have been selected on an *ad-hoc* basis depending on the level of knowledge of officials involved and the analytical capabilities of selected laboratories.

4. water quality data collected by consultants or technicians associated with specific on-going point-processes of contamination, particularly the discharge of sugar and orange waste - characterized by infrequent but relatively detailed studies over a short-period of time of upstream, downstream and pollution source quality characteristics. Variables analyzed have been determined by the nature of the pollution source. Samples have usually been analyzed on-site using field kits or by in-house laboratories. Belize Sugar Industries (BSI) monitors the water quality of the New River on a regular basis, measuring salinity, temperature, Chemical Oxygen Demand (COD), pH and dissolved oxygen and have done so since September, 1990.

5. water quality data collected on an irregular basis to fulfil institutional statutory responsibilities - rural and small water supply systems not run by WASA are sampled on an annual, and sometimes less frequent basis for certain water quality parameters related to human health (nitrates, iron, etc.) and for bacteriological contamination, to comply with public health responsibilities. Sources are usually groundwater wells or rainwater tanks. Samples are collected using basic protocols by trained health officers and transported by approved methods to the Public Health Bureau laboratory. A December 1994 review by the Public Health Bureau indicates the extent of water quality data, including over 1,100 well water samples over 9 years both for coliform and chemical parameters, all of which have been entered into the LIC GIS database. Nitrate increases were reported in some sugar cane areas. River low flows are fed by groundwater, thus groundwater quality may be inferred from river water quality monitoring.

6. water quality data collected by CZMU, often up to 1.5 kilometers up river from the coastline.

Samples are generally collected monthly from sites including the Mullins, Manatee, Sibun and Sittee rivers.

As indicated in the Belize report to the UNCED (GOB, 1992a), the government has insufficient baseline data from which to monitor trends in the environment or water quality. It suspects, for example, that inland deforestation is causing increased sedimentation in the rivers discharging to the coast and that this is damaging the barrier reef and associated fragile ecosystems. However, it cannot say definitely if this is the case or how serious the problem is. Similarly, it is difficult to develop suitable controls on environmental pollution from point-sources such as factories or sewage plants without understanding the assimilative capacity of the receiving water.

It is the opinion of UNIDO consultant Newell (1993) that Belize requires at a minimum, an environmental monitoring program to establish the assimilative capacities of Belize rivers subject to point pollution discharge. He mentions specifically the organic loading (in terms of Biochemical Oxygen Demand (BOD) or the more easily monitored COD), dissolved oxygen, temperature, pH, alkalinity, hardness and oxidation/reduction potential of the water, bearing in mind the largely agro-industrial nature of point dischargers. Monitoring would provide a means of classification of the rivers although this would be expensive and he mentions as an alternative, the possibility of establishing a biotic index. While probably cheaper and useful from the point of view of establishing aquatic healthiness, it is less useful for the multiple-purpose monitoring needed by Belize with respect to the characteristics, elements and constituents of water bodies important for their multiple uses.

Table 1.4 Mean Values of Water Quality Parameters for Selected Stations Sampled by Department of Hydrology (*)

Station		pH	Total Alkalinity	Conductivity	Hardness	Nitrate	Phosphate	Chloride	Sulfate
Belize	Benque Viejo	7.9	172	385	222	0.03	-	8.0	29.3
Belize	Cristo Rey	7.3	83	153	62	1.05	0.60	3.5	11.5
Belize	Rio On	7.4	12	46	13	1.00	0.74	2.4	3.1
Belize	Big Falls Ranch	7.9	151	580	383	-	0.40	19.3	155.0
Belize	Double Run	7.8	138	600	340	-	-	53.5	143.5
Sibun	Freetown	7.6	93	587	185	-	-	90.5	47.7
North Stann	Middlesex	7.7	23	131	21	-	-	9.0	11.3
Sittee	Kendall	7.1	30	81	27	-	-	7.0	-
Rio Grande	Big Fall	7.7	123	-	185	-	-	7.5	40.0
Moho	Station 15 (Blue Creek)	7.6	150	-	330	-	-	35.0	120.0
Moho	Station 17 (Jordan)	7.7	155	-	350	-	-	35.0	135.0

* sample size ranges from 1 - 7

Table 1.5 Average Drinking Water Quality Parameters in Belize (WASA)

Parameter	Limit	Belize	Orange Walk	Corozal	Dangriga	Punta Gorda	San Ignacio	Benque Viejo	San Pedro	Belmopan
Alkalinity (mg/l)	**250**	100	231	348	18	249	136	338	235	127
Chloride (mg/l)	**250**	30	7.3	69	12	6	11	9	727	11
Chlorine (mg/l)	-	0.5	0.4	0.4	0.9	0.6	0.4	0.5	0.6	0.5
Color (units)	**5 units**	-	49	0	23	9	25	-	17	-
Fluoride (mg/l)	**1.5**	0.29	-	0.62	0.08	0.17	0.22	0.3	0.63	0.22
Hardness-T (mg/l)	**300**	337	529	623	76	263	158	383	554	152
Hardness-Ca (mg l)	-	265	491	478	31	234	144	328	296	103
Hardness-Mg (mg/l)	-	72	37	145	45	29	14	66	258	49
Iron (mg/l)	**0.3**	-	0.08	0.02	0.35	0.02	0.11	0.02	0.23	0.01
Sulfate (mg/l)	**250**	90	160	205	3.8	9	16	25	140	12
Turbidity (NTU)	**5**	14	0.8	0.3	2.7	0.6	4.6	1.0	1.4	1.0
EC (μmhos/cm)	-	580	1130	1440	64	490	340	750	2880	3.0
Temperature (°C)	**25**	26.5	27.1	27.8	20	24.4	23.3	23.5	20.5	23
pH (units)	**6.5-7.5**	7.5	7.06	6.85	7.5	7.4	7.78	7.9	7.63	7.8
Nitrate (mg/l)	**10**	0.3	1.7	2.0	1.3	2.2	1.7	2.8	2.9	2.2
Phosphate (mg/l)	-	0.06	-	-	0.26	-	-	-	-	-
TDS (mg/l)	**500**	-	-	-	40	-	-	-	-	-
Total Coliform (colonies/100ml)	**1**	0	0	0	0	0	0	0	0	0

1.5 Water Quality Standards

The following table indicates the water quality standards for drinking water used by WASA and proposed from the World Health Organization (WHO).

A recent consulting report has made recommendations to the Department of Environment for industrial effluent quality standards (Miller and Miller, 1994). The status of these recommendations is not known.

Currently, there are no water quality standards established for non-point source pollution sources. The paucity of water quality data in Belize precludes the assessment of natural variability in water quality and background or baseline conditions are not defined.

Table 1.6 Acceptable Limits (WASA) and Guideline Values (WHO, 1993) for Surface Waters

Parameter	Acceptable Limits (WASA)	Guideline Values (WHO)
Temperature	25°C	none
pH	6.5 - 7.5	6.5 - 8.5
Color		15 TCU
Turbidity	5 units	5 NTU
TDS	500 mg/l	1,000 mg/l
Conductivity	N/A	none
Hardness (total)		none
Alkalinity	250 mg/l	N/A
Chlorine - free	N/A	5 mg/l
Coliform	1/100 ml	0/100 ml
Nitrate - N	10 mg/l	10 mg/l
Chloride	250 mg/l	250 mg/l
Fluoride	0.5 - 1.5 mg/l	1.5 mg/l
Phosphate	N/A	none
SO_4	250 mg/l	250 mg/l
Mg^+	N/A	none
Al^{3+}	N/A	0.2 mg/l
Ca^{2+}	N/A	none
Fe	0.3 mg/l	0.3 mg/l
Pb	N/A	0.01 mg/l

1.6 Water quality standards for shared rivers

1.6.1 Belize-Mexico Rivers

As indicated, Belize shares one major river with Mexico, the Rio Hondo, which forms the northern limit of Belize. The Rio Hondo forms a meandering border with Mexico for approximately 160 km, 110 of these as the Rio Hondo, and the other 50 km as the Blue Creek. The eastward draining Blue Creek and the northward draining Booth's River join at Dos Bocas to form the Rio Hondo. Prior to forming the border with Belize, the Blue Creek curves north to east through the south-east corner of the Mexican state of Campeche after leaving Guatemala. Prior to this it branches just inside Guatemala with its southern extension draining northwards into Campeche out of the more highly elevated and heavily forested Peten region of Guatemala. Its northern extension curves from the northern Peten into Campeche and back into Guatemala before joining with the southern branch. In Mexico and Guatemala the river is called the Rio Azul. The major tributary to the Booth's River, the Rio Bravo, also flows out of the Guatemalan Peten through an area of karstic geomorphology represented by the dissected Bravo Hills. On the Mexican side, the Rio Hondo has one major tributary, the Rio Escondido, that joins the river at Juan Sarabia. It has a large catchment area of 4,582 km^2.

Mexico's statutory instrument for the management and protection of natural waters is the 1992 Ley de Aguas Nacionales, prepared by the Secretaria de Agricultura y Recursos Hidraulicos and passed by the Congress of the United States of Mexico (GOM, 1992). Title seven, chapter one, articles 85 to 96 refer to the prevention and control of water contamination and state that it is in the public interest that the Ley de Aguas Nacionales promotes measures and actions to protect water quality. The law, among other things, empowers the Comisión Nacional de Agua to promote, implement and operate the necessary federal infrastructure and services to preserve and improve the quality of water in national catchments and aquifers in agreement with the official water quality norms and waste discharge limitations in force. These norms are not explicitly stated in the statutory document. It is also the task of the Comisión to determine the parameters with which the dischargers of waste must comply based on the capacity of national water bodies for assimilating and diluting this waste. The Diario Oficial de la Federación, the congressional gazette, publishes the Declaratorias de Clasificación de Cuerpos de Aguas Nacionales of Mexico which sets water quality parameters and assimilative limits for determined water bodies. These parameters were not included with the documents sent from Mexico authorities. The other main law relevant to natural waters is the Ley General del Equilibrio Ecológico y la Protección al Ambiente.

1.6.2 Belize-Guatemala Rivers

The radial nature of the drainage descending the igneous, intrusive mass of the Maya Mountains means that several of the Belize rivers and creeks temporarily drain out of Belize and into the Guatemalan Peten, returning once again as the rivers skirt this outstanding land-mass and resume the eastward trend of the Coban limestone formation towards the Belize coastline and the lower-lying Caribbean basin.

The five major river systems with a significant portion of their contributing drainage area in Guatemala include the Sarstoon River (which forms Belize's southern border with Guatemala), the Temash River, the Moho River, the Rio Hondo (both its main channel and its tributary, the Rio Bravo) and, most importantly, the Belize River.

The Sarstoon River forms a meandering border with Guatemala across the broad coastal lowlands formed by the Tertiary and Quaternary sediments that lie over the slumped limestone fringe around the Maya Mountain intrusions. This border section of the river is approximately 45 km long after which the Sarstoon then extends more than 80-100 km into Guatemala, occupying a broad valley between the south-western extension of the Maya Mountain chain and the more elevated Sierra de Chama of Guatemala that stretches eastward to the Gulf of Honduras.

The Temash River runs parallel to the Sarstoon but drains directly out of the south-western Guatemalan extension of the Maya Mountains, extending only a short distance into Guatemala from which it drains eastward across the border.

The Moho River, and one of its main tributaries, the Aguacate Creek also drain out of the south-western Guatemalan extension of the Maya Mountain range. A branching series of streams mostly radiate south away from the main divide of the range, and are forced north-east by limestone ridges before turning south-eastward again to the Gulf of Honduras.

The Belize River drains the opposing side of the main divide of the Maya Mountains in a broadly looping path comprising a series of smaller tributaries that radiate north-west and west from the igneous intrusion and metasediments of the mountains, enter Guatemala and coalesce in the form of an asymmetrical, trellis network to form the Mopan Branch of the main Belize River. The Mopan Branch flows northwards for around 50 km through the eastern Peten of Guatemala before entering Belize at the border town of Benque Viejo where it continues its loop north-east around the edge of the Maya Mountains and its limestone fringe before finally cutting back south-east across the coastal plain to the Caribbean basin.

A recent paper to the workshop on managing the water resources of Central America (GOG, 1994) by the Secretaria de Recursos Hidraulicos de la Presidencia de la Republica de Guatemala, states that little effective water quality monitoring is undertaken in Guatemala, least of all on the remote rural rivers which Belize shares with this nation. Activities that are carried out are sectoral and in relation to the monitoring of physical and chemical quality of water bodies, no program at a national level exists, only programs with sporadic measurements of drinking and irrigation water quality. Hydrometeorological monitoring at the national level has been the responsibility, since 1976, of the National Institute for Seismology, Volcanology, Meteorology and Hydrology (INSIVUMEH).

Apparently, as of 1994, there were 232 and 100 functioning meteorological and hydrological stations in Guatemala, respectively. However, INSIVUMEH is currently not capable of carrying out a systematic and complete evaluation of water quantity and quality within its national territory (GOG, 1994).

It is thought by the government that the majority of surface water bodies in Guatemala are contaminated, particularly with sewage wastewater. Guatemala has no specific law related to water, the responsibility for management of this resource being divided between different laws and different judicial levels. The establishment and application of water quality norms has thus been difficult. Guatemala has eight laboratories equipped to do some form of water and wastewater analysis (Yánez Cossio, 1993), but only one, at the Escuela Regional de Ingeniería Sanitaria, is equipped with a full array of equipment suitable for water pollution control, although some is outdated and quality control and assurance is not evident.

As part of the PAHO MASICA project, it is planned to enhance the water quality monitoring and pollution control potential of Guatemalan institutions, including a program to quantify the assimilative capacities of Guatemalan waterways to receive domestic and industrial waste (Yánez Cossio, 1993). In terms of the shared rivers with Belize, no plans for monitoring appear to exist. Guatemala has one hydroelectric power project planned for the Mopan River at Chiquibul, and which is expected to generate 12 mW of electricity. The impacts of this system on river flow and quality into Belize is not known. The Sarstoon River is used for transportation. Little mention can be found of shared catchments and rivers with Belize or their significance in reports obtained from Guatemala.

1.6.3 International Agreements

The Convention of 1859 between the United Kingdom and Guatemala, set the boundary of Belize and Guatemala at the median line of the Sarstoon River, while under the 1893 Treaty between the United Kingdom and Mexico, the boundary follows the deepest channel of the Hondo River. Neither of these agreements, which both remain in force, govern water use, pollution control, and so forth. In fact, in the case of Belize and Guatemala, little communication has taken place concerning upstream uses of shared waterways and possible downstream impacts on the receiving country. For example, the construction of a hydroelectric plant on the upstream, Guatemalan portion of the Mopan River has not been communicated officially to Belize even though it could have significant short and longer term hydrological impacts.

In 1991, the Government of Belize exchanged Notes with Mexico for the cooperation on the use of international rivers and border environmental conditions and an agreement was signed on cooperation for the protection and improvement of the environment and conservation of the natural resources of the border zone (GOB, 1994a). Amongst other things, the two countries agreed to undertake and share information on efforts to address water pollution. No references or data was found during the extensive literature and data research for this project that illustrates that this has been put into effect for the issue of water quality management and monitoring. Although Mexico indicated in correspondence that it has a number of monitoring stations on the Hondo River, no evidence was located that this information has been transferred to users and decision makers in Belize. Belize currently has no monitoring station of its own on the border waterway with which to reciprocate with Mexican monitoring agencies.

The Belize Minister of Natural Resources has suggested a similar border agreement for Guatemala that Belize currently has in effect in the case of Mexico. Historically, communication and exchange of data has been extremely limited between Belize and Guatemala due to past territorial disputes and diplomatic difficulties.

1.7 Report Organization

The following outline lists project tasks by title:

Task 1 Establish contextual basis for the Belize Water Quality Monitoring Plan

- 1.1 Identify water quality standards for shared rivers
- 1.2 Collect and review background water quality
- 1.3 Develop river basin descriptive profiles
- 1.4 Establish main catchment input-output dynamics
- 1.5 Establish wider perspective of monitoring program

Task 2 Establish water quality indicators to meet applied information needs.

- 2.1 Review available data on water quality indicators
- 2.2 Evaluate key water quality problem areas
  - 2.2.1 Evaluate pesticides and agrochemicals
  - 2.2.2 Evaluate sediments
  - 2.2.3 Evaluate faecal coliform
- 2.3 Review cause and effect relationships for water quality
  - 2.3.1 Assess loading risk factors
  - 2.3.2 Locate high risk areas

Task 3 Evaluate technical and institutional capacities for water quality monitoring

- 3.1 Review capacity to analyze indicators
- 3.2 Review other environmental evaluation activities
- 3.3 Assess institutional framework
- 3.4 Determine feasible indicators

Task 4 Develop proposed Water Quality Monitoring Plan

4.1 Inventory proposed sampling locations
4.2 List sampling and analysis techniques
4.3 List institutional responsibilities
4.4 Provide guidelines for data management
4.5 Suggest appropriate training program
4.6 Develop official monitoring protocol manual

Task 5 Prepare Final Report

The report organization slightly differs from the proposal, but provides a format such that sections/chapters can be used separately or as stand alone documents.

Table 1.7 Task Numbers and Corresponding Report Section

Task	Report Section
1	
1.1	1.6
1.2	1.4
1.3	2.1
1.4	2.2
1.5	2.3
2	
2.1	3.0, 3.1
2.2	3.2, 3.3
2.3	3.5
3	
3.1	3.6
3.2	3.6
3.3	3.7
3.4	3.1.1
4	
4.1	4.1
4.2	Sampling Protocol
4.3	3.7
4.4	4.3 & Sampling Protocol
4.5	4.5 & Sampling Protocol
5	

Chapter 2

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2.3 Wider perspective of monitoring program 43
2.4 Design of Water Quality Monitoring Networks 46
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2.0 Water Quality Monitoring

One of the key steps in the development of any water quality monitoring program is the establishment of descriptive profiles of the river systems to be monitored and their contributing catchments. These profiles integrate the available knowledge of natural and anthropogenic factors that do or could give rise to natural and induced water quality characteristics and hence may influence the choice of water quality variables to measure. The selection of water quality variables must reflect the sensitivities appropriate to each environment or the range of environmental conditions. Because of the complexity of influences within natural aquatic environments that determine water quality, there are no universal standards that can be adopted for all water bodies as norms (Chapman, 1993). Selection of variables is a balance between the desire to adequately assess the range of potentially important environmental factors and the desire to keep the monitoring process manageable both logistically and financially.

At a national level, it is necessary to establish a preliminary survey of each water system that can inventory the following (Chapman, 1993):

a. Geographical features of the contributing area - topography, geology (and soils), climate, land-use, hydrology, hydrogeology.

b. Water uses - dams, out-takes, irrigation use, navigation, fisheries.

c. Pollution sources (present and forecast) - non-point and point sources of domestic, industrial and agricultural contaminants.

This framework has been adopted in this report including the preparation of major catchment profiles, with sub-sections for discharge and water quality data. The majority of rivers in Belize are utilized for navigation by small craft throughout the coastal plains but almost all cease to be navigable in large part once they enter the karstic limestone hills or the steeply sloping metasediments radiating from the Mayan Mountains. The presence of riffles, sediment bars, rapids and small waterfalls impede water traffic once the steeper hydraulic gradients of the descending rivers are encountered. The only river in Belize used greatly for commercial navigation is the New River, where sea-going barges carry the production of sugar and molasses from plants at Tower Hill and La Libertad to bulk transport ships anchored off shore. The navigation category was thus not considered. The range of and major activities or characteristics with potential impacts on water quality have been identified as best as possible, using available information such as the recent study of land-based sources of industrial, domestic and agricultural pollution (Archer, 1994). Available descriptive statistics concerning water quality and stream discharge and their variability provide broad indicators of major hydrological characteristics. Available map information, selected field visits and aerial reconnaissance provided a broad impression of geographical factors. It is expected and hoped that these preliminary profiles will provide a nucleus for the development of a series of full-scale ecosystem profiles planned by DOE.

2.1 River Basin Profiles

The following tables contain broad summaries of each of the sixteen major catchments of Belize, each of which are discussed in full detail in Annex 1 of this report.

Table 2.1 Summary Profile of the Rio Hondo Catchment

	RIO HONDO
Topography	Largely lowland topography. Broad meandering valley with tributaries up into limestone scarps and hilly lands of Mexico and Guatemala. Elevation between 0 and 250m with majority below 100m with slopes less than 5 degrees.
Geology and Soils	Limestone rocks and soils which vary considerably. Alkaline geochemistry.
Land-Use	Mixed land use ranging from majority forest land down through subsistence milpa through mechanized arable to plantation sugar cane from the higher to lower elevations inland to the coast. Total agricultural land 57,076 ha. Urban 1,145 ha.
Climate	Annual rainfall between 1000-1500mm.
Hydrology	Branching upland tributaries off locally steep scarps feeding a meandering, sluggish and floodable channel influenced by tidal activity. Discharge regime not known. Drainage area of 15,075.5 km^2, 2,617.5 km^2 in Belize.
Water Quality	No water quality data obtained.
Pollution Sources	Largely non-point across the drainage network. Probable agricultural runoff particularly from sugar cane, arable and livestock, discharge of domestic wastewater from small river towns, natural mineral leaching. Relatively low risk and loading of all expected pollutants.
Use of Water	Irrigation, probably waste disposal and small hydropower generation.
Gauging Sites	None in Belize, apparently four on main river in Mexico and three on tributary Rio Escondido.

Table 2.2 Summary Profile of the New River Catchment

	NEW RIVER
Topography	Largely lowland topography. Over 99% of land area less than 100m elevation, most close to sea level, flat or with a slope of less than 1 degree.
Geology and Soils	Limestone rocks and soils which vary considerably. Alkaline geochemistry.
Land-Use	Predominant productive land use is sugar-cane in the lower valley with mixed broadleaf forest, savannah and marshy scrubland elsewhere. Total agricultural land 40,563 ha, urban land 791 ha.
Climate	Annual rainfall varying from 2000mm to 1000mm east to west.
Hydrology	Slowly meandering river with few tributaries. Influenced by tidal activity with an apparent minimum recorded flow of 117,000 m^3/day (1.4 m^3/s) and flood ranges of 4m causing flooding. The 1992/93 stage range was recorded as 2.5m (low of 2.6m and a high of 5.1m at Tower Hill). Drainage area of 1,864 km^2.
Water Quality	High natural DO, hardness and alkalinity.
Pollution Sources	Significant point pollution. Industrial discharge of BOD, caustics, phosphates, nitrates, iron, oil and grease from two sugar refineries at Tower Hill and La Libertad. Various additional small industrial and domestic waste discharges below Tower Hill. Probable non-point agricultural runoff and flooding related input of sediments and organic material below Tower Hill. Natural mineral leaching. Relatively high risk and heavy loading of agro-industrial pollutants.
Use of Water	Industrial use for the sugar refineries, some irrigation, and for waste disposal.
Gauging Sites	Tower Hill toll-bridge. Selected sampling at refinery sites.

Table 2.3 Summary Profile of the Belize River Catchment

	BELIZE RIVER
Topography	Largest catchment in Belize with significant part in Guatemala. Mixed topography broadly divided between a lower, long coastal plain section below 100m with slopes less than 1 degree, and upper, highly dissected mountain basins and plateaus with slopes over 25-30 degrees and elevations to 1000m.
Geology and Soils	Broad mix of limestone, igneous and metamorphic rocks with associated soil variations from thin, leached and stony to deeper sedimentary varieties. Varying geochemistry with both acid and basic zones and areas of leachable salts and metal ions.
Land-Use	Reflects geological and topographic variation, from forestry, through milpa, fruit, cattle and vegetables. Total agricultural land-use is 48,134 ha. Major urban land-uses of Belize City, San Ignacio and Belmopan (3,217 ha in total). Forest predominates.
Climate	Medium annual rainfall varying from 2500mm in the highlands to 1000mm north and west and 1500 along the coast.
Hydrology	Significant branching and large sub-basins. The major mountain tributaries feed a largely slow moving, meandering coastal river prone to high flood peaks (+5m). Headwater stage increases of up to 15m in a day occur at sub-basin confluences. The Macal River at Cristo Rey experiences minimum flow depths as low as 1m and as high as 18m with flows well over 1000 m^3/s (the rating formula computed 16,000). Benque Viejo station shows that the major Guatemala branch produces average daily discharges varying from 1 m^3/s to 275 m^3/s with an annual daily mean between 20 and 40. Peaks are attenuated on to the coastal plain due to the staggered floodwater arrival through the drainage network and shallowing of the channel. Average daily discharge to the ocean is thought to be in the range of 155 m^3/s. Double Run has recorded peak flows in the range of 550-600 m^3's, low flows down to 10-20 m^3/s and annual average daily flows between 100-150 m^3/s, similar to Big Falls and Banana Bank. Depths apparently vary from 40cm to over 6m at Double Run. Drainage area of 9,434.2 km^2, 6,542.7 km^2 in Belize.
Water Quality	Background water chemistry depends on flood stage and timing but generally alkalinity and hardness of baseflows are high. Both will go down in concentration with higher flows. pH is slightly basic. High sulphate levels have been measured.
Pollution Sources	Several mid-size point pollution sources exist including domestic and small industrial outlets at San Ignacio and Spanish Lookout, the wastewater treatment plant at Belmopan, the water treatment plant at Double Run and food industry plants at Ladyville. BOD, pathogens and suspended solids are likely the most significant contaminants with secondary ones including caustics, chlorine and oil and grease. Some non-point agricultural runoff and flooding related input of sediments and organic material could be expected below San Ignacio. Sediment loads may also originate from construction (e.g. hydro-plant and quarrying). Cattle rearing could be source of BOD and pathogens. Worries exist about miscellaneous waste, especially hospital waste, being dumped in the Mopan River upstream in Guatemala.
Use of Water	Urban use for Belmopan, San Ignacio and Belize City, some irrigation below San Ignacio, waste disposal and hydroelectric generation (pending).
Gauging Sites	Up to eight sites were gauged, with seven permanent and three occasional sites currently operational: Rio On, Cristo Rey, Benque Viejo, Banana Bank, Big Falls, Bermudian Landing, and Double Run; and Mexico Creek, Black Creek and Mussel Creek occasionally. Two stations appear to exist on the Mopan branch in Guatemala.

Table 2.4 Summary Profile of the Sibun River Catchment

	SIBUN RIVER
Topography	High topographic variation, either very steep (45% over 25-35 degrees) or very flat (45% less than 1 degree) with local elevation to 1000m. Very steep, branched and karstic upper tributaries feed a marshy and mangrove filled lower meandering floodplain.
Geology and Soils	Acidic igneous rocks and metasediments give way to progressively younger carbonate rocks and alluvial soils.
Land-Use	Predominant land use is forestry and marsh with a small % of workable shallower mid-slopes under agriculture, particularly citrus, cacao or milpa (2,547 ha) with some pasture. Urban area 504 ha.
Climate	Orographically controlled, with up to 3000mm on the highlands down to 1500-2000mm on the coastal plain.
Hydrology	Fast and turbulent tributaries, some through caves and gorges, give way to a more sluggish and floodprone coastal reach probably subject to periodic sediment flushing with high peak flows. Average discharge is thought to be 50 m^3/s. Freetown Sibun has shown stage to range from 1 to 4m with mean daily flows between 35 and 65 m^3/s and recorded highs and lows of 250 and 1.8 m^3/s. Drainage area of 967.8 km^2.
Water Quality	Background chemistry reflects the mix of geologies with carbonate hardness and alkalinity balanced by the more acidic or neutral inland runoff. Inland erosion potential is balanced by coastal sedimentation potential.
Pollution Sources	In-stream sand and gravel mining associated with the rapid loss of sediment transport potential in the main coastal channels probably maintains suspended sediment levels. Some agricultural non-point inputs might occur from cultivated mid-slopes and milpa, particularly on leachable igneous soils. Loading and risk is expected to be low.
Use of Water	Water is probably used in the mining and washing process for sand and gravel.
Gauging Sites	Freetown Sibun.

Table 2.5 Summary Profile of the Manatee River Catchment

	MANATEE RIVER
Topography	High topographic variation, either very steep (60% over 25-35 degrees with half as karst) or very flat (40% less than 1 degree) with local elevation to 400-600m. Flat lands occupy the lowland half of the catchment.
Geology and Soils	Metasediments feed the southern tributaries and the carbonate rocks underlie the northern tributaries and coastal river.
Land-Use	Predominant land use is forestry, marsh and lagoon with a small % of workable shallower mid-slopes clear-cut for banana, citrus and mango (1,052 ha of agriculture). Urban land only 5 ha.
Climate	Orographically controlled, with up to 2500mm on the headwaters down to 1500-2000mm on the coastal plain.
Hydrology	Relatively fast and turbulent tributaries, more highly branched to the south off the older rocks. The more slow-moving main body of the river feeds and drains the Southern Lagoon. Discharge and flow regime is not known. Drainage area of 484 km^2.
Water Quality	No water quality data exists. Background chemistry probably reflects the mix of geologies with carbonate hardness and alkalinity from the northern sub-basins balanced by the more acidic or neutral southern basin runoff.
Pollution Sources	In-stream sand and gravel mining near Government Landing probably aggravates suspended sediment levels. Some agricultural non-point inputs might occur from citrus cultivated mid-slopes. Loading and risk is expected to be low.
Use of Water	Water is probably used in the mining and washing process for sand and gravel.
Gauging Sites	None. Tidal levels monitored for Southern Lagoon at Gales Point.

Table 2.6 Summary Profile of the Mullins River Catchment

	MULLINS RIVER
Topography	Small short catchment with only 300 m elevation but with 45% of steep slopes between 25 and 30 degrees.
Geology and Soils	The upper catchment is metasediments bordered by the lowland coastal carbonates and alluvial soils.
Land-Use	Predominant land use is forestry with only a small clearance for citrus. Some shrimp farming. Agricultural land-use is 799 ha and urban 28 ha.
Climate	The majority of the catchment is in the 2000-2500mm belt with the headwaters receiving up to 3000mm.
Hydrology	Convexo-concave river basin profiles with the rivers flowing off the flatter uplands descending steeply and turbulently down to the coastal mangrove belt. Discharge and flow regime is not known. Drainage area of 156.9 km^2.
Water Quality	No water quality data exists.
Pollution Sources	Few point or non-point contaminants are expected. Loading and risk is expected to be low.
Use of Water	No developed uses are known for this river water.
Gauging Sites	None.

Table 2.7 Summary Profile of the North Stann Creek Catchment

	NORTH STANN CREEK
Topography	Comprised of a predominantly flat or slightly sloping valley and coastal outflow plain (30% less than 1 degree slope) or else steeply incised hillslopes between 25 and 35 degrees (70%). Upland sub-basins extend to 800-900m.
Geology and Soils	Largely ancient igneous rocks and metasediments except for the carbonate coastal plain and young sediments.
Land-Use	Land vocation is forestry with considerable, expanding clearance for orange groves (6,230 ha or 22% of area) and local milpa conversion. Higher lands are still forested. Agricultural activity occupies 7,383 ha with 251 ha of urban land.
Climate	Orographically controlled, with up to 3000mm on the highlands down to 2000-2500mm on the coast.
Hydrology	Fast and turbulent tributaries, particularly from the southern sub-basins. Average daily discharge is thought to be in the order of 15 m^3/s. Flow depth averages at around 55cm with a recorded average daily low of less than 10cm up to a high of 3.9m at the old Middlesex station. Drainage area of 281.4 km^2.
Water Quality	Background chemistry reflects the siliceous rocks with low hardness and alkalinity and a largely neutral pH.
Pollution Sources	Currently, road construction and citrus clearing has created a heavy available and active sediment budget that can be expected to show up as high TSS, particularly at peak events. Point pollution includes two citrus processing plants at Pomona and Alta Creek with toxic low pH and high BOD. Fish kills have been observed. Non-point agricultural inputs are highly likely from off-drainage of leached citrus fertilizers and pesticides.
Use of Water	Water is taken from the river to supply Dangriga (3 km upstream from the estuary) and for orange plant production and waste disposal.
Gauging Sites	The two previous gauging stations have both been discontinued.

Table 2.8 Summary Profile of the Sittee River Catchment

	SITTEE RIVER
Topography	Narrow, steep basin comprised of somewhat parallel sub-basins descending steeply from basin sideslopes of 800-1000m and separated by interfluves of 300-400m. The majority of the basin comprises 25-35 degree slopes (80%) with a relatively short and narrow coastal plain section.
Geology and Soils	The upper basin is largely the fringing metasediments between the inner ancient igneous rocks and tertiary coastal sediments.
Land-Use	Land vocation is forestry with important and expanding clearance for citrus groves onto even steeper, but unsuitable midslopes. Higher lands are still forested. Agricultural land is 1,422 ha with 66 ha urban.
Climate	Orographically controlled, with up to 3000mm on the highlands down to 1500mm on the coast.
Hydrology	Fast and turbulent flows from the sub-basins upstream of the main valley outflow near Kendall. Average daily discharge is thought to be in the order of 14 m^3/s at a stage of 1.3m with variations recorded between 0.67 and 4m at the outflow on the coastal plain. Drainage area of 451.2 km^2.
Water Quality	Background chemistry reflects the silicious rocks with low hardness and alkalinity and a largely neutral pH, even at low baseflows.
Pollution Sources	Citrus clearing through slash-and-burn and windrows is probably aggravating TSS, particularly at peak events. Non-point agricultural inputs are highly likely from off-drainage of leached citrus fertilizers and pesticides.
Use of Water	No known uses.
Gauging Sites	Kendall Bridge.

?.9 Summary Profile of the South Stann Creek Catchment

	SOUTH STANN CREEK
ıphy	Forming half of the Cockscomb basin, it originates as a broad network of coalescing tributaries that flow off relatively low elevations (200-500m) but among steep slopes, over 60% between 25-35 degrees. Once past the Long Falls gap, the basin is low elevation with mostly less than 1 degree slopes.
ı and Soils	Mostly ancient igneous rocks and metasediments with acid leached soils. The shorter coastal plain is tertiary sediments.
se	Land vocation is forestry partially protected as the Jaguar reserve, mostly pine on slopes and mixed forest in valleys. Increasingly the foothills and outflow plain are being covered with citrus orchards and bananas. Total agricultural land is 580 ha, with 130 ha urban.
	Orographically controlled, with up to 3000mm on the highlands down to 1500-2500mm on the coast.
›gy	Extremely dense drainage network of multiple, branching tributaries, generally steep and incised and coalescing to form the major creek and its short path to the ocean through the Cabbage Haul Hills. The stage discharge curve shows flow depths ranging from 90cm to 4.3m and discharges from 4 to 100 m^3/s. Velocity varies from 0.4 to 0.8 m/s. Drainage area of 258 km^2.
ʔuality	No data is available. Background chemistry will reflect the siliceous rocks with low hardness and alkalinity and a largely neutral pH.
n Sources	Citrus clearing through slash-and-burn and windrows is probably aggravating TSS, particularly at peak events. Non-point agricultural inputs are highly likely from off-drainage of leached citrus fertilizers and pesticides.
Water	It is possible that citrus and banana growers irrigate with river water, but little other use is expected or known.
ʒ Sites	South Stann Creek Bridge.

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Table 2.12 Summary Profile of the Golden Stream Catchment

	GOLDEN STREAM
Topography	Mostly coastal plain below 200m (70% of slopes less than 5 degrees) with rolling and karstic headwaters up to 500m with 25% of steep slopes greater than 25 degrees in the limestone hills.
Geology and Soils	Majority of Jurassic and Tertiary limestones.
Land-Use	Predominantly forestry with lush riparian zones along the main river channel. Some milpa, cattle and bananas. Total agricultural use 2,636 ha with 20 ha urban.
Climate	Mostly the whole catchment is in the 3000-3500mm belt.
Hydrology	Relatively limited channel network of a few branching major channels. Meandering main channel. Drainage area of 204.1 km^2.
Water Quality	No data is available. Background chemistry will probably reflect the carbonate rocks and be high in hardness and alkalinity.
Pollution Sources	Largely natural forest. Some sediment yields from milpa farming expected. Few other anthropogenic contaminants expected.
Use of Water	No known abstractive uses.
Gauging Sites	Hellgate Village.

Table 2.13 Summary Profile of the Rio Grande Catchment

	RIO GRANDE
Topography	Relative relief up to 900m with most of the upper catchment between 200 and 700m. Karst formations and valley development has resulted in more rolling and varied topography with a broad, relatively even mix of slope types from less than 1 to over 30 degrees.
Geology and Soils	Majority of Jurassic and Tertiary limestones.
Land-Use	Predominantly forestry with significant milpa clearing on the flatter valley bottoms and adjacent hillsides of the upper main channel. Pasture and cattle also widespread. Total agricultural land is 15,874 ha with 225 ha urban.
Climate	The steeper catchment receives 2500-3000mm while along the coast, the main channel and its minor tributaries are in a 3000-4000mm zone.
Hydrology	Meandering main channel with a major branching tributary system extending a broad dendritic network further back up into the karst. Apparent average flows of around 24 m^3/s. Flows down the Columbia branch produce a mean daily flow at San Pedro of around 14 m^3/s with a 3-4m stage variation possible. Minimum flows drop to around 1-2 m^3/s. The river is very flashy. Drainage area of 718.5 km^2.
Water Quality	Background chemistry reflects the carbonate rocks in hardness and alkalinity.
Pollution Sources	Largely natural forest with some Milpa and a little citrus expansion. Little if any anthropogenic contaminants expected.
Use of Water	No known abstractive uses.
Gauging Sites	San Pedro, Big Fall.

Table 2.14 Summary Profile of the Moho River Catchment

	MOHO RIVER
Topography	Relatively large catchment area extending into Guatemala. A trellised system of tributaries drain a 600-700m plateau and are each separated by low undulating hills, while the main, relatively non-branching channel flows behind low hills along a flat valley out of Guatemala and onto the low coastal plain. A range of slope types occur with steep karst, short steep hillslopes and broad, shallow areas.
Geology and Soils	Majority of Jurassic and Tertiary limestones.
Land-Use	Predominantly forestry with considerable milpa clearing and rice production on the flatter valley bottoms and adjacent slopes. Swampy conditions on the coastal plains. Agricultural land-use is 17,612 ha and urban 405 ha.
Climate	The steeper catchment receives 2500-3000mm while along the coast, the main channel and its minor tributaries are in a 3000-4000mm zone.
Hydrology	The main channel flows in from Guatemala and branches little within Honduras but is fed by two northern tributaries, Aguacate and Blue Creek, that capture a trellis-type drainage network flowing off the fringing karst of the southern Mayan Mountain chain. Data suggest a flashy discharge range of over 500 m^3/s with minimum flows down to 1 m^3/s and maximum flows of more than 600 m^3/s. Recorded mean daily flow ranges from 30 to 80 m^3/s and flow depths of 20cm to 5m at the Jordan station. The tributary Blue Creek mean flow depths have varied between 0.7m and 1.5m with an annual daily recorded low flow level of 0.24m and a high of 6.5m. Aguacate Creek stage discharge curve suggests a normal flow range from 0.3 to 13.7 m^3/s, depths from 0.07 to 0.8m and velocities from 0.5 to 0.7 m/s. This would suggest Blue Creek to be a major contributor. Drainage area of 1,188.5 km^2, 812.5 km^2 in Belize.
Water Quality	Background chemistry reflects the carbonate rocks in hardness and alkalinity.
Pollution Sources	Few if any anthropogenic contaminants expected, possibly TSS from milpa and other clearing of land for annual crops.
Use of Water	No known abstractive uses.
Gauging Sites	Blue Creek, Jordan Village.

Table 2.15 Summary Profile of the Temash River Catchment

	TEMASH RIVER
Topography	Extends into Guatemala through the Toledo foothills, with Belize portion almost all below 100m elevation with around 90% of slopes below 1 degree.
Geology and Soils	Majority coastal sediments extending up onto Jurassic and Tertiary limestones.
Land-Use	Predominantly forestry with significant milpa clearing and rice production. Total agricultural use is 5,259 ha and urban 180 ha.
Climate	Receives around 3500mm on average.
Hydrology	Meandering, slow-moving and silt filled main channel with complicated, winding micro-drainage similar to large areas of mud-flats. Some branching of tributaries but dominated by single low-order main channel. Marshy conditions and flooding. No discharge regime established. Drainage area of 474.6 km^2, 359.6 km^2 in Belize.
Water Quality	No available data.
Pollution Sources	Largely natural forest with some slash and burn milpa and some rice. Little if any anthropogenic contaminants expected, possibly TSS from milpa.
Use of Water	No known abstractive uses.
Gauging Sites	None. Difficult access.

Table 2.16 Summary Profile of the Sarstoon River Catchment

	SARSTOON RIVER
Topography	Extends into Guatemala, with Belize portion almost all below 100m elevation with around 98% of slopes below 1 degree.
Geology and Soils	Majority coastal sediments extending up onto Jurassic and Tertiary limestones.
Land-Use	Predominantly forestry with some milpa clearing and rice production. Agricultural use is 767 ha with no urban.
Climate	Receives 4000mm on average.
Hydrology	Meandering, slow-moving and silt filled main channel with only minor, largely non-branching tributaries at periodic intervals draining the broad flat coastal plain. Marshy conditions and flooding. No discharge regime established. Drainage area of 2,217.5 km^2, 194 km^2 in Belize.
Water Quality	No available data. Probable TSS from large-scale milpa disturbances.
Pollution Sources	Largely natural forest with some slash and burn milpa. Little if any anthropogenic contaminants expected, possibly TSS.
Use of Water	No known abstractive uses.
Gauging Sites	None. Very difficult access.

2.2 Catchment input-output dynamics

An objective of the monitoring program is to develop a better understanding of the linkages between the level or loading of pollutants into Belize water bodies and the impact on the various catchment ecosystems, particularly the input of these pollutants to the nearshore marine system. Clearly the linkages and impacts will vary from catchment to catchment based on the characteristics of the water bodies; their flow, volume and the range and type of agricultural, urban and industrial activities inventoried for each catchment. This is discussed in more detail in Chapter 3.

An important factor to consider when establishing monitoring sites is the coastal zone dynamics off Belize and particularly the range of tidal influence for each of the major rivers and the zone of saltwater-freshwater inter-mixing. This delimitation is important because in the estuarine zone, the upstream freshwater influences and impacts of anthropogenic activities are obscured and meshed with diurnal and seasonal marine influences. This added level of complexity makes data interpretation and comparison with upstream water quality unaffected by this marine interaction a difficult task, especially considering the relatively small number of samples that will be taken annually at each sampling location in Belize.

The characteristics of the Belize near-shore environment and the geography of the barrier reef and cays suggest that there is a gradual washing and concentration of any river-derived estuarine contaminant plumes in a southerly direction towards the Gulf of Honduras (UNDP, 1993). The offshore environment can be divided into two parts on the basis of topography and geology, north and south of Belize City. In the northern sector, the shelf is shallow with most depths less than 4.5 meters. Currents in the northern shelf lagoon flow southward due to the discharge of water into the Chetumal Bay by the New and Hondo Rivers. In the southern sector, the shelf lagoon deepens towards the Gulf of Honduras where depths exceed 60 meters. Drainage density is high on the coast where streams commonly terminate in small deltas that fringe the coast, with the formation of mangroves. However, the dynamics are not well-understood concerning the relationship between land-derived substances and their potential accumulation on the offshore cays. Characterization of peakflow volumes and peak flow water quality will better enable the DOE and CZMU to evaluate the rivers on the basis of environmental risk. The proposed coastal zone dynamics study (Danish Hydraulics Institute for the Department of Geology and Petroleum) may provide additional characterization data.

2.3 Wider perspective of monitoring program

From an assessment of the laws of Belize (Boles, 1990), responsibilities for natural resource management cut across legislation and agencies and, in some cases, are potentially contradictory or in conflict. For example, DOE is charged with the prevention of contamination of national water bodies while at the same time, The Water and Sewer act gives WASA powers to declare any area, which includes water bodies, as a sewage disposal area. Similarly, the Public Health Bureau is charged with the power to determine where domestic waste can be discharged.

The Water and Sewer, Public Health and Mines and Minerals, and Geology and Petroleum Ordinances and Acts interact and overlap with the EPA in relation to the use and contamination of Belize water bodies. This situation makes the institutional relationships and responsibilities between DOE, Public Health, Geology and Petroleum, WASA and Natural Resources an important factor in the future of water quality monitoring and the application of results. The Coastal Zone Management Unit (CZMU), which is part of Natural Resources, and the National Hydrological Service (reassigned in 1995 as part of the Ministry of Science, Technology and Transport) are key players in environmental monitoring. For example, the National Hydrological Service is responsible for the collection and analysis of data on the quantity, quality and variability of the nation's water resources; hydrological investigations for engineering and water resources purposes and publication and dissemination of information (FAO, 1994). In deciding upon water quality sampling points and methodologies, each agency must be consulted. Because of its historical role in stream discharge gauging, the National Hydrological Service should logically be empowered to assume a leadership role in the environmental water quality monitoring program.

Currently, the monitoring of river water quality is not allocated to any single authority at present nor is it carried out on any kind of routine basis. Agencies such as DOE, WASA, or Public Health will only take samples if they suspect problems such as an industrial discharge to have occurred. In the past, the agencies have combined with the Hydrological Service as a joint team to examine serious environmental disorders such as observed fish-kills on the North Stann Creek or the New River (Fabro, personal communication). Based on a broad interpretation of the Environmental Protection Act (GOB, 1992b), the DOE is responsible for environmental protection and the rational use of water resources such as the nation's rivers. According to Article 2 of the EPA, the DOE is responsible for the continuous and long-term assessment of natural resources and pollution. The DOE is responsible for undertaking surveys and investigations into the causes, nature, extent and prevention of pollution and to assist and cooperate with other persons or bodies carrying out similar surveys or investigations. It is required to undertake resource inventories, surveys and ecological analyses to obtain information on the social and biophysical environments in Belize with special reference to environmentally sensitive areas and areas where development is currently taking place or likely to take place. It is required to monitor environmental health, where environmental health is classified as the control of environmental factors that have an adverse direct or indirect effect on the physical, mental or social well-being of humans. The DOE is expected to conduct studies and make recommendations on standards relating to the improvement of the environment and the maintenance of a sound ecological system.

DOE has the power to formally recognize one or more laboratories or institutes as laboratories to carry out the functions entrusted to a laboratory under the 1992 EPA or its regulations and to specify the procedure for submitting samples of air, water, soil or other substances for analysis. This is largely in relation to compliance monitoring in which polluters will be instructed to take samples on a predetermined basis for official testing. However, this power also implies that the DOE does not necessarily have to set up its own laboratory but instead can establish a set of criteria by which a national laboratory must operate to produce data that is acceptable for the purpose of complying with the EPA and its regulations. DOE could then appoint this lab as an approved facility and base their legislative decisions on their official findings. This will be an important issue in future pollution control activities and in the use of monitoring data to underlie legislative actions. The Minister and DOE is charged with the right to specify quality standards for the environment and mechanisms by which those quality standards can be maintained.

As with many other countries, there are currently several agencies responsible for different aspects of water quality protection and management. Based on the legislative tools available and a logical assessment of institutional strengths, weaknesses and areas of core concern the government of Belize needs to secure the fact that a single agency is both responsible for and coordinates this national monitoring system. This decision must take into account other initiatives in progress that impinge on this area and may result in governmental decisions independent of the findings and recommendations of this program, the three main ones of which include the:

- activities of the Coastal Zone Management Unit and UN Global Environmental Facility to establish a marine water quality monitoring capacity and control program

- activities of the nascent Water Commission and its FAO-funded consultant which are likely to bring forth recommendations to create an official water watchdog institution like the UK OFWAT, one of whose many proposed responsibilities will be to take charge of monitoring and regulation of environmental water quality

- activities of the NARMAP project and its attempts to formalize and finance the Conservation and Environmental Data System (CEDS), designed to be a recipient and distributor (and possibly analyzer) of all environment-related data, including water quality, through the broadening activities of the LIC and its GIS facility.

Efforts to develop a more systematic hydrological monitoring system by the National Hydrological Service, includes their desire to link up quality and quantity variable measurement. This program has tried to keep in mind and adapt to the institutional setting in Belize, with an eye to coopting workable and logical capabilities into an efficient and, in the short-term at least, pragmatic utilization of available resources. A key resource is the human skills and equipment already found in the Hydrological Services, founded in 1980 and led by Mr. Frank Panton. Mr. Panton and his eventual successor (he is scheduled to retire shortly) could play a key leadership role in the water quality monitoring program both to integrate selected, existing discharge stations into a water quality monitoring framework, and also to supervise the joint collection of quality and quantity data from which background and pollution loadings can be estimated.

2.4 Design of Water Quality Monitoring Networks

In general, water quality monitoring programs are initiated based on specific objectives defined by the responsible agency or user. General water quality monitoring program classifications include:

- **Baseline Monitoring -** generally established to define the existing conditions of a system;
- **Inventory Monitoring -** established to determine the nature of constituents affecting a system;
- **Compliance Monitoring -** established in order to indicate compliance with existing water quality standards or
- **Event Based Monitoring -** established in response to a specific event in order to determine cause and effect. Typically associated with a release to the environment (e.g. oil spill).

In order to provide Belize administrators with a clear idea of the level of detail and planning involved in implementing a typical water quality monitoring network, the following procedure developed from North American experiences is provided. As indicated previously, Belize already has a partial hydrological monitoring network developed and modified over time by a small cadre of natural resource professionals concerned with quantifying and categorizing the water resources of Belize. The steps and desired outcomes described below provide useful points of reference when considering the current status of water quality monitoring in Belize, as outlined in this report, and the goals of the 1992 EPA.

2.4.1 General Monitoring Program Procedure

A catchment monitoring program is typically initiated to correct a perceived or documented water quality problem. The water quality problem to be addressed by the program should be defined in terms of measurable stream variables or attributes. The main objective of a water quality monitoring program is to detect changes due to land use management compared to changes attributed to natural variability. It is therefore important in program planning to select key variables at representative sites that are expected to respond to management decisions. Selection of variables involves a sorting process, based on catchment program objectives and considering the realistic constraints of monitoring.

The development of a monitoring program includes compilation of existing information and collection of data from field reconnaissance to focus the scope of the program. These factors should be included throughout development of the program:

- What are the issues and concerns that resulted in program initiation?
- What are the beneficial uses of water in the stream?
- What are the potential limiting factors for sensitive beneficial uses?
- Are these limiting factors influenced by non-point source activities in the drainage?
- What is currently known about the existing stream condition?
- What additional information is needed to make an assessment of the existing stream condition and cause and effect?
- Of the potential stream/riparian variables, which key variables are expected to respond to project management?
- What are the monitoring program constraints in terms of budget, personnel availability, expertise, site conditions, and other factors?

The planning steps below comprise a process of collection and evaluation of cursory information to assist in answering the above questions and the subsequent development of a responsive water quality monitoring program. A more extensive discussion of each of the steps follows:

1. Identify issues and concerns;
2. Stratify and classify stream reaches (initial classification);
3. Conduct reconnaissance: Assess existing conditions, refine water quality issues, and complete stream classification;
4. Establish specific goals and objectives;
5. Select parameters and monitoring design;
6. Select representative monitoring and reference sites;
7. Conduct first year or pilot program monitoring;
8. Reassess assumptions and objectives and modify monitoring program.

1. Identify Issues and Concerns

Water quality issues and concerns for the basin are formulated with program managers, project sponsors, cooperating agencies, and interested public. The status of beneficial uses for a particular water body is a primary issue and will dictate water quality objectives for the basin. The stream may be unsuitable for swimming or the fishery may have declined in response to specific land use impacts. Issues may also include an analysis of the resources available to conduct the monitoring, such as budget, personnel, equipment and laboratory costs.

General program goals are formulated. These goals provide the framework for organizing and reviewing existing data and selection of the approach for conducting the field reconnaissance. Program goals should include an identification of the geographic area of interest, beneficial uses of concern, and the impact of land use decisions on these beneficial uses. These assumptions will be evaluated in the field and as part of the first year of monitoring.

A goal is considered the overall aim or endpoint of the program. Objectives are a subset of project goals; one goal may have several objectives. Program goals may be expressed qualitatively, but objectives are expressed in quantitative terms. The general issues and concerns provide the sideboards for the stratification of stream reaches and collection of additional information.

Specific objectives for monitoring are formulated based on a comparison of the existing condition to the expected condition. The potential for the program to influence measurable stream attributes within the time frame established for the program is assessed.

2. Stratify and Classify Stream Reaches

Physical, chemical and biological attributes of streams vary between catchments because of differences in climate, hydrology, geology, landform, vegetation and soils. Streams vary along their length as changes occur in gradient, channel substrate, sinuosity, stream size, and riparian vegetation. Stream types described by classification systems exhibit differential response to a given management activity. The ability to predict a response is an important objective of stream classification. Classification allows identification of representative monitoring sites and reference stations.

The initial classification is an office procedure that utilizes existing information - aerial photographs, topographic maps, soil surveys - to identify stream reaches. This initial stream stratification provides a basis for organizing the collection of data during the reconnaissance phase. Field data collected during reconnaissance is used to adjust reach boundaries and complete the stream classification.

Soil type and riparian vegetation communities are the other components of stream reach classification. Soil family mapping units from a soil survey are used to delineate major differences in soil chemical characteristics (e.g. cation exchange capacity). Riparian vegetation is identified by community type. Community types are named on the basis of the dominant overstory species and the dominant or most characteristic undergrowth species. Soil type, riparian community type and stream type provide a useful method to stratify streams for the purpose of locating monitoring stations.

Stream reaches can be divided further into subreaches based on land use or land ownership. these subreaches distinguish the differences in administration and management that will affect project implementation. Monitoring sites are located within selected subreaches based on program objectives.

3. Conduct Reconnaissance: Evaluate Existing Condition and Identify Potential Limiting Factors

Field reconnaissance completes identification of stream reaches and identifies riparian communities. The field reconnaissance also provides a qualitative evaluation of the existing stream condition and a determination of possible causes and effects of water quality degradation. The objective of this phase is to identify those factors which are thought to limit the beneficial uses. Limiting factors are stream attributes which prevent the full attainment of the beneficial uses. For example, high summer temperatures, lack of suitable spawning conditions, or lack of pools and cover may limit fish populations.

Potential limiting factors are evaluated in the field by qualitative measurements and professional judgement. Stream attributes are discussed in greater detail in the following section.

Water Column

During reconnaissance, temperature, nutrients and bacterial impacts are evaluated indirectly by observation of stream conditions. This evaluation can be improved by including a limited number of grab samples. Temperature conditions are evaluated by observation of the amount of stream surface area exposed to solar radiation. Wide and shallow streams with little shading would be expected to experience high summer temperatures. Maximum registering thermometers can be used during a reconnaissance to better assess high temperatures before deciding whether to monitor temperature with recording thermographs.

The potential for bacterial contamination is assessed by observation of fecal material within the stream channel and adjacent riparian area. Fecal matter can enter the stream during a runoff event or as a point discharge from domestic sewage systems. Grab samples can provide additional information for assessment of fecal coliform bacteria. Results of the grab samples are evaluated by relating the time of collection to recent development or agricultural input to the stream system in the area.

Algal/aquatic plant growth can be stimulated by minor increases in concentrations of nutrients. Potential nutrient input is assessed at the reconnaissance level by observation of agricultural or domestic wastes within the stream. Grab samples for nutrients can be collected to provide additional information. Total phosphorous and total nitrate + nitrite will generally provide sufficient information for initial purposes. Nutrient concentrations are determined by laboratory analysis of a water sample. Because nutrients are rapidly cycled within a system, grab samples collected during lowflows may be of limited value.

Stream Channel and Stream Bank Condition

Alteration of stream banks and stream channels are the most widespread impacts associated with wildland development. These changes can be caused by direct development within the riparian zone or alteration of surficial conditions in remote sections of the catchment. Development of uplands may alter the supply of sediment and the flow regime causing readjustment in channel shape and scouring and deposition of sediment.

Overuse of the riparian zone may contribute to bank instability and reduce bank cover, causing an increase in bank erosion. Stream channel shape adjusts to these impacts by widening and becoming more shallow or the channel downcuts, lowering the water table and reducing the extent of the riparian zone. Sediment from upland and channel erosion also changes stream bottom composition and increases the percentage of fines. Available habitat space decreases as the stream is altered from a narrow and deep channel to a wide and shallow channel.

The critical attributes to consider include channel morphology, streambank stability, vegetative overhang, streambank undercutting, substrate sedimentation, and pool quality. Streambank undercuts and overhanging vegetation provide protective cover, shade for temperature control, and a supply of terrestrial insects as food for fish. Determining the percent of the streambank that is stable, covered by vegetation, undercut, or has overhanging vegetation is done by ocular estimates, pacing, or measurements at representative locations.

Substrate composition provides information on in-stream hiding cover, quality of spawning substrate, and production of insects. Ocular estimates are made of substrate composition and embeddedness. Pebble counts, which are relatively quick and easy, may be used to improve estimates of substrate composition.

Stream channel morphology is usually measured by establishing permanent cross sections. Channel characteristics evaluated at each cross section include bankfull width and depth, low flow width and depth, width/depth ratio, and cross sectional area. Estimates are also made of the occurrence of pools and rating of pool quality.

Streambank Vegetation

Streambank vegetation provides cover for fish, shades the stream to maintain temperature, and provides habitat for terrestrial insects utilized by fish. Streamside vegetation is the primary tool available to the manager to stabilize stream banks and restore natural channel features. The roots of riparian plants hold the soil together to resist erosion. The vegetative mat along the stream traps sediment during high water to build banks and increase plant production and vigor.

Biological Assessment

A biological evaluation is a direct measure of macroinvertebrate and fish communities. These communities reflect the quality of the stream environment over time by integrating the effects of the water quality and habitat factors. Benthic macroinvertebrate communities are good indicators of localized conditions and respond fairly rapidly to changes in the environment. Fish are indicators of long-term effects and broad habitat conditions because they are long-lived and mobile.

Rapid Bioassessment Protocols (RBP) can supplement the aquatic habitat parameters by providing an estimate of the health of the aquatic community (Plafkin et al., 1989). Protocol I is a screening assessment which uses field identification of benthic macroinvertebrates to the order/family level. Impairment is indicated by the absence of pollution sensitive taxa; the dominance of pollution tolerant groups; or overall low abundance and taxa richness. Protocol II is a more intensive assessment using kick net samples. Subsamples are sorted and counted, allowing for the use of additional metrics and the Index of Biotic Integrity.

The field reconnaissance will provide some answers as well as raise additional questions about the initial assumptions of the cause and effect of pollution. Additional inventories or a pilot water quality study may be needed to answer these questions before completing a study design. The first year of monitoring can be considered a pilot study, with revision of the study design based on the initial data set.

4. Establish Specific Goals and Objectives

The identification of potential water quality limiting factors provides the basis for development of monitoring objectives. It is important to evaluate which of these factors result primarily from each land-use type and will respond to project implementation before development of project goals and objectives.

5. Select Parameters and Monitoring Design

Monitoring Parameters

Non-point source activities and natural processes affect the riparian ecosystem in a complex manner. Different procedures to measure these effects have been developed and continue to evolve as professionals apply the methods under various field conditions.

Considerations when selecting parameters

In general, parameters included in water quality monitoring programs are of two classes;

water column parameters and habitat parameters. Water quality parameters are those that include chemical and physical characteristics of the water itself. Habitat parameters are those that include channel and riparian characteristics used in the evaluation of the physical attributes of a system as related to habitat suitability.

Many traditional water column parameters may be influenced by land-use management decisions, but these parameters tend to be flow dependent and may be difficult to sample under conditions encountered in the field. Automatic samplers are an alternative, but are rarely used by management agencies due to cost, vandalism and maintenance requirements.

During planning, the recommended sample frequency, estimated collection time, laboratory process cost, specialized equipment needs, and expertise required for each parameter is evaluated. Generally, methods which depend on observed ratings require experienced professionals to make necessary judgement calls. When considering a method, the ease of data collection should be balanced against the ability to detect change, given the method's precision and accuracy. Riparian systems exhibit high natural variability, which affects an ability to detect treatment differences.

The preferred parameters are those that are measured at low frequency during the base flow period. These parameters reflect the condition of the stream and riparian area as a result of the yearly cycle of runoff, stream channel response, vegetative growth, and non-point source impacts.

Monitoring Design

Monitoring design refers to the overall strategy for locating stations and development of an approach to data analysis and interpretation. Common water quality monitoring designs include: Reference Area, Paired Catchment, Above and Below, and Before and After.

The following discussion of each type of monitoring design describes factors to be considered in the selection process. A monitoring design may depend on a particular design or may incorporate a combination of these approaches.

For the evaluation of non-point impacts, the *Reference Area Design* is the preferred approach. The US Environmental Protection Agency's (USEPA) Non-point Source Manager's Guide recommends comparative monitoring of project stations to reference sites as the most effective design for detecting treatment effects (Coffey and Smolen, 1991).

Reference areas are stream reaches that contain habitat of sufficient quality to maintain biological integrity. Biological integrity is defined as:

The condition of the aquatic community inhabiting the unimpaired waterbodies of a specified habitat as measured by community structure and function (USEPA, 1990).

The reference area design can be used when suitable reference sites for the project area can be located. Reference areas provide a control for the determination of background effects related to weather and hydrologic events. Storms, drought, and temperature are examples of variables that can affect water quality. The reference area can also be used to develop objectives for the project catchment by providing data to describe the potential desired condition.

Identification of reference sites is not a simple task in areas that have past land use impacts. The reference site may have experienced some level of impact, but still represents a habitat that supports an aquatic community in good or excellent condition. In practice, reference sites are chosen that reflect the least impacted conditions possible.

Reference areas may be incorporated into the study as site specific reference sites or as reference sites that describe the regional reference condition. *Site-specific reference sites* are identified within the same drainage or nearby drainage and will be sampled at the same time as the study site. Although no perfect match exists, monitoring reference sites will help identify land use effects.

The *Paired Catchment Design* involves monitoring two comparable catchments over time; one catchment receives treatment and the other does not. In the evaluation of catchment scale projects, Spooner et al. (1985) suggested that paired catchment designs have the greatest potential for documenting improvements from Best Management Practice (BMP) implementation because meteorologic and hydrologic variability can be accounted for.

USEPA recommended the paired catchment strategy for projects participating in the National NPS (Non-Point Source) Monitoring Program (USEPA, 1991). These studies measured primarily water column parameters, such as nutrients and suspended sediment, which are flow dependent and require frequent samples to account for high variability. The paired catchment design may be appropriate where the primary objectives focus on water column parameters. However, monitoring high flows is usually infeasible unless automatic samplers are used.

Above and Below design involves sampling a stream upstream and downstream from a non-point source activity. This design is useful where there is a distinct boundary between the upstream and downstream segment or above and below the entry of a tributary. This design is more effective with water column parameters rather than habitat parameters. Sampling should encompass the runoff period when pollutants tend to enter the stream. This design is usually not effective for areas in which land use activities are not defined by distinct segment boundaries or land use activities are changing and where pollutant entry during runoff may mask any upstream-downstream differences.

Before and After Design is characterized by monitoring of sites prior to project implementation and for some period of time following implementation. the design can be applied to both water column and habitat parameters. Climatic and hydrologic variables are not accounted for by this approach, so long periods of monitoring before and after project implementation are required to detect changes (Spooner, 1985).

6. Select Monitoring Sites

Stream reaches for inclusion in the water quality monitoring program are identified on the basis of stream type and riparian community type. The number of unique stream reaches that will be monitored is determined and representative monitoring sites are established within those reaches. Monitoring sites selected should be representative of the composition of macro-habitats (riffle/run/pool) that occur within the stream reach. The stream reach classification provides a basis for identification of comparable reference reaches or regional reference conditions.

Monitoring sites are designated differently for water column and stream channel parameters. The monitoring site is a single point where a grab sample is collected or a cross section from which a depth/width integrated sample is collected for water column parameters. For stream channel and stream bank (i.e. habitat) parameters, a monitoring site consists of a representative stream reach divided into multiple transects. The transects provide a means of collecting replicates for stream channel and stream bank parameters.

Selection of monitoring sites is a function of objectives, monitoring design, access and budget. Stream classification provides a systematic method to identify stream reaches which are expected to respond to management in a similar manner.

The recommended sampling strategy uses a modification of the stratified-systematic approach to divide the stream into non-overlapping strata, each strata being the stream reach or subreach (Gilbert, 1987). Systematic sampling results in measurements according to a spatial pattern of equidistant intervals along the stream channel. Since individual strata, the stream reaches are often too large in practice, the suggested approach is to select a representative monitoring site within the reach based on hydraulic characteristics.

The stream is divided into designated stream reaches on the basis of natural features (morphology, soils, community type) and into sub-reaches on the basis of land-use. Within a designated reach, there is a characteristic pattern of hydraulic units: fast water (riffles and runs) and slow water (pools and glides). Sampling within the reach occurs in proportion to these units since changing velocity and depth affects many stream channel parameters. To select a representative reach, the occurrence of fast and slow waters is calculated. A representative reach is selected that has similar riffle to pool pattern as that calculated for the stream reach.

The length of the stream reach and the number of transects recommended for sampling depends on site variability and the desired precision. The recommended reach length is in multiples of the bankfull width, from 20 to 40 times the bankfull width. The state of Idaho (U.S.) protocols for monitoring riparian vegetation (Cowley, 1992) recommend a minimum of 20 times the bankfull width or a minimum of 100 meters, using ten channel cross sections. Ten cross sections may be adequate to detect change in channel parameters.

Once sampling is initiated, the investigator may need to evaluate whether the data are sufficient to determine statistical significance. The five interacting factors assessed are sample size, variability, level of significance, power and minimum detectable effect (MacDonald et al., 1991).

If more data are required to detect change, additional transects may be added upstream at the same spacing or at intervals between transects. For some parameters, the number of samples for statistical tests may be increased by increasing the intensity of sampling on existing transects.

Identify Reference Areas

Site specific reference areas are selected to be comparable to the project monitoring sites and to represent minimally disturbed conditions. Regional reference sites are selected using two primary criteria. These criteria are also useful in considering site-specific reference areas (Hayslip, ed. 1992).

Least or minimal impact: Sites that are not disturbed by human activities are ideal as reference sites. Human activity has altered much of the landscape, so truly undisturbed sites are generally unavailable. Therefore, a criteria of least or minimal impact should guide selections from a suite of candidate reference sites.

Representativeness: Reference sites must be representative of the waterbodies under consideration.

Variables used to classify the monitoring site can be used to measure the representativeness of the reference site. Reference sites should be comparable by general classification criteria, including soils/geology, stream morphology, and riparian vegetation. Specific criteria include:

- Valley bottom type
- Stream size class
- Gradient
- Sinuosity
- Channel width/depth ratio
- Channel particle size class

- Channel entrenchment
- Riparian community type
- Dominant soil family

Reference sites should represent minimally disturbed conditions for the parameters that will be evaluated in the program. Candidates for reference sites are selected by consulting land ownership records, land-use maps, and local experts about the degree of disturbance in the catchment. Riparian areas where human activity has been excluded to allow recovery should be sought. Candidate sites are examined through field reconnaissance to determine their value as reference sites. Assumptions regarding minimal disturbance and physical and biological integrity of the riparian area are evaluated. Some guidance criteria (Hayslip, 1992) are:

- Perennial flow
- Similar stream size class as study site
- Relatively unimpacted: minimal human disturbance to the catchment and stream system
- Substrate materials representative of undisturbed stream type
- Natural channel morphology: varied in channel width and depth, presence of pools, riffles and runs typical of streams in the area
- Natural hydrograph; flow patterns typical of the region
- Stable banks: banks covered with vegetation, little evidence of bank erosion and undercut banks stabilized by root typical of the stream type
- Natural color and odor
- Relatively abundant and diverse algae, benthic macroinvertebrates, and fish assemblages
- Land use stability: consistent land use management over time
- Interdisciplinary team selection of reference site

2.4.2 Development of Study Plan

A detailed study plan is an excellent communication device because it provides information to coworkers regarding their role in the overall project; communicates to managers and interest groups how monitoring will measure the desired outcomes; and displays the resource needs and commitments of the project. The study plan can also illustrate tradeoffs between costs and information gained.

Study Plan: Introduction

The introduction should be clearly describe the project, monitoring start-up, and ending dates, monitoring approach, and methods to provide feedback for mid-course corrections when required. Background information on natural resources in the catchment and an evaluation of previous studies and preliminary investigations are described. The roles of participating agencies, project participants and interest groups are discussed.

Study Plan: Goals and Objectives

Goals and objectives based on the limiting factors for beneficial uses are listed. The reason for suspecting these limiting factors and the rationale of the monitoring design are discussed.

Study Plan: Study Approach

Sampling design details include monitoring parameters, monitoring periods, monitoring sites, and the rationale for these decisions.

Study Plan: Data Collection

Data collection methods are described in detail, including the assumptions and limitations of the methods. Resources needed to carry out the program are listed by personnel, equipment, laboratory support, and estimated budget. Quality assurance (QA) and quality control (QC) procedures should be incorporated into each step of the monitoring program. Quality assurance objectives are described by five attributes (USEPA, 1992):

precision -	Precision is defined as the degree of agreement between the numerical values of two or more measurements on the same homogenous sample made under the same conditions. The term is used to describe the reproducibility of a measurement or method. Precision can estimated be examination of variability between replicate samples.
accuracy -	Accuracy is defined as the degree of closeness of a particular measurement t it's true value. Estimates of accuracy for field measurements are difficult to make since the population true value is rarely known.
data completeness -	Data completeness is defined as the percentage of measurements made that are judged to be valid.
data representativeness -	Data representativeness is the degree to which data accurately represents a characteristic of a population or environmental condition.
data comparability -	Comparability is a measure of the confidence with which one data set can be compared to another.

Study Plan: Data Reduction and Analysis

For each parameter category, the methods for data reduction, analysis and interpretation are described. Data reduction refers to the office procedures required to transcribe data from field sheets to computer or paper files. Analysis and interpretation may refer to water quality criteria, desired future condition analysis, or use of similarity indices. The report format, expected delivery dates, reviewers, and audience for the report are described. Preparation of a monitoring study plan assures the investigator will do a thorough job and anticipate problems and scheduling conflicts.

Study Plan: Outline

I. Introduction and Background
   A. Project overview and purpose
   B. Review existing information
   C. Project organization, responsibility, and participating agencies

II. Goals and Objectives
   A. Issue identification: identify limiting factors
   B. Project goals (repeat for each goal)
      1. Monitoring objective
      2. Summary of monitoring technique

III. Study Approach
   A. Overall monitoring strategy; identify design and type of monitoring
   B. Sampling design
      1. Design rationale
      2. Station location description
      3. Station location maps
      4. Parameters, frequency, duration
      5. Monitoring schedule

IV. Data Collection Methods
   A. Monitoring procedures
      1. Sampling procedures (including QC checks)
      2. Calibration procedures and preventative maintenance
      3. Analytical methods (including QC checks)
      4. Provide reference to methods manuals or fully describe any modifications
   B. Discuss assumptions and limitations
   C. Describe quality assurance objectives
      1. Precision and accuracy
      2. Data representativeness
      3. Data comparability
      4. Data completeness
   D. Data forms
   E. Resource needs - personnel time, laboratory costs, equipment, etc.

V. Data Reduction and Analysis
   A. Describe data documentation and reduction
   B. Data analysis and basis of interpretation, e.g. use of water quality criteria, desired condition, analysis, or similarity indices
   C. Report format and schedule

VI. Discussion

VII. Conclusion

Study Plan: Review and Revision

The study plan should be reevaluated periodically. Data should be reviewed at the end of each sampling season to evaluate the adequacy of the study plan. This evaluation provides an opportunity to determine which parameters are effective and sensitive to detecting change. Parameters that exhibit high variability may require deletion since their ability to detect change is limited. The study plan should specify plan review and revision to assure that this vital step is accomplished.

Study Plan: Reassess Assumptions and Objectives and Modify Plan

Assumptions made during the planning about monitoring sites, parameter utility, natural variability, grazing impacts, or other factors are evaluated using the first season of monitoring data. Precision can be evaluated and replication increased where required or other methods adopted. Adjustments are made in the monitoring program to assure that it remains on target; parameters that have proven effective are retained and parameters that are ineffective are dropped or modified to increase their utility.

Chapter 3

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3.0 Hydrological Context and Water Quality Characteristics

Surface water quality depends on four principal factors at any given time (Chapman, 1993):

- the proportion of surface runoff and sub-surface runoff,
- the reactions within the river system governed by internal processes,
- the mixing of water from tributaries with different quality characteristics (for example with different land-use or geology),
- inputs of pollutants from point and non-point sources

In addition to the differences observed in the physical characteristics of Belize catchments, the varying factor of rainfall inputs across the country over time can be expected to lead to variations in contaminant loading (the mass of individual contaminants transported into the moving water bodies) and their flux (the concentrations in mg/l per unit of discharge m^3/s) determined by the state in which they encounter that water body at any time.

According to Belize's Chief Meteorologist (Carlos Fuller, personal communication), climate differences produce distinct variations between catchments over a typical hydrological year. During the rainy season months (April to October), frontal systems dominate Belize's weather and so rainfall is more uniform, with strong orographic controls such that rivers tend to fall and rise with similar frequencies, the magnitude and rate of their rise determined by their proportion of mountainous land and individual rate of runoff response. In the dryer months (November to March), occasional rainfall is dominated by cellular developments giving rise to locally intense and isolated hydrologic responses that can cause extreme and flashy flow events in one catchment, but not in another adjacent to it or in another part of the country. For example the 10-15 m rise in flood levels recorded in one day on the Macal River is an example of this phenomenon. The southern and central coastal plains are subject to regular floods that have recently taken catastrophic dimensions, causing economic damage and loss of agricultural production (GOB, 1992c). Given the potential for extreme fluctuations in river discharge, accurate calculation of total contaminant loadings over a hydrological year requires frequent water quality sampling.

3.0.1 Expected Contaminants

Belize has the interesting distinction of geologically, being broadly and clearly divided into zones of igneous, largely acidic rocks made up of siliceous igneous and metamorphosed granites and ashes and sedimentary, carbonate rocks in the form of Jurassic, Tertiary and Quaternary limestones. Some catchments drain large areas of both rock types, usually in the format of acidic rock headwaters and basic rock mid- and estuarine sections, while others drain largely one type or the other for most of their course.

In terms of expected water quality characteristics, anthropogenic derived pollutants aside, one can expect that in the tropical climate of Belize with the abundance of water in the highland zones, that the igneous and metamorphic parts of the catchment will weather rapidly to release the major cations (Ca, Mg, Na and K) as well as dissolved silica and bicarbonates (Chapman, 1993). Weathered soils weather to leached clays with residual oxide concentrations (King et al, 1993). Aquifers, rivers and lakes in catchments that consist of acid rocks will generally have waters low in calcium and magnesium with a low buffering capacity. The largely carbonate sedimentary rocks result in higher concentrations of bicarbonate. Chlorides are not expected to occur except along the coastal margins of Belize where they can be transported onto land by wind-drift.

Table 3.1 Natural Factors Affecting Water Quality in Belize

Parameter	Characteristic	Causes
Hardness	High background carbonates or salts of Ca and Mg	Geology - soluble calcium and magnesium rocks e.g. limestone
Phosphates	High background phosphates	Geology - phosphorous bearing rocks
Sodium	High background sodium	Geology - sodium rich rocks and soils
Bacteria	High total coliform levels	Animal faeces and soil erosion
Solids	High suspended sediment loads	High natural erosion, e.g. active channel down-cutting and migration
Organic material	High BOD and total organic carbon loads	Riparian flooding and algal blooms
Dissolved Oxygen	Low dissolved oxygen levels	High BOD inputs, slow-moving deep water

Table 3.2 Anthropogenic Factors Affecting Water Quality in Belize

Parameter	Characteristic	Predominant Causes
Hardness	Increased levels of hardness	Industrial effluent
Nitrates	Increased levels of nitrates Na	Agricultural runoff and domestic wastewater
Phosphates	Increased levels of phosphates	Domestic wastewater, especially containing detergents, industrial effluent and agricultural runoff
Sodium	Increased levels of sodium	Domestic wastewater and industrial effluent
Potassium	Increased levels of potassium	Agricultural runoff
Chloride	Increased levels of chloride	Domestic wastewater, marine water inflow
Bacteria	High total and faecal coliform counts	Domestic wastewater and livestock.
Organic Material	High BOD, COD or low DO	Domestic wastewater, industrial effluent and agricultural runoff
Ammonia and Nitrogen	High organic nitrogen levels	Domestic wastewater and agricultural runoff
Oil and grease	Detectable or noxious levels	Industrial effluent and urban runoff, accidental discharges
Heavy metals	Detectable levels of trace elements	Industrial discharge, urban runoff
Solids	Increased sediment loads and turbidity	Accelerated erosion from slash and burn agriculture, road construction, forestry and mining
Chlorine	Detectable levels of chlorine and its by-products	Industrial effluent, water treatment plant effluent
Pesticides and Fertilizers	Detectable levels of pesticide residuals and elevated nutrient levels	Agricultural drainage and soil leaching

According to the report prepared by FAO consultants (FAO, 1994), the most potential sources of pollution in Belize are leachates from solid waste tips, improper discharge of industrial effluent, agricultural use of agro-chemicals, domestic sewage and soil erosion following deforestation.

3.0.2 Levels of Risk in Belize

Given the size of the population of Belize, its level of urbanization, and its degree of industrialization, it is unlikely, at an overall national environmental level, that the types of manufactured chemicals and other toxic substances mentioned above will be found in significant proportions. This can probably be said also for the water flowing into Belize from its neighbors Mexico and Guatemala since neither of the zones adjacent to the border occupied by the shared catchments appear to be developed to any significant degree. However, due to the growing use and concentration of agro-chemicals in certain zones (particularly between the North Stann Creek and Monkey River), the value of the unique offshore marine environment to Belize, and the fear that even small concentrations of chemicals may exert damaging effects on the offshore ecosystems, this assumption should clearly be tested to establish current baseline conditions and be monitored, depending on the observed results, to determine future patterns.

In water quality monitoring programs, continuous samples are seldom taken at any location of variable concentrations and flow volume. Instead, discrete, usually equal interval samples of variable concentrations are taken, coupled with automatic and continuous discharge measurements based on a recording of stage variations and the establishment of an empirical relationship between stage and discharge. The mass loadings of variables can then reasonably be estimated by extrapolating flux measurements (instantaneous mass per unit time) using the measured river discharge. Comparable measurements taken at different locations along the river, allow a basic sense for the change in loading along the river system. Clearly, this methodology will most likely underestimate loadings since rarely are there adequate amounts of quality data to develop sensitive flux values. This is clearly true for the higher flow levels, which tend to be missed on a regular sampling sequence, which will dominate the total mass balance calculation, especially in the many flashy tropical rivers of Belize. Past water quality measurements taken in Belize during the 1980s have not allowed estimations to be made of loadings because of the lack of paired discharge data.

Without more detailed data on the water quality and flow characteristics of the 16 major Belize rivers and their tributaries, it is difficult to make realistic assessments of loadings, fate and persistence of contaminants and particularly difficult to estimate what might actually be flowing off land and accumulating in the nearshore marine environment. However, it is possible to use anecdotal information, knowledge of the river systems and land-use and expressed concerns within Belize with respect to water quality to develop a starting list of parameters that can be measured as part of the Belize monitoring program.

3.0.3 Quantified Point Pollution Risks

Two specific risks already exist in Belize for concentrated point pollution. Organic material inputs from the two main agro-industrial dischargers of sugar refineries and citrus pulping plants is of special concern in Belize and the fate and persistence of their polluting effects are important factors to consider as part of any effluent monitoring and control program implemented by DOE parallel to its overall environmental monitoring. A little is known already for the two major sugar plants, due to the work of UNIDO consultant Newell (1993) on the recuperative effects of the New River downstream of Tower Hill and Libertad from a short period of study of pollution effects from the industry. The release of waste rich in organic material into rivers has a marked effect by reducing the oxygen concentration, in extreme cases, to the point in which anoxia or anaerobic conditions occur in which organisms dependent on dissolved oxygen will die. As well as reducing oxygen concentrations, conversion of oxidized nitrogen to ammonia and nitrites can result. The effects, depending on the loading of waste relative to the river conditions at the receiving point and downstream, are usually short-lived. Measurements of the water body downstream of the inflow exhibits what is termed the oxygen-sag curve (Chapman, 1993) in which the organic material reduces the dissolved oxygen level to a minimum level which then recovers at a rate governed by river turbulence and mixing, temperature and photosynthetic activity by phytoplankton, algae and aquatic vegetation. In the case of the New River, which is a relatively deep, sluggish, laminar, poorly mixed river body downstream of both polluting plants (even more so below Libertad), slow but steady recovery was seen at Tower Hill but only partial recovery at the downstream Libertad where largely anoxic conditions continued on to the Corozal Bay outflow after documented discharge incidents (Newell, 1993). This is discussed in more detail in the New River catchment profile.

In the case of the orange processing plants on North Stann Creek, less data exists. A characteristic of this waste is that it is of a low pH as well as high in BOD resulting from the mass of left-over pulp and degrading peels that the juicing and concentrating process produces. Since both hardness and alkalinity appears to be relatively low for the North Stann Creek (Newell measured 12 mg/l $CaCO_3$ in 1993), the buffering capacity of the river will also be low, aggravating the impact of the low pH discharge on aquatic life.

In both cases, pollution persistence will figure as a major factor in fixed station environmental monitoring (as a cause of periodic variations in observed water quality passing the station) and in the selection of appropriate downstream sites for discharge compliance monitoring.

3.1 Water Quality Indicators to Meet Applied Information Needs

The following list of constituents of concern have been determined for use by the environmental water quality monitoring program through review of existing land use and industrial discharges in Belize as well as review of current literature. They represent those indicators most likely to characterize and indicate overall water quality conditions and patterns of degradation throughout the major catchments and water bodies of the country. Moreover they represent factors critical to consider in environmental and resource management decisions such as the exploitation of a given water body for drinking or agricultural use, or the protection of receiving bodies, especially the coastal zone, from the secondary degradation that might result from the constituents of concern listed. The general list of constituents of concern meet multiple agency criteria, being important from the point of view of overall environmental quality (environment and tourism), ecosystem healthiness (fisheries and coastal zone) and water purity (WASA and public health, agriculture and mining).

The general list will be used to determine station-specific monitoring constituents based on loading, assimilative capacity of the receiving waters, analysis cost and laboratory availability. As explained elsewhere, these important factors cannot be determined without institutional discussion and decisions that can be guided by information presented in this report. Depending on the results of early sampling, each station may not require sampling of the same constituents at the same frequency. The general list of constituents of concern include:

Discharge
Temperature
pH
Conductivity
Dissolved Oxygen
Alkalinity
Turbidity
Total Suspended Solids
Total Dissolved Solids
Pesticides
Herbicides
Biochemical Oxygen Demand
Chemical Oxygen Demand
Nitrate Nitrogen
Total Kjeldahl Nitrogen
Soluble Reactive Phosphorous (orthophosphorous)
Chlorides
Total Organic Carbon
Total Petroleum Hydrocarbons
Sulfate
Metals
Coliform Bacteria

3.1.1 Description of Parameters

Each of the above constituents of concern have their specific characteristics and methods of measurement and analysis. These are summarized below. A detailed discussion of the protocols required is presented in the accompanying document to this report (Stednick and Gilbert, 1995). These protocols adopt well-established, standard sampling procedures and provide solid scientific guidelines to monitoring field and laboratory personnel.

Discharge

Stream discharge is defined as the quantity of water passing a specific point over a specified period of time. Measurement of discharge is critical in any water quality monitoring program in order to determine total contaminant loading and to more accurately predict changes in water quality associated with point or non-point contaminant discharges. Discharge is typically measured by determination of velocity and cross-sectional area. Velocity is measured using a current meter (horizontal or vertical axis) and cross sectional area measured using tape or tagline methods. Stream discharge is generally reported as cubic meters per second (m^3/s). Many of the existing hydrological monitoring stations in Belize have stage-discharge relationships established using historical data. In cases where reliable rating curves have been developed, measurement of stage is adequate for the reporting of discharge.

Streamflow recording and measurements are normally problem oriented and analysis is concerned with quantities rather than with the particular qualities of the records. Record quality is of primary interest and analysis is undertaken with a view to a better understanding of the interaction of water in the catchment. Lowflows and days with no flow present problems not entirely overcome by present day instrumentation and procedures.

The gauging station location should be situated where measurements taken will best serve the purpose for which they are required, be accessible, measurements are sufficiently accurate for the study purpose, and be economical to attain. Advantage should be taken of favorable geological formations which ensures that the catchment outflow (at the selected section) is as surface channelized flow.

Temperature

Temperature is defined as the thermal character of a water on an absolute scale. The temperature of a water will determine the solubility of constituents, maximum dissolved oxygen content and related redox potential. Biologically, temperature is important in terms of organism tolerance. Temperature is measured using a standardized thermometer that is calibrated against a reference thermometer (e.g. ASTM). Temperature should be reported to the nearest 0.5°C. Since many constituents require preservation at a temperature of 4°C, temperature measurements should be made in the field.

pH

pH is defined as the negative logarithm (base 10) of the hydrogen ion (H^+) activity of a water. In most natural systems the hydrogen ion activity $\{H^+\}$ is approximately equal to the molar concentration of the hydrogen ion $[H^+]$. pH is important for the determination of constituent speciation and solubility. Introduction of contaminants to a system can be expected to alter the pH of the system through the interaction (e.g. consumption of H^+) of the specific contaminant and the receiving water. Each system can therefore be expected to possess differing capacity to buffer pH changes based on regional geochemistry and existing contaminant sources. Methods for the measurement of pH include colorimetric and electrometric. pH is reported in pH units (e.g. an increase of one pH unit equals a tenfold decrease in H^+ concentration) to the nearest 0.1 unit. pH measurements are subject to high fluctuation with changes in (among other things) temperature and redox potential. pH measurements should therefore be taken at the sampling location.

Specific Conductance (Conductivity)

Specific Conductance is defined as the ability of water to conduct an electrical current across a unit length and unit cross section at a specified temperature. In general, specific conductance or conductivity is a measure of the dissolved constituents within a water and can be used to make generalizations regarding the dissolved load of a specific water. Conductivity is measured electrometrically and reported in microSiemens per centimeter at a given temperature. Conductivity should be measured in the field.

Dissolved Oxygen

Dissolved oxygen is defined as the molar concentration of O_2 within a water. Adequate dissolved oxygen is required for most aquatic organisms and is frequently depleted through addition of contaminants high in organic constituents. The dissolved oxygen concentration of a water can also be used to make inferences regarding speciation and solubility of particular contaminants. Dissolved oxygen is measured using either titrometric or electrometric methods. Reporting of dissolved oxygen should be reported to the nearest 1 mg/l O_2. Since dissolved oxygen concentration is a function of temperature, pressure, presence of dissolved solids and biologic activity, all dissolved oxygen measurements should be made in the field.

Alkalinity

Total alkalinity is qualitatively defined as the ability of a water to neutralize an acid to a specified pH endpoint (typically pH 4.5). *Phenolphthalein alkalinity* is determined using an endpoint of pH 8.3. Alkalinity is useful in the assessment of the assimilative capacity of a receiving water with respect to acidic constituents. Since the alkalinity of natural waters is typically a function of carbonate species, reporting of alkalinity is usually in terms of mg/l $CaCO_3$. Determination of alkalinity, as the definition implies, consists of titration using either methyl orange indicator (for total alkalinity) or phenolphthalein (for P alkalinity).

Turbidity

Turbidity is defined as the optical property of a suspension that causes light to be scattered rather than transmitted through the suspension. Turbidity can be considered a general parameter that includes the effect of color and total suspended solids on light penetration. Turbidity is included in the environmental water quality monitoring program due to the negative effect of decreased light penetration on aquatic organisms. Turbidity is generally measured using photometric methods. Turbidity is reported in NTU (nephelometric turbidity units).

Total Suspended Solids

Total suspended solids (TSS) are defined as the total suspended (undissolved) load carried by a particular water. Operationally, TSS is defined as the constituents present in a water with a diameter greater than 0.45 μm (i.e. the portion of solids retained by a filter of average pore size 0.45 μm). Excessive TSS quantities may result in decreased photosynthetic productivity due to decreased light penetration and/or excessive sediment deposition resulting in degradation of the benthic environment. TSS is measured gravimetrically and is generally reported in mg/l.

Total Dissolved Solids

In general, total dissolved solids (TDS) are defined as the quantity of material in solution within a particular water. TDS is operationally defined as the quantity of material not retained by a 0.45 μm average pore diameter filter. Excessive TDS loading may result in stress or mortality of aquatic organisms. The method for determination of TDS is filtration followed by gravimetric analysis. TDS is typically reported in mg/l.

Pesticides/Herbicides

Pesticides are chemicals used to control undesirable plants (weeds, fungus) and animals (insects, worms, bacteria, etc.). The term pesticides also includes herbicides, insecticides, fungicides and nematocides. Pesticides are of significant water quality concern due to persistence in the environment and bioaccumulation in higher organisms. Pesticides typically enter the aquatic environment through agricultural application or runoff from agricultural areas. Pesticides are determined in the laboratory using gas chromatograph - mass spectrograph (GC-MS) methods, liquid chromatography or densitometry. Specific compounds or brand names (e.g. Atrazine, Sevin) are typically reported in μg/l or parts per billion (ppb).

Biochemical Oxygen Demand

Biochemical Oxygen Demand (BOD) is defined as the quantity of oxygen consumed by microbial organisms in the process of metabolization of organic matter to inorganic form. The measurement of BOD is generally indicative of the amount of oxygen depletion within a water associated with organic contamination. If the rate of oxygen depletion exceeds the rate at which dissolved oxygen can be replenished by the atmosphere (or photosynthetic processes), stress or mortality of aquatic organisms may result. BOD is measured using titrometric or manometric methods generally using a 5 day incubation period at 20°C. BOD is reported as mg O_2 required per liter of sample.

Chemical Oxygen Demand

Chemical Oxygen Demand (COD) is defined as the material load within a water that is oxidizable using a strong oxidizing agent. COD is used in the assessment of overall oxidation potential of a water including organic and inorganic constituents. Comparisons of COD values over time can be used to document water quality degradation by anthropogenic sources over long periods. COD is measured by dichromate reflux digestion or spectrophotometric methods and reported as O_2 equivalent.

Nitrate Nitrogen (NO_3)

Nitrogen in natural systems typically exists in the oxidized form NO_3. Nitrogen sources to the environment are, in general, atmospheric (through nitrification and subsequent oxidation) and biologic (including anthropogenic). Agrochemical applications and septic system effluent are particularly significant sources in developed areas. Undeveloped areas typically have very low aqueous nitrate concentrations. Nitrate contamination may lead to eutrophication of aquatic systems and/or reduced dissolved oxygen conditions within a water. Nitrate is generally measured in the laboratory using cadmium reduction or ion chromatographic methods. Nitrate is reported as mg/l NO_3 or mg/l NO_3 - N.

Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen (TKN) is defined as the sum of the nitrogen contained in the free ammonia and other nitrogen compounds which are converted to ammonium sulfate [$(NH_4)_2SO_4$] under specific digestion conditions. TKN is measured using manual digestion or semiautomated colorimetric Berthold methods. TKN is used to determine the quantity of organic and ammoniacal nitrogen within a water. Excessive concentrations of these forms of nitrogen may contribute to eutrophication and depleted dissolved oxygen concentrations within a water. TKN is typically reported in mg/l N.

Soluble Reactive Phosphorous (orthophosphate)

Phosphorous can exist in solution in oxidation states ranging from P^{3-} to P^{5+}, the most common form in natural systems is the fully oxidized PO_4^{3-} phosphate ion. The most stable of the phosphate ion species is the orthophosphate ion. Phosphorous is typically a limiting nutrient in natural aquatic systems. Presence of phosphorous within a water is therefore usually associated with anthropogenic contamination. Sources of phosphorous to the aquatic environment include: industrial and domestic wastewaters, agricultural runoff and landfill leachate. Phosphorous contamination of the aquatic environment may result in eutrophication and depleted dissolved oxygen concentrations. orthophosphate is measured using colorimetric or ion chromatographic methods and is typically expressed in mg/l PO_4.

Chlorides

Chlorides are a general category including the chloride specie of several cations (typically Na, K, Ca). Chloride concentration is generally used to indicate the presence of anthropogenic contaminants such as septic systems, irrigation return flow and landfill leachates typically contain high chloride concentrations. Chlorides are measured electrometrically in the laboratory using an ion specific electrode or ion chromatograph and reported in mg/l.

Total Organic Carbon

Total organic carbon (TOC) is defined as the particulate and dissolved carbon from organic sources within a water. Excessive levels of TOC may be indicative of industrial and domestic contamination. TOC is measured using flame ionization and oxidation or infrared detection methods. TOC is typically reported as mg/l C.

Total Petroleum Hydrocarbons

Total petroleum hydrocarbons (TPH) include a large number of organic carbon compounds and are generally indicative of contamination associated with leaking underground storage tanks, bilge water discharge and urban runoff. TPH is of concern to aquatic biota and for aesthetic reasons. TPH is measured using fluorocarbon extraction - infrared detection methods and is reported as mg/l TPH.

Sulfate (SO_4)

Sulfur can exist in several oxidation states ranging from S^{2-} to S^{6+}. In natural systems, sulfur typically exists in the fully oxidized form SO_4 but is highly dependent on the redox properties of the system. Although sulfur exists geologically (e.g. sulfide ores, igneous and sedimentary sources), the presence of sulfur species (SO_4 in particular) in a water may be indicative of industrial effluent, irrigation return flow and acidic precipitation. Sulfate is measured in the laboratory using colorimetric or ion chromatographic methods. Sulfate is typically reported as mg/l SO_4 or mg/l SO_4 - S.

Metals

Water Quality analyses for metals is typically associated with land use and industrial activities that may affect the mobility (solubility) of metals that are associated with the land use or industrial activity (e.g. mining or battery manufacture). Metal analyses are for metals in the total or dissolved state. The operational definition of dissolved is the metals which can pass through a 0.45 µm filter. The dissolved fraction is bioavailable and thus of greatest concern.

A spectrophotometer manufactured by Hach Chemical Company (USA) has several colorimetric procedures for the measurement of metal concentrations. Other analytical techniques include atomic adsorption spectrophotometry and inductively coupled argon plasma emission spectrophotometry. The latter methods are expensive to maintain and operate and should be of lower priority.

Coliform Bacteria

The coliform bacteria group is generally used to indicate the presence of pathogenic bacteria associated with fecal contamination. The coliform group includes bacterial types of non-anthropogenic origin (e.g. soils) and fecal origin. For this reason, total coliform bacteria counts may be misleading whereas fecal coliform bacteria presence is generally associated with anthropogenic sources. Areas of high development and wastewater treatment plant outfalls are typically high in fecal coliform contamination. Fecal coliform is measured using membrane filtration techniques and is reported as the number of colonies per 100 ml of sample.

3.2 Key water quality problem areas - non point source

Three key water quality parameters are thought to be important in the Belize hydrological system, (i.e. present in locally significant concentrations); pesticides and other agrochemicals, sediments and other solids, and faecal coliform.

3.2.1 Pesticide and agrochemicals

In 1979, PAHO officials who analyzed the state of the Belize environment urged that monitoring for the presence of pesticides in Belize aquatic environments be initiated and given special consideration, stating that the Belize River in particular was probably already contaminated with their residues (Olszyna-Marzys, 1981). Since then, no study has been conducted on this or any other river to determine if indeed pesticides are a persistent problem as a water quality variable.

Although little to no hard data exists on the presence of agrochemicals, particularly pesticides, in the national rivers and lakes of Belize, anecdotal information and personal fears abound amongst the community. Growing citrus plantations and the expansion of arable lands by Mennonite farmers into forestry areas is changing catchment dynamics in large parts of the country, particularly in Orange Walk, Stann Creek and Toledo. Similarly, the expansion of Milpa slash and burn agriculture in the south and along major highways and interior access roads is a major agent for change, particularly concerning the release of nutrients, pesticides and soil particles into runoff and hence the major river systems of Belize.

Agroindustries, particularly those associated with citrus, banana and sugar-cane processing, provide point sources of concentrated contaminants that have significant local impacts on riverine ecosystems and possible broader impacts on the coastal zones downstream. Fish kills in Placencia lagoon, algal blooms on the Belize River, fish kills in drainage channels of banana plantations and other events have been pointed towards the specter of agrochemical pollution.

Freshwater contamination by agricultural runoff is one of the most serious environmental problems in Belize (Pendleton, 1991). It has been reported that the increase in agricultural activity and production has increased the erosion of soil which flows to the coast and marine areas with adsorbed pesticide and fertilizer residues (Archer, 1994). No data or numerical evidence is given to support this statement although it seems to mirror the general consensus within the Belize natural resource community. According to Archer (1994), who lists the main types of pesticides used in Belize, the toxicity and persistence of pesticide residues and their proximity to coastal and marine areas need to be monitored to determine any degrading effects on coastal and nearshore marine ecosystems.

The environmental impacts of current levels of development are relatively minor (King, et al. 1993). While this may be true at a national level, it is clear that there are problems which locally result in ecological damage. According to Fernandez (1993), Belize farmers, like most pesticide users, are prone to use more or less than the recommended rates of pesticides, use the wrong pesticides or apply them at the wrong times. They have also been seen to dispose of residues and containers in or near to water bodies. At the level of the complete catchment, the primary concern appears to be the contamination of sensitive freshwater and marine systems by polluted runoff and accelerated soil erosion. In particular, the twin aspects of nutrient enrichment and suspended sediment outflow to the barrier reef coral ecosystem with the disruptions to coral growth and sustainability are the most frequently mentioned environmental damage that water quality monitoring followed by good resource management policy can help to prevent or reverse.

Records from the Central Statistics office (Contreras, 1992) showed a considerable overall increase in pesticide imports, particularly insecticides, over the period 1982-1990. Insecticides are the most commonly used pesticides, followed by fungicides and herbicides. In 1985, the Pesticides Control Act sought to eliminate or limit the use of certain of these agrochemicals known to be most detrimental to the environment. They prohibited 22 specific types of pesticides and fumigants although anecdotal evidence has suggested that many of these, such as Aldrin and Endosulfan, continue to enter the country illegally in cross-border traffic from old stockpiles in neighboring countries.

According to Ministry of Agriculture figures, imports of fungicides, insecticides and pesticides appear to have risen substantially over the two years of 1992 and 1993 compared to 1989-91. In 1993, a total of 2.3 million pounds of these chemicals were imported into Belize. A total of 2.2 million pounds were imported in 1992. During the previous three years, the annual imports varied between 1.70 and 1.79 million pounds. It is not known if the change in classification procedures or registration in 1991 caused any increase in the quantities of imports officially recorded. Fertilizer import figures have varied considerably from 1989 to 1993, ranging between 17,519 tons in 1989 to 99,503 tons in 1992, with 20,526 tons imported in 1993.

Through the collection of secondary data and assumptions concerning the predominant types and locations of use, it is possible to approximate the quantity and types of agrochemicals used in Belize and their associated risk as environmental pollutants. However, these estimates are crude because of the general lack of information on where, when and how much agrochemicals are used in the major catchments.

Using criteria based on their known toxicity, quantity and apparent risk, it is thus possible to suggest which substances should or could be included in any future analyses for agrochemical residual concentrations in water bodies. However, data on the persistence, toxicity and residual impacts of most agrochemicals in tropical ecosystems are generally lacking.

According to Archer (1994), notable pesticides, because of their high toxicity or long half-life used in Belize include Carbofuran, Paraquat, Tamaron, Aldicarb and Mocap.

Annex 2 contains a list of fungicides, herbicides and insecticides imported by Prosser Fertilizer and Agrotec Co. Ltd. in 1993, Belize's largest supplier of packaged and break-bulk agrochemicals. It was suggested by personnel at the Ministry of Agriculture, Pesticides Control Board and the Custom's Office that cross-border traffic with Guatemala and Mexico probably results in the illegal import of a number of pesticides prohibited or restricted in Belize but available in these markets. It is suspected that this includes such chemicals as Endosulfan and Aldrin. No estimates are available as to quantities, but compared to overall agrochemical use they are expected to be small. The lists of imported pesticides provide a useful basis for selecting target substances in chromatograph analyses of water samples.

Sugar Cane

The more than 24,000 hectares of sugar cane fields in Belize receive significant quantities of agrochemicals each year. However, it is thought that because of the generally flat morphology of the growing region and retention of surface runoff within the low-lying fields, there is little danger of runoff carrying chemical residues to the New River or the Rio Hondo. The absence of a well-defined tributary network of influent streams would support this observation. While this may be true under normal rainfall conditions, periods of high flow and inundation of surrounding lands may result in episodic removal of residue-rich sediments into the northern rivers and lakes. Data obtained by the Public Health Bureau suggests that nitrate contamination is occurring in groundwater of the region, since it is showing up as elevated nitrate levels in well water samples (PAHO, review correspondence 2/16/95). Since dry season flow in the rivers will partly result from lateral sub-surface drainage from sugar cane fields and shallow slopes in the Hondo and New River valleys, there could be a risk of periodic higher nitrate concentrations in river flows, resulting from fertilizer applications.

Pesticides are most commonly applied against the frog-hopper which occurs in localized outbreaks prompting intense pesticide application of Propoxur, Undane or Sevin by aerial spraying. Pesticides are also used against the False Looper (Atkison, 1989). In 1990, 800 hectares were sprayed at 1-2 kg/ha, a total of approximately 1-2 tonnes of pesticide. Around about 70-80% of the sugar-cane fields receive herbicide treatment (King et al, 1993) including Gramoxone, Gesapax, Diuron, Velpar K3 and Asulox, usually all in combination with 2-4D Amine and by manual application. The herbicides are applied at either 4 L or 3 kg per hectare, with the 2-4D Amine at 3 L/ha. Using liquid herbicides as a guide, this would suggest an annual input of around 117-134 m^3 of chemicals or about 100-120 tonnes.

Fertilizer application is extensive, both of NPK formulations and urea. Around 110 kg/ha of urea are applied on 70% of the total hectares over the year, with a recommended application of 220 kg/ha of 18.46.0 when sugar cane is planted (King et al, 1993). How much replanting takes place is not clear and therefore estimations of total fertilizer use are difficult to make. Fertilizers are applied June through August during the season of heavy rainfall. Major surface flows from the flatlands are said to begin in September, once the low-lying land is fully saturated, with the assumption being that minimal loss of fertilizers to rivers and lakes occurs (King et al, 1993). While it may be true that nutrients are retained within the field systems, this is not known for certain, and fertilizer-enriched standing water may give rise to the production of a high aquatic biomass which itself can be washed into the river system in September causing high background BOD levels. Anecdotal evidence indicates that periodic algal blooms do occur in Belize water bodies (GOB, 1990).

Sugar cane is subjected to biannual burnings prior to and after harvesting. It is not known whether ash residues give rise to seasonally high TSS and TDS in river water.

According to a list developed in Archer (1994) during 1993, the following pesticides and fertilizers are currently in use in the sugar cane industry:

Pesticides: Mirex, Paraquat, Round-Up, Latigo, Carbyl, Malathion, 2,4-D, Propoxur, Tamaron, Ametryne, Asulam, Atrazine, Diuron, Hexazinone and Ixoxynil
Fertilizers: Urea, 18-46-0, 28-28-0, 19-19-19.

Citrus

Citrus is a likely major source of contamination in Belize since it receives a good dosing of fertilizers and pesticides each year, combined with the fact that cleared land occupies the broad areas immediately between drainage channels. It is increasingly expanding onto hillside slopes where soils are leached and do not easily retain applied fertilizers. Depending on who's estimate is taken, 1990 studies give a total of 10,000 to 11,500 ha of land under citrus production (King et al, 1993) with an average expansion of between 250 and 300 ha per year between 1985 and 1990. Most is located in Stann Creek District, with half as much in Cayo District and a quarter as much in Toledo. Agricultural runoff is pronounced due to the tendency to plant citrus in bulldozed windrows with lateral off-site drainage, usually to local tributary creeks of the major rivers. Citrus runoff is likely to be important locally for the Belize River, and for all of the creeks and rivers from the Manatee River all the way down to the Monkey River, particularly in the area around North Stann Creek.

Pesticide application in the citrus industry is mostly against leafcutter ants although fungicides and nematicides are also sprayed. According to Atkinson (1989), the leaf-cutter ants are a serious pest that can completely defoliate trees and thus are a target of much chemical spraying. Also controlled by chemical sprays are the Mexican fruit-fly and the black citrus aphid which is becoming an important pest. Malathion is widely used to control leafcutter ants (Cayetano, no date). The most common herbicide applied is Gramoxone using backpack sprayers at around 2 kg per ha per year (20 to 23 tonnes per year), split in two doses (King et al, 1993). Round Up is used in a similar fashion, with 2.8 L/ha, or about 28,000 to 32,000 L per year split in two doses. Karmax is used to prevent weed emergence at around 6.8 kg per ha, in two doses, a total of 68 to 78 tonnes. According to Canton (1993), the Belize industry uses mostly glyphosate and paraquat, both of which become inactivated, combining with clays and organic material to minimize environmental damage.

Fertilizer, in the form of urea and various NPK compounds, are widely used in the citrus industry. They are applied two to three times per year (D/J, J/J, O/N) at a rate of around 100 kg of nitrogen per ha or a total of 3,000 to 3,450 tonnes per year for the total plantation coverage in Belize. Application is greater and more frequent for young trees. Currently, this would imply that the potential for nutrient-rich runoff is increasing in Belize since many of the new plantations receiving this high fertilizer load are expanding on to steeper slopes, with poorer, leachable soils and greater potential for rapid runoff to creeks.

According to a list developed in Archer (1994) during 1993, the following pesticides and fertilizers are currently in use in the citrus growing industry (note that it does not include several of the substances mentioned by King):

Pesticides: Paraquat, 2,4-D, Malathion, Diuron, Disyston, Mirex, Lorsban, Aldicarb, Volaton, Tamaron, Metasystox

Fertilizers: Urea (12-11-22 or 19-19-19), Urea (33-0-0)

<u>Bananas</u>

Another major source of agrochemical inputs to aquatic systems will be the banana plantations. Constructed along major drainage lines to promote easy irrigation, natural riparian vegetation is usually cleared right down to the riverside. The 66 feet buffer strip of natural vegetation required by Belize's forestry regulations is seldom observed. Pesticides are applied by air, with overflies and drift resulting in direct pollution of water bodies. Infrequent inundation can wash off surface soil and fertilizer residues and overland flow during rainstorms can flush out the plantations, particularly where soils are thin and unable to fix applied chemicals. Plastic banana bags are also a nuisance pollutant, showing up in flood flows and along river banks. The area under banana production was around 2,100 ha in 1991, one quarter of which is at the Banana Control Board plantations at Cowpen on the Swasey Branch of the Monkey River. The rest is mostly located to the north along the coastal plain and many smaller rivers that drain it between the Monkey River and South Stann Creek (for example Big Creek).

Banana production usually requires irrigation, providing the opportunity for return flows of agrochemicals. Forecasts for irrigation use indicate an expected volume of 240,000 m^3 per year (King et al, 1993) when fully installed. Water is also used to wash fruit, often mixed with Alum (aluminum sulfate), which then drains away, presumably to local creeks, with its higher levels of suspended sediments and organic materials.

As well as summer irrigation, banana plantations usually have elaborate drainage to remove excess winter moisture. Pesticide runoff is known to occur into these drains which feed into small creeks and eventually the large river system. King et al (1993) report anecdotal evidence of periodic fish-kills in the permanent drains on banana plantations. Pesticides are sprayed primarily to fight the Black Sigatoka. They are also used to fight the banana weevil and burrowing nematode (Atkinson, 1989). Most common fungicides used include Tilt, Punch, Bravo and Dithane, usually eight and sometimes 16 times a year. Herbicides are sprayed by hand for weed suppression 4 to 6 times per year, usually Gramoxone and sometimes Round Up (King et al, 1993). Data would suggest an application of between 14,000 and 21,000 liters of Gramoxone is used each year on the banana plantations therefore.

Fertilizer use on bananas is considerable, estimated between 1,000 and 4,000 tonnes of urea per year and one application with 18-18-46 or 18-0-46 NPK fertilizer (King et al, 1993). The quantity of NPK use is not known.

According to a list developed in Archer (1994) during 1993, the following pesticides and fertilizers are currently in use in the banana industry:

Pesticides: Mocap, Counter, Curater (Furadan), Nemacur, Mertec, Benlate, Bravo, Paraquat, Fungaflor, Calixim (Tridemorph), 2,4-D, Maneb, Propineb, Tilt, Thiram, Round-Up, Copper Sulfate, Imazalil.

Fertilizers: 16-4-36, Urea, KCL

Other agronomic crops:

Corn, rice, beans, cocoa and vegetable production, as well as other fruits such as mango and papaya involve the use of fertilizers and pesticides also. Pesticide and fertilizer use in the last two is not known. However, Archer (1994) collected data from 1993 on pesticide and fertilizer used for corn, rice, beans, cocoa and vegetables:

In the vegetable sector, chemical control is particularly applied to cabbage production and tomatoes to control aphids, moths, worms and weevils (Atkinson, 1989). In 1989, Aldrin and Dieldrin were still in use in vegetable fields despite their prohibition by the Pesticides Control Board. According to a NARMAP report (NARMAP, 1993), vegetable farmers in Cayo District apply a wide range of chemicals, especially pesticides. The most widely used appeared to be Tamaron, a restricted pesticide in Belize due to its high toxicity. Tomatoes and Peppers receive the greatest applications due to the risks of damage from the Gemini virus. Pesticide abuse in the form of improper use and over-application has apparently reached alarming levels.

Table 3.3 Pesticides and Fertilizers Used on Corn, Rice, Beans, Cocoa and Vegetables

Crop (1992)	Pesticides	Fertilizers
Corn	Volaton, Baythion, 2,4-D, Paraquat, Prowl, Atrazine, Racumin	18-46-0, 14-36-12, 19-19-19, 10-26-26
Rice	Nuvacron, Propanil, 2,4-D, Ambush, Pyrethrin, Lissent, Permethrin, Toxaphene	Urea, 18-46-0, 16-36-12
Beans	Thiram, Benlate, Bravo, Metaldehyde, Tamaron	18-46-0, 14-36-12
Cocoa	Paraquat, Round-up, 2,4-D, Lorsban, Copper Oxychloride, Kocide	18-46-0, Urea, Iron Chalate, Magnesium Sulphate
Vegetables	Manzate, Bravo, Talstar, Baythroid, Tamaron, Monitor, Actellic, Lannate, Ambush, Folidol M (Parathion-Methyl), Antracol, Sevin, Ratak, Pirimor, Paraquat	20-20-20, Urea (14-36-12), 14-28-14, 22-11-22

Corn has a number of serious pests that require chemical control. Bean production, already marginal due to the climatic variations in Belize, is also subject to a variety of pests that cause chemicals to be applied in many cases including leaf hoppers, borers, beetles, flies, slugs and miners (Atkinson, 1989). No reliable data is available on the quantities of pesticides applied but they are thought to be used largely on the medium to large farms, rather than on the small Milpa landholdings.

Cacao is susceptible to black pod fungus and requires large quantities of fungicides to be applied (Atkinson, 1989).

There are various rice pests that occur in Belize, the most important being the Chinch bug, army worm and the leaf cutter ants (Atkinson, 1989). Chemical sprays are often applied to control these two pests.

Based on the distribution of agricultural production, rice field runoff is likely to be important locally for the Belize River, Sibun River, and the rivers of the Toledo District, in particular the Rio Grande and Moho River. Corn and bean field runoff, which will be rare except on some of the more clay soils during the rainy season, would affect the areas of the Rio Hondo, Sittee River, Belize River and the Moho River. Other Toledo District creeks and rivers also flow through or close to corn and bean fields. Runoff from vegetable production will be very isolated, with possible local minor effects in the Cayo, Orange Walk and Toledo Districts.

Cattle production in Belize has been declining but is relatively extensive, with around 50,000 animals grazing 47,000 ha of pasture (King et al, 1993). An unknown but probably sizeable portion of this land is on marginal slopes with high erosivity, particularly from surface wash and gullying of trails. The Belize Livestock Development Project is promoting the intensification of livestock production (King et al, 1993). This would give rise to more concentrated runoff of animal waste with its associated nutrients, bacteria and helminths. Moreover, intensification of stocking densities would require pasture improvement and the application of herbicides such as Round Up is proposed. At the moment, manual methods of pasture management are used due to the marginal economic base for livestock in Belize.

Shrimp production in Belize may be a local source of contamination of the aquatic environment, but more likely the nearshore coastal system rather than in the inland river system. Aquaculture enterprises are generally located close to the sea and discharge is usually to small creeks leading directly to the marine waters. According to Alegria (1993), aquafarms can cause an overloading of nutrients into the natural waters due to excess feed being used. These can cause algal blooms which can lead to oxygen depletion, and increased turbidity.

3.2.2 Total Suspended Solids (TSS)

Given high air temperatures, seasonally varying rainfall with periods of high intensity and high rates of chemical degradation of rock and soil materials, soil erosion in Belize may be significant. High soil erosion rates may result in high total suspended solids (TSS) in surface waters. High temperatures and oxidizing conditions result in relatively high organic TSS and turbidity levels due to the presence of autochthonous (naturally present) organic materials in surface waters. TSS levels and turbidity increases as flood stage and flow velocity increase throughout the river system due to entrainment of materials from the river bed, bed and bank erosion and surface runoff from adjacent contributing hillslopes and streams.

The characteristics of TSS are a function of depth, gradient, river cross-sectional shape, origin of flow and pattern of contribution from coalescing tributaries, over time and space. At any point, the TSS mass and size distribution will be a function of the sorting and selective deposition and entrainment to that point. The destination and fate of those solids, particularly at river outflow points to the ocean and channel confluences, will reflect the physical conditions at and/or downstream of that point.

While this can only be determined by observation, it can be expected that the immediate coastal plain after the break in slope from the interior mountains (particularly the zone immediately inland of the Southern Highway) is a broad zone of deposition during low or base flow periods and flushing during storm runoff. Low solids masses made up of fine grained particles can be expected at downstream monitoring sites under normal flows, with higher masses and a broader range of suspended sediment sizes and solids types during storm flows.

One of the important trends in Belize agriculture is the increasing expansion of citrus production onto what can only be described as marginal sloping lands fringing the already developed lowlands between the major river channels. This is largely happening from North Stann Creek southward. Many of these soils are heavily leached, poorly structured and erodible with few capabilities for the retention of fertilizers and little organic material. Often bulldozers are used to clear land, with felled vegetation burned and the ashy residues left to wash away down the windrows. The construction of windrows of trees with intervening lateral drainage and the use of heavy equipment allows not only extensive erosion post clearing, but also continued erosion from the drain areas even when orchards are established. Construction of roads, usually unsurfaced, also adds to the available sediment budget. The granitic soils of Belize are the thinnest and most erodible. No buffer strip is usually left between the plantation and river channels and creeks.

Forestry Department officials estimate 6,000 to 12,000 hectares of forest land were cleared in 1990 (King et al, 1993). A large part of this clearance has taken place along the Hummingbird Highway in the Stann Creek Valley, mainly for citrus but also for milpa production. Other clearings on highways have been for milpa cultivation.

The armed conflicts in Guatemala and El Salvador and land pressure in neighboring countries have led to an influx of refugees (estimates are up to 40,000), most of whom practice slash and burn agriculture. Milpa is thought to use roughly 40,000 hectares of Belize land (LIC, 1994). While there are no clear estimates of the rates of deforestation for the period 1990-1993, it is thought to be anywhere between 2 and 7% (GOB, 1993a). Because the 50% of agricultural land suitable for production still not utilized in Belize is generally in hard-to-reach locations, the new agriculture, particularly the milpa, is expanding onto unsuitable areas best left under forest cover. Milpa production will become an increasingly important source of sediments in river systems as the number of Central American immigrants and their descendants practicing this technique increases. As yet, the sediment production from the isolated cleared plots is thought to be relatively minor (King et al, 1993) although no data is available on turbidity variation. As villagers consolidate and as cleared plots expand and coalesce into broader milpa regions (for example in the Rio Grande catchment in Toledo), the ability of the downslope areas to catch and hold runoff and sediments could well be overwhelmed.

Milpa farming, primarily for self-sufficiency, can be found in all districts but is most common in the south. An average "milpero" planting maize will have around two hectares of land cultivated annually, out of an area of 15 to 20 hectares in successive stages of post-milpa regeneration (GOB, 1992a). High natural population growth and immigration is adding to the demand for milpa production and competition for land by the citrus industry is forcing milperos to expand onto ever more marginal areas.

Slash and burn practices on steep slopes, particularly in the igneous and metamorphic regions, gives rise to rapid soil degradation, particularly because soil conservation technologies are not widely applied. Sheet-type erosion and local gullying can occur with some more massive slumps and slides on the highly silicious soils. Moreover, uncontrolled burning produces a wave of forest wild fires each year, which can result in subsequent heavy sediment and ash loads in adjacent rivers following the first heavy rains, leading to seasonally high turbidity and BOD levels. Burned soils can turn hydrophobic leading to locally intense runoff and intense downslope erosion as critical entrainment depths and velocities of rill-flow are obtained.

The processes of sediment erosion, transport and deposition in tropical, vegetated catchments and the rivers that drain them are complex and still relatively poorly understood and documented at the catchment scale. Though research has taken place at the field plot level and even within hillslope sequences, our ability to forecast sediment budgets, as opposed to the measurement of sediment concentrations, is limited. TSS is and will be a significant variable to measure and monitor, because:

- it is expected to vary greatly, exhibiting different characteristics from river to river and over time in relation to land use and runoff and flow conditions,
- potential for the entrainment of large masses of sediment is present in a large number of catchments at different locations in the hydrological network
- its impact on beneficial uses of water (it is an undesirable component for potable, irrigation and industrial water uses),

- its potential impact on the marine ecosystem (due to its effects on light penetration of turbid marine waters, deposition over sensitive coral reefs, and its ability to pick-up and transport important pollutants including pesticides and nutrients).

During the course of this study, no TSS data were located for rivers in Belize. Combined with the lack of hillslope erosion rates, it is difficult to indicate what range of solids levels could be expected. However, to give an idea of the order of magnitude of solids concentrations that could be encountered in Belize rivers, some estimates can be made using some simple, crude calculations and indices. Firstly, grades of potential sediment removal from Belize catchment slopes must be estimated. A recent report by the World Bank (Lutz et al., 1993) produced the following data:

Table 3.4 Sediment Yields Per Year Per Hectare from Erosion Documented for Central American and Caribbean Farming Systems (Lutz et al., 1993)

Country	Rainfall (mm)	Slope (%)	Farming System	Sediment Yield (Metric Tons)	Sediment Yield (mm/yr)
El Salvador	1724	30	Corn & Beans	230	15.3
Honduras	2000	45	Corn & Beans	42	2.7
Panama	~2000	na	Pasture	35	5.0
Haiti	1214	25	Grass Hedges	8	na
Panama	~2000	na	Coffee	77	11.0

Generally, the ranges presented by the World Bank review (Lutz et al., 1993) are considerable, from a low of around 4.0 to a high of over 200 metric tons per hectare per year. Many factors are at play and it would be difficult to estimate soil erosion rates for different Belize land-uses without more data. However, as a simplified example, assuming an average loss per hectare of 5 metric tonnes for all agricultural land and zero erosion for forested land, a relatively simple calculation can be made to develop an order of magnitude of sediment loading at a country wide-level.

Example (using rounded numbers):

Land under agriculture = 225,000 hectares
Soil erosion rate per annum per hectare = 5.0
Total sediment load = 1,125,000 metric tonnes
Total land area = 2,250,000 hectares
Sediment production = 0.05kg per m^2 per year
Runoff production (Annexes) = 600-1500 liters per m^2 per year
Average potential sediment concentration = 30-80 mg/l

According to a table of natural ranges of constituents in rivers (Chapman, 1993), for rivers draining catchments of up to 100 km^2, TSS variation between 3 and 15,000 mg/l can be expected. A global average "most common natural concentration" of TSS is around 150 mg/l for river runoff.

Sediment Associated Contaminants

In terms of the relation between sediments and water chemistry, sediments are major mechanisms for the transport and release of trace elements, particularly fine particles on to which they have been absorbed. The portion of clays and very fine silts suspended in the water at a given point will be a key variable, since they will have greatest tendency to continue on a downstream path to the coastal environment, thus determining the fate of measured trace elements, particularly metals and, in many cases, soil-erosion derived pesticides and nutrients. As far as trace elements are concerned, collection and assessment of TSS and chemistry for largely pristine and converted parts of the catchment or between similar catchments exploited to different levels (for example moving south along the Southern Highway) will provide useful indices of the level of pollution.

With reference to the fate and persistence of organic pollutants, little data exists for the highly varied tropical rivers found in Belize with their flashy, turbulent headwaters and placid, floodable valleys. Particularly in the context of Belize, no data is known on the presence of substances such as individual pesticides (DDT, aldrin, heptachlor, chlordane, paraquat, metham-sodium and carbamate, triazine and 2,4-D), solvents (benzene, tri and tetrachloroethylene, toluene), phenols and hydrocarbons that are increasingly showing up in developing countries around the world as they did in the developed world over the last 5-20 years. Persistence and fate are determined by the individual properties of these substances under different environmental conditions, which encompass the principal elements of their volatility, solubility in water, solubility in lipids (fats and fat-like substances that constitute one of the principal structural materials of living cells), photodegradation, biodegradation and bioaccumulation (Chapman, 1993). Clearly this depends on the complete range of water quality characteristics not least flow velocity, turbidity (light penetration), temperature and concentration of microorganisms.

An important factor to consider in the Belize case, is the fate of the proportion of important trace element pollutants, particularly pesticides and nutrients, absorbed onto TSS particulates that make it through the river systems to the estuaries and inner channel off the Belize coastline. As indicated in Chapman (1993), where waters rich in these types of particulates encounter saline estuarine or coastal waters and mixing occurs, the major cations can cause the release of a proportion of the previously absorbed trace elements because the cations have a stronger bonding to the absorption sites. Accordingly, the pollutants can be made more readily available to organisms in the water, notably the coral ecosystem, and serious bioaccumulation can result. Therefore, measurements of TSS should almost certainly be combined with particulate trace element studies to develop orders of risk for the different rivers upstream of marine outflow points (note that dissolved trace element studies are usually not recommended for routine monitoring programs). It may be that the already cation rich waters expected from the igneous catchments are less prone to transport these types of contaminants, if present in the catchments, because already the absorption potential of particulate material is reduced prior to marine discharge and any pollutants accumulate closer to their point of origin through a range of physical and chemical fixation or accumulation processes. The fate of contaminants input to these types of river systems, for example, the Sittee River or South Stann Creek, would thus tend to be local and short-lived as opposed to distant and persistent in cation-poor, basic limestone catchment runoff and groundwater return flow.

Mining as a Source of TSS

According to the UNDP (1993), the demand for sand around the river mouths, estuaries and beaches of Dangriga, Belize City, Sibun, Placencia, Monkey River Town, San Pedro and Punta Gorda is presently met by mining of these areas at an escalating rate that is clearly not sustainable. The end result is changing patterns of erosion and deposition that can lead to locally high suspended solids levels in river and marine waters.

Other than its affects on sediment levels in water bodies, mining does not appear to have any other serious effects because as yet, there are no operations that involve the use of hazardous chemicals (Garcia, 1993). The majority of mining is for aggregates and other building materials. However, with continuing interest in the interior of Belize as a possible location for hydrocarbon exploration, this may change.

Very little data is available on suspended sediment and turbidity of Belize water bodies. Few data have been developed concerning the concentration of sediments (mg/l and nephelometric turbidity units) and annual volumes (in m^3 and mm/km^2 of catchment area) for any of the major catchments or their sub-areas. Data that does exist is summarize in Annex 3.

3.2.3 Faecal coliform

In Belize, domestic wastewater pollution consists of miscellaneous flows to municipal sewer systems as well as discharges and leaks from septic systems and latrine pits or direct deposits of waste in the form of night-soil. Municipal sewer systems collect waste from residential homes, apartments, hotels, commercial establishments and either dispose of it directly to the ocean or to rivers, or treat it and dispose of effluent and overflow from the treatment system in the same manner.

Domestic waste is said to contribute a large quantity of pollutants to the coastal and nearshore marine areas and their ecosystems (Archer, 1994). Out of the 199,000 inhabitants estimated for 1992, around 135,000 are served by sewer systems, septic tanks or ventilated improved pit latrines. Many of the urban sewer and septic tanks discharge or leak their wastes to creeks and rivers. Cases are cited of numerous hotels, commercial establishments and small settlements using septic tanks and direct soakaways for laundry water that flow directly or indirectly to creeks. However, no estimates appear to be available of the loading of solids, BOD, nutrients and coliform that this waste water provides to each river network. The study of domestic waste appears to be an incomplete review of both the magnitude and the distribution of the problem, since other river systems such as the Sittee and the Hondo were not mentioned. However, special mention is given to the pollution from domestic sources of Haulover Creek, New River, North Stann Creek and Belize River. No mention was made by Archer of the seasonality of the problem nor suggestions as to how better estimates could be made. Archer does indicate that estimates of loading from hotels and guest houses is difficult due to lack of occupancy rates. The review is useful in that it does point out the fact that direct avenues exist for the entrance of faecal material and household cleaning products and detergents into Belizean water bodies at both the household and municipal level. Given the relatively low population levels in Belize, this problem will not be as serious as in other Central American countries and low background levels of domestic waste related contaminants can be expected.

One notable exception to this situation appears to be the Belize River downstream of Belmopan. A PAHO study showed that this plant appears to be discharging almost raw sewage into the river at a rate of some 158,000 gal/day (van de Kerk, 1993a). Based on a limited number of samples, PAHO engineers found that the effluent still had extremely high fecal coliform counts and high phosphate and nitrate concentrations together with BOD of 250 mg/l and suspended sediments of 335 mg/l. The effect on the river appeared to be a drop in dissolved oxygen of some 3 mg/l and an increase in the level of phosphates and faecal coliform amongst others.

With a population density of only around 8/km^2, domestic waste as yet is unlikely to represent a major problem at a national scale. However, the population is becoming increasingly concentrated, particularly in small rural communities made up of newly settled immigrants and refugees from other Central American nations. Considering the relative absence of systems for the collection and treatment of human wastes, the opportunity for significant local contamination of surface water bodies with organic materials and bacteria of human origin is nevertheless present in Belize. Perhaps more important than the coliform found in domestic waste is the organic loading, the nutrients that can pass untreated into river water and enter nearshore and coastal water bodies, giving rise to algal blooms (GOB, 1992c).

Nothing else appears to have been written or is known as yet on the presence of faecal coliform bacteria in natural water sources. The only data available is on coliform in small developed water systems and in the raw water intake for WASA treatment plants.

3.3 Key Water Quality Problem Areas - point sources (industrial pollutants)

Point pollution is locally a serious problem on several river stretches in Belize. The solid waste leachate and liquid waste streams of the two major citrus processing plants are causes of periodic eutrophication, de-oxidation and high acidity in the North Stann Creek.

3.3.1 Sugar Cane

Processing of sugar cane has proven to be one of the most consistent and serious point pollution sources in Belize, affecting the New River at the floodplain sites of Tower Hill and Libertad upstream of the estuary outlet into Corozal Bay. Effluent from the two sugar and high-test molasses plants contain large amounts of organic material (sugar residue), caustic soda, hydrochloric acid (which reacts with evaporator scale to produce calcium chlorides), and oils. According to Avella (1993), the four main waste streams within the Tower Hill refinery are the main condenser, the factory floor waste stream, the ash-pit drainage and the drainage from the molasses tanks. Waste is discharged from the boilers and heat exchangers during periodic cleaning. According to calculations by Miller and Miller (1994), the average daily production of waste from the Tower Hill Refinery is around 6,500 tonnes per day or around 48 mg/l BOD. At the Libertad refinery, it is around 25,000 tonnes per day, or around 300 mg/l BOD.

The report of Newell (1993) gives a full discussion of the nature of industrial pollution caused by the sugar cane refineries at Tower Hill and Libertad. They represent the two largest point pollution sources in Belize, both discharging into a river that appears to have insufficient assimilative capabilities to deal with the waste, particularly at low flow conditions. Newell analyzed the water for dissolved oxygen, COD, temperature, sulfate, phosphate, nitrate, iron, hardness and alkalinity and found that there is an overall major deterioration in water quality from Lamanai lagoon down to the point of discharge in Corozal Bay. For example, dissolved oxygen was seen to decrease from a super-saturated 10.5 upstream to around 0.25 mg/l at the mouth of the river.

3.3.2 Citrus

According to a report by UNIDO consultants on the Belize Citrus Industry (Haskoning, 1994), between 45-50% of the solids inputs and 55-60% of the liquid inputs to the citrus processing plants are deposited as waste. Citrus plantations cover over 16,000 hectares and produce 175,000 tonnes of fruit, of which around 112,000 tonnes were processed in the two plants of Belize Food Products and the Citrus Company of Belize in 1993 which have a developed capacity of 150,000 tonnes. Out of this input, concentrate production is around 9% by weight.

According to Haskoning (1994) discharge of liquid wastes and leachate from solid wastes is a threat to the quality of surface water due to the high organic content of the waste which exerts high oxygen demands. The dissolved oxygen content of the wastes is zero. Currently, there is no effective waste management control and treatment at the citrus processing plants with opportunities for periodic leakage from holding pits. Belize Food Products do have stabilization lagoons for the acceptance of their liquid wastes but overflows from these can pass to the river. UNIDO consultants recommended a process of cattle feed recycling and lagoon treatment of wastes to reduce the risks of future river contamination (Haskoning, 1994).

In the four years to 1993, citrus hectarage doubled (Haskoning, 1994). Overall, the citrus processing plants are thought to produce close to 75,000 tonnes of solid waste per year and 82,000 tonnes of liquid waste from a total combined citrus and water input of 170,000 tonnes (Haskoning, 1994). The solid wastes, liquid wastes, wash/water and condensate and cold press liquids contain very high organic loads represented as high COD values per liter:

Solids	20,000-50,000 mg/l
Wash water	4,000 mg/l
Cold press water	30,000 mg/l

Solids are dumped on flat areas several miles from each processing plant and leachate from each drains to a creek or directly to the North Stann Creek. Leachate COD levels were measured at around 1,000 mg/l. Liquid wastes are usually discharged directly to receiving water bodies (Haskoning, 1994). Following fish-kills in a local tributary river, DOE took samples of the drain water leaving the Citrus Company of Belize dump-site and found COD levels as high as 50,000 mg/l. According to Avella (1994), the fish-kills associated with the Stann Creek citrus industry have been due to leakages of leachates from holding pits for rinds and other solid wastes from the pulping and concentrate process.

3.3.3 Other Industries and Their Impacts

Apparently, polluted river stretches can be found in the Sarstoon, Hondo, New and Belize Rivers (GOB, 1993b). On the Belize River, only around 24% of the urban wastewater receives any kind of treatment and there is no waste treatment for the industrial zones close to San Ignacio and Ladyville. Poultry, milk, fish and other food industry plants almost exclusively dispose of their processing wastes into the nations' rivers and creeks (Archer, 1994).

Miller and Miller (1994) carried out selected one-day sampling of the effluent and impacts of various industrial facilities in Belize in late 1993 and early 1994. While they provide data on observed concentrations, they do not provide information on flow rates. Contaminants analyzed include: Total Coliform, Fecal Coliform, BOD, COD, Chloride, Sulfate, Nitrate, Phosphate, Alkalinity, TDS, Lead, Iron, pH, Salinity, Conductivity, Dissolved Oxygen and Temperature. Locations analyzed included the Travellers Refinery (Belize City), Belikin Brewery (Ladyville), Pepsi Cola Bottling (Ladyville), Western Dairy Limited (Spanish Lookout), Quality Poultry Products (Spanish Lookout), Northern Fisherman Cooperative (Belize City), Nova Shrimp Farm (Ladyville), Citrus Company of Belize (Pomona), Williamson Industries (Ladyville), G.N.W. International (Belize City) and WASA (Double Run). Their results show considerable variation in the quality of effluent for different industries and also in the characteristics of the receiving bodies. As expected, there are considerable changes in concentration depending where in the waste stream and assimilation process the samples were taken, a function of both changing water to contaminant volume ratios (which are unknown in the Miller and Miller samples) and to physical, chemical and biological changes to the effluent through the system.

3.4 Cause and effect relationships for water quality

The following consists of a preliminary synthesis of available information, both anecdotal and quantitative, on the cause and effect relationships between land and water use practices and water quality current in Belize.

Major land uses and industrial activity have been identified in Belize through review of current literature and reports indicating the following major categories:

Sugar Processing
Rum Refining
Breweries
Soft Drink Bottling
Dairy Processing
Poultry Processing
Fish Processing
Shrimp/seafood Processing
Citrus Processing
Garment Manufacture
Battery Manufacture
Timber Harvest
Agriculture
Wastewater treatment
Power Generation (Diesel)

Each category has been researched in order to determine typical effluent constituents and concentrations. This analysis has been used to identify constituents of concern for each industry/land use category.

3.4.1 Sugar Processing

Sugar processing in Belize occurs in two processing plants located in the north of Belize at the Tower Hill Factory located near Orange Walk (Belize Sugar Industries, Ltd) and Libertad (Petrojam Belize Ltd.). Both plants discharge wastewater to the New River. Effluent constituents associated with sugar processing include:

Chemical Oxygen Demand
Total Suspended Solids
Biochemical Oxygen Demand
Organic Acids
Caustics
Petroleum Hydrocarbons

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3.4.2 Rum Refining

Rum refineries in Belize operate mainly near Belize City. Constituents associated with effluent generated by rum refineries include:

Chemical Oxygen Demand - associated with the discharge of fermentation waste
Total Suspended Solids - associated with the discharge of fermentation waste
Biochemical Oxygen Demand - associated with the discharge of fermentation waste
Detergents - associated with equipment cleaning
Total Organic Carbon - associated with the discharge of fermentation wastes

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3.4.3 Breweries

Breweries in Belize operate mainly in the Ladyville area north of Belize City. Common constituents associated with the effluent generated by the brewing process include:

Biochemical Oxygen Demand - associated with the discharge of brewing waste
Chemical Oxygen Demand - associated with the discharge of brewing waste
Caustics (e.g. Na_2CO_3) - associated with equipment cleaning and bottle washing
Chloride - associated with equipment cleaning and bottle disinfection
Total Organic Carbon - associated with the discharge of brewing waste

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3.4.4 Soft Drink Bottling

Common effluent from soft drink bottling include the following constituents:

Caustics (e.g. Na_2CO_3) - associated with equipment cleaning and bottle washing
Biochemical Oxygen Demand - associated with the discharge of product waste
Chemical Oxygen Demand - associated with the discharge of product waste
Chlorides - associated with equipment cleaning and bottle disinfectant
Detergents - associated with equipment cleaning and bottle disinfectant

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3.4.5 Dairy Processing

Effluent associated with dairy processing operations include the following constituents:

Detergents - associated with equipment cleaning
Biochemical Oxygen Demand - associated with the discharge of product waste
Chemical Oxygen Demand - associated with the discharge of product waste
Total Suspended Solids - associated with the discharge of product waste
Total Organic Carbon - associated with the discharge of product waste

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3.4.6 Poultry Processing

Constituents typically generated by poultry processing operations include:

> Biochemical Oxygen Demand - associated with the discharge of product waste
> Detergents - associated with equipment cleaning and disinfection
> Total Organic Carbon - associated with the discharge of product waste
> Chemical Oxygen Demand - associated with the discharge of product waste

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McGrail, D.T., 1976. Poultry processing wastewater - advanced treatment and reuse. in Proceedings Seventh National Symposium on Food Processing Wastes; April 7 -9, 1976. p 298 -307.

Miller and Miller Ltd., 1994. Recommendations on industrial effluent quality standards for Belize. Draft Final Report to NARMAP.

Woodard, F.E. et al., 1977. New concepts in treatment of poultry processing wastes. Water Research, Vol. 11, No. 10, p 873 - 877.

3.4.7 Fish Processing

Fish processing operations typically generate wastewaters containing the following constituents:

Biochemical Oxygen Demand - associated with the discharge of product waste
Chemical Oxygen Demand - associated with the discharge of product waste
Chlorides - associated with equipment cleaning
Total Suspended Solids - associated with the discharge of product waste
Detergents - associated with equipment cleaning
Nutrients (e.g. N, P) - associated with the discharge of product waste
Coliform Bacteria - associated with the discharge of product waste

References

Archer, A.B., 1994. Land-Based Sources of Marine Pollution Inventories: Belize & Cayman Islands. UNEP Regional Coordinating Unit Report, May.

Miller and Miller Ltd., 1994. Recommendations on industrial effluent quality standards for Belize. Draft Final Report to NARMAP.

3.4.8 Shrimp/seafood Processing

Wastewater effluent associated with the processing of shrimp and other seafood include the following constituents:

Biochemical Oxygen Demand - associated with the discharge of product waste
Chemical Oxygen Demand - associated with the discharge of product waste
Chlorides - associated with the cleaning and disinfection of equipment
Ammonia - associated with the discharge of product waste

References

Archer, A.B., 1994. Land-Based Sources of Marine Pollution Inventories: Belize & Cayman Islands. UNEP Regional Coordinating Unit Report, May.

Miller and Miller Ltd., 1994. Recommendations on industrial effluent quality standards for Belize. Draft Final Report to NARMAP.

3.4.9 Citrus Processing

Citrus processes effluent typically contains the following constituents:

Biochemical Oxygen Demand - associated with the discharge of product waste
Chemical Oxygen Demand - associated with the discharge of product waste
Organic Acids - associated with the discharge of product waste
Total Organic Carbon - associated with the discharge of product waste
Nutrients (e.g. N, P) - associated with the discharge of product waste

References

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Jones, R.H., 1970. Lime treatment and in-plant re-use of an activated sludge plant effluent in the citrus processing industry. Proceedings, First National Symposium on Food Processing Wastes; April 6 - 8, 1970. p 177 - 188.

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Soderquist, M.R. and J.L. Graham, 1977. Fruit-, vegetable-, and grain - processing wastes. Journal Water Pollution Control Federation; Vol. 49, No. 6. p 1118 - 1123.

3.4.10 Garment Manufacture

Constituents associated with the effluent from garment manufacture include:

> Biochemical Oxygen Demand - associated with the discharge of industrial wastes (e.g. dyes)
> Chemical Oxygen Demand - associated with the discharge of industrial wastes
> Detergents - associated with the discharge of equipment cleaning wastewater
> Chlorides - associated with the discharge of equipment cleaning wastewater

References

Archer, A.B., 1994. Land-Based Sources of Marine Pollution Inventories: Belize & Cayman Islands. UNEP Regional Coordinating Unit Report, May.

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Nosek, J., 1976. Work of the centroproject on the problems of textile effluent treatment. Textil; Vol. 31, No. 12. p 463 - 465.

3.4.11 Battery Manufacture

Effluent constituents of concern associated with the manufacture of lead-acid batteries include:

Acids (H_2SO_4, in particular) - associated with the discharge of industrial waste
Metals (Pb in particular) - associated with the discharge of industrial waste

References

Archer, A.B., 1994. Land-Based Sources of Marine Pollution Inventories: Belize & Cayman Islands. UNEP Regional Coordinating Unit Report, May.

Miller and Miller Ltd., 1994. Recommendations on industrial effluent quality standards for Belize. Draft Final Report to NARMAP.

Shapiro, N.I. et al., 1981. Removal of heavy metals and suspended solids form battery wastewaters: application of hydroperm cross flow microfiltration. Environmental Protection Agency Project Summary EPA-600/S2-81-147. 5 p.

Shapiro, N.I. et al., 1981. Demonstration of a cross flow microfiltration system for the removal of toxic heavy metals from battery manufacturing wastewater effluent. Chemistry in Water Reuse; Volume 1. p 281 - 309.

USEPA, 1980. Development document for proposed effluent limitations guidelines and new source performance standards for the battery manufacturing point source category. Report EPA-400/1-80/067-2. 847 p.

3.4.12 Timber Harvest

Contaminants typically associated with the effects of timber harvest include:

> Total Suspended Solids - associated with increased runoff and decreased vegetative cover
> Nutrients - associated with decreased vegetative consumption

References

Adams, P.W. and C.W. Andrus, 1990. Planning secondary roads to reduce erosion and sedimentation in humid tropic steeplands. IAHS Publication No. 192. International Association of Hydrological Sciences, Washington DC.

3.4.13 Agriculture

Contaminants generally attributed to agricultural development include:

Total Suspended Solids - associated with agricultural land use (e.g. plowing)
Nutrients - associated with fertilizer use
Pesticides - associated with application techniques and runoff characteristics
Herbicides - associated with application techniques and runoff characteristics

References

McCune, D.L. 1982. Fertilizers for tropical and subtropical agriculture. International Fertilizer Development Center.

Samson, J.A. 1986. Tropical Fruits 2nd ed. Wiley and Sons, Inc.

Stover, R.H. and N.W. Simmonds. 1987. Bananas 3rd ed. LC 85-2340. Halstead Press.

Thomton, T. 1991. Pesticides in tropical agriculture. State Mutual Book and Periodical Service.

3.4.14 Wastewater treatment

Contaminants generally associated with wastewater treatment effluent include:

- Biochemical Oxygen Demand - associated with the discharge of wastewater containing undegraded human waste
- Chemical Oxygen Demand - associated with the discharge of industrial wastes discharged to the wastewater treatment plant
- Detergents - associated with the discharge of domestic cleaning wastewater
- Chlorides - associated with the discharge of domestic wastewater
- Total Suspended Solids - associated with the discharge of domestic wastewater
- Fecal Coliform Bacteria - associated with the discharge of wastewater containing human waste

References

Kutcher, J.G. and R.P. Kramer, 1977. Municipal water pollution control abstracts: November 1976 - October 1977. Report EPA 600/9-77-037.

van de Kerk, A., 1993a. Assessment and Recommendations for the Sewage Treatment Plant of Belmopan. PAHO, July.

3.4.15 Power Generation (Diesel)

Mineral oils and petroleum products used in thermal power generation are known to contain a significant number of compounds including naphthenic hydrocarbons, unsaturated heterocyclic compounds, polychlorinated biphenyls (if present in transformer heat exchangers) and numerous oxygen, nitrogen and sulphur compounds. Recommended maximum concentrations for drinking water supplies and fisheries protection are generally between 0.01 and 0.1 mg/l of mineral oil and petroleum products (Chapman, 1993). Contaminants associated with power generation from small and medium, diesel-powered thermal plants include:

Temperature - associated with cooling water
Oil and grease - associated with leakage and runoff
Various hydrocarbon compounds and by-products - associated with diesel leakage and combustion
PCBs - from leaking transformer oils

References

Alloway B.J. and Ayres D.C., 1993. Chemical Principles of Environmental Pollution. Blackie Academic & Professional.

APHA, 1992. Standard Methods for the Examination of Water and Wastewater. 18th Edition.

Identification of water quality parameters for use in the program is primarily based on the specific program objectives and cost of implementation. The attached matrix was developed to provide a prioritization scheme for each of the constituents of concern identified in section 3.1. The matrix allows development of the program such that cost, laboratory availability and personnel considerations can be evaluated and a phased approach can be facilitated over a period of years based on changing levels of capability and expertise.

3.5 Loading risk factors

From data provided by the Land Information Centre (LIC, 1994), it can be seen that in overall terms, Belize is still in largely pristine or close to pristine condition. Almost 92% of the land is classified as savannah rangeland, forest and other wooded areas (broadleaf forest, pine forest, thickets, shrubland, riparian zone, coastal forest, mangrove or swamp), or unproductive land (bare or water). Moreover, only 6.8% of this is indicated as showing evidence of being secondary regrowth or regenerated land following prior farming or clearing. Only 0.38% of the landscape is classified as under urban usage, although the majority of this is close to or along rivers and streams around the country. By subtraction, it would thus appear that agriculture occupies the remaining 7.6% of the land-surface based on data produced from the Belize GIS of digitized land-use data. The following table presents the land area, in percentage and in hectares, of the agricultural zones around the country. Note that based on a calculations using the GIS data, it would suggest that agriculture occupies some 9.9% of the land rather than the 7.6% calculated by subtracting the other use categories. It could be assumed that there was some double counting of agricultural land, in stages of regrowth and with partial clearance of vegetation, as forest and other wooded areas. Regardless, the total is still relatively low as a portion of total land area.

Table 3.7 allows us to calculate which of the agricultural land-uses are most important on a national land-use scale and therefore, in terms of potential agricultural chemical inputs and or suspended sediments resulting from land-use. Clearly, over half, almost 60% of the agricultural land, is devoted to herbaceous crops, with around 17% for shifting cultivation, 16% for pasture, with the remainder dedicated to tree crops.

Pasture, where it also takes place on slopes, can result in soil erosion due to dislocation of soils by animal footfall and by the process of local compaction giving rise to storm runoff. Tree crops, particularly new plantations established in rows, can be both sources of sediments and of agrochemicals due to their infrequent groundcover, effective surface drainage and constant application of agrochemicals to augment yields and fight pests. Banana and sugar-cane plantations are known to be causes of pollution both through agricultural drainage and through the application of pesticides from the air that fall directly onto the river surface. Both bananas and sugarcane are frequently located along and right up to the banks of river sections. Shifting cultivation is a source of sediments resulting from the burning process that creates ash and reduces soil fertility and stability in the long-run, particularly since much of it takes place on slopes.

Table 3.5 Qualitative Rating of Parameters for the Assessment of Environmental Water Quality

	Parameter									
Land Use/Industry	**Discharge**	**Temp**	**pH**	**EC**	**DO**	**Alkalinity**	**TSS**	**TDS**	**Pesticides**	**Herbicides**
Sugar Processing	1	1	1	1	2	2	2	3	4	4
Rum Refinery	1	1	1	1	2	2	2	3	4	4
Brewery	1	1	1	1	2	2	2	3	4	4
Soft Drink Bottling	1	1	1	1	2	2	3	4	4	4
Dairy Processing	1	1	1	1	2	2	2	3	4	4
Poultry Processing	1	1	1	1	2	2	3	4	4	4
Fish Processing	1	1	1	1	2	2	2	3	4	4
Shrimp Processing	1	1	1	1	2	2	3	4	4	4
Citrus Processing	1	1	1	1	2	2	3	3	3	3
Garment Manufacture	1	1	1	1	2	2	3	3	4	4
Battery Manufacture	1	1	1	1	2	2	3	3	4	4
Timber Harvest	1	1	1	1	2	2	2	3	4	4
Agriculture	1	1	1	1	2	2	2	3	2	2
Wastewater Treatment	1	1	1	1	2	2	2	3	4	4

KEY: 1 = Primary 2 = Secondary 3 = Tertiary 4= Quartic

Table 3.6 Qualitative Rating of Parameters for the Assessment of Environmental Water Quality

Land Use/Industry	Parameter										
	BOD_5	COD	NO_3-N	TKN	SRP	Cl	TOC	TPH	Sulfate	Metals	Coliform
Sugar Processing	2	2	3	3	3	4	3	4	2	3	3
Rum Refinery	2	2	3	3	3	4	3	4	2	3	3
Brewery	2	2	3	3	3	4	3	4	2	3	3
Soft Drink Bottling	2	2	3	3	2	4	3	4	2	3	3
Dairy Processing	2	2	3	3	3	4	3	4	4	4	2
Poultry Processing	2	2	3	3	2	4	3	4	2	3	2
Fish Processing	2	2	2	2	2	2	3	4	4	4	2
Shrimp Processing	2	2	3	3	2	4	3	4	2	3	3
Citrus Processing	2	2	2	3	3	3	3	4	2	3	3
Garment Manufacture	2	2	3	3	3	4	3	4	2	3	3
Battery Manufacture	3	3	4	4	4	4	3	4	2	2	3
Timber Harvest	3	3	2	2	2	3	3	4	2	3	3
Agriculture	3	2	2	2	2	2	3	4	2	3	3
Wastewater Treatment	2	2	2	2	2	2	3	4	2	3	1

KEY: 1 = Primary 2 = Secondary 3 = Tertiary 4= Quartic

Table 3.7 Agricultural Land-Use in Belize (1989-92)

Land Use	Percentage	Total Land Area
Herbaceous Crops		
Annual crops		
Mechanized	1.80	41,437 ha
(with grazing)	(0.86)	(19,202 ha)
Non-mechanized	0.90	20,200 ha
(with Milpa/thickets)	(0.16)	(3,696 ha)
(with regrowth)	(0.13)	(3,001 ha)
Bananas	0.09	2,118 ha
Sugar-cane	2.94	65,969 ha
(with regrowth)	(0.97)	(21,788 ha)
Tree Crops		
Citrus	0.59	13,343 ha
Mango	0.08	1,703 ha
Cocoa	0.01	207 ha
Cashew	0.00	34 ha
Shifting Cultivation (Milpa)	1.71	38,262 ha
(with thickets)	(0.20)	(4,545 ha)
Pasture	1.64	36,677 ha
(with annual crops)	(0.29)	(6,520 ha)
Clearing for Farming	0.13	3,028 ha
Shrimp Farming/Aquaculture	0.01	260 ha
AGRICULTURAL TOTAL	9.90	223,238 ha

Shrimp farming and aquaculture which take place in lagoons are sources of nutrient-rich and chemical-rich water, usually directly to the ocean rather than to rivers. Mechanized agriculture is usually a source of sediments due to the tendency to maintain incomplete cover over part of the year and to prepare soil surfaces which can then be exposed to the erosive effects of rainstorms. This is mitigated by the fact that mechanized agriculture takes place on mostly flat land with only slight erosional potential from running water.

3.5.1 Identification of High Risk Areas

According to King et al (1993), understanding of the transport processes that could potentially carry polluted river discharge out over the Belize barrier reef (perhaps the major concern of environmentalists and politicians alike) is not sufficiently developed to identify the critical catchments for nearshore water quality protection. However, from the development of preliminary catchment profiles during this project to develop a water quality program, it is clear that certain high risks exist and, moreover, an adequate program of water quality monitoring coupled with the pending study of the coastal zone could go a long way towards identifying critical risks as well as preliminary forecasts that can be monitored and tested by DOE and CZMU in a coordinated fashion.

Note that one method of water quality monitoring, particularly in hybrid approaches with multiple objectives is to decide quality monitoring locations on the basis of use orientation and sensitivity as much as expected environmental and anthropogenic differentiation.

The following table presents a summary of the priority risk zones, by catchment, as judged by the consultants on the basis of available information at this time. The zones are identified using simple descriptions that include the river channel name (for the location of possible sampling sites above or below), geographic location, and some idea of the extent:

Table 3.8 Priority Contamination Risk Zones for Anthropogenic Contamination

Catchment	Zone	Reasons	Contaminants
Rio Hondo	Rio Hondo; August Pine Ridge to Corozal Bay; Coastal Plain.	Sugarcane plantations	Nutrients Pesticides Fertilizers
New River	New River; Tower Hill to Corozal Bay; Coastal Plain.	Sugarcane plantations. Two heavy point polluters (Tower Hill and Libertad refineries), domestic wastes.	Pesticides Fertilizers Nutrients Temperature TSS BOD Caustic chemicals
Belize River	Macal River; Upstream of Cristo Rey; Mollejon Hydro Plant.	Construction of roads and dam site causing sediment movement.	TSS
Belize River	Mopan River; Downstream of border.	Discharge of hospital and domestic waste from Guatemalan riverside towns.	Coliform, etc. Nutrients TSS Caustic Chemicals
Belize River	Haulover Creek; Belize City environs; Canal Banks.	Domestic wastewater.	TSS Nutrients BOD Coliform

Catchment	Zone	Reasons	Contaminants
Belize River	Belize River; Ladyville to airport; Riverside industrial zone.	Industrial discharge - brewery, distillery and bottling plants.	Nutrients BOD TSS Caustic chemicals
Belize River	Belize River; Belmopan environs; Treatment plant outflow.	Untreated domestic wastewater.	BOD Nutrients TSS Coliform
Belize River	Belize River; Spanish Lookout environs; Industrialized zone.	Small agro-industry plants discharging waste to creeks.	BOD Nutrients Oil and Grease
Sibun River	Caves Branch; Sibun confluence to 3km upstream; River bed and banks	Sand and gravel extraction	TSS
Sibun River	Sibun River; Caves Branch confluence to 3km upstream; River bed and banks	Sand and gravel extraction	TSS
Manatee River	Soldier or Plantation Creek; Government Landing; Riverbank Mining.	Sand and gravel works along river channel.	TSS
Mullins River	Mullins River; Gales Point area; Riverside farms.	Growth of existing citrus plantations expected.	Pesticides Fertilizers TSS
North Stann Creek	North Stann Creek; Middlesex to Melinda FS; Valley bottom and <20% sideslopes.	Orange groves, Highway reconstruction, Citrus Processing Plants	Nutrients Pesticides Fertilizers (N, P, K) TSS BOD Citric acids
North Stann Creek	North Stann Creek; 1km inland to coast; Dangriga urban area.	Domestic sewage and greywater disposal	TSS Nutrients (Na) BOD Chlorine E.Coli

Catchment	Zone	Reasons	Contaminants
South Stann Creek	South Stann Creek; Locust Bank to Highway and below; Lower slopes.	Citrus orchards.	Pesticides Fertilizers TSS
Monkey River	Swasey Branch; Swasey Stopper Fall to Logans Bank; Valley bottom and coastal plain +-2 km	Banana plantations (particularly Cowpen area)	Fertilizers (N, P, K) Pesticides (Benlate) Alum (Al, K, SO_4) Organic material
Moho River	Rio Blanco; Guatemala Border to Blue Creek; Valley sideslopes.	Milpa production and expansion.	TSS Nutrients

Attempts can be made to estimate the relative loading of the various catchments based on available data wherever possible. Estimations in terms of quantities and quality impacts is not feasible at this time due to the lack of detailed knowledge concerning pollutants, erosion, etc. Over time, it will be more feasible to develop more detailed profiles of actual loading and assimilation/elimination characteristics of the river systems.

3.5.2 Establishing a Risk Index for Belize

One of the stated objectives of the water quality monitoring plan was to develop a contamination risk index for the catchments as a way of understanding the expected dynamics of river contamination in Belize prior to any full-scale field monitoring study, and to help prioritize monitoring efforts with limited resources.

The development of a risk index, in the absence of detailed data on contaminant loading and runoff production, is a subjective process. Nevertheless, adopting a common sense approach and some broadly acceptable assumptions, it is possible to approximate a relative risk index for Belize, one that can be improved over time as the knowledge base expands and deepens. The index can only be used to compare between Belize catchments due to the lack of comparable information for other regions.

The first step in the development of a risk index is the selection of categories. Based on available data, certain broad categories present themselves and include the relative amounts of agricultural land, urban land, land under permanent tree crop and the relative level of industrial activity. These categories can be considered important for the following reasons:

Agricultural Land

Logically, one would expect to see a broad relationship between the total loading of agriculture-derived contaminants such as pesticides and fertilizers, organic materials and sediments and the total area of agricultural land in a catchment, all things remaining equal. Clearly, the actual risk of contamination from a given hectare of agricultural land depends on the type of soils and slope and its location relative to the river systems in the catchment, and the nature of the farming practices and risk involved (for example over-use of chemicals, absence of controlled drainage, return-flows, etc.). This information is not readily available nor could it be easily developed for Belize at present.

Urban Land

Without access to population figures by catchment, the only real indicator of the potential for contamination from domestic wastewater and other urban-related ills such as stormwater drainage from roads and tracks, is the number of hectares devoted to urban land-use. While the actual risk will be more a function of the population density in the urban hectares and the nature of sanitation and other drainage systems, this information is not readily available for Belize at present.

Land Under Permanent Tree Crops

Given the investment made into the establishment of tree crops, both in terms of time and money, and the desire to recoup that investment over future years, there is a tendency for considerable and sustained input of agrochemicals into these land-uses. Moreover, the establishment of many tree crops on hillslopes with poor soils means that there is considerable potential for off-site losses of applied chemicals to water bodies as well as sediment loss associated with the clearing of vegetation and windrowing or other drainage construction. Quantifying the number of hectares under citrus, bananas, mangos, cacao or cashew is therefore a potentially useful risk indicator.

Level of Industrial Activity

Industrial activity is usually a key source of river contamination in developing countries for a number of reasons including the absence of waste treatment systems, the absence of programs of pollution control and fees for contaminant discharge based on strength and volume, the advanced age of many installations and equipment, and the lack of adequate operation and maintenance. Contamination is usually of a point-source nature with recognizable discharge outlets from individual facilities to specific water bodies. Where facilities are located as broader industrial estates which drain into an array of ditches, lagoons and streams, the pollution can approximate a non-point input.

Data on industrial activity and particularly discharge of combined waste streams to water bodies is sketchy for Belize. The Archer (1994) study of land-based sources of pollutants identifies a range of industries but seems incomplete. However, sufficient is known to state that there are clearly three catchments in which industrial sources of contamination are of high potential and where actual contamination as well as risks of future contamination, are taking place. These are the New River, the Belize River and the North Stann Creek. For the other catchments, particularly those in the south, for which little is listed of commercial and industrial sources of waste, risk can be assumed relatively low.

Other potential indicators that could be considered in a risk index and for which limited data is available in Belize include:

Drainage Density

The drainage density in a catchment is an important factor in the dynamics of surface water hydrology and the probability of overland flows generated on the hillslopes reaching a river or stream and thus contributing to the drainage of waterborne contaminants. Moreover, drainage density is often a reflection of the erosivity of the catchment and the potential for sustained production of sediments into surface water bodies. Due to problems of digitization in the GIS drainage files, it has not yet proven possible to generate tables of total drainage length per catchment from which a density number and average flow length could be calculated. This could be performed at a later stage once the GIS drainage files have been cleaned and upgraded.

Average Slope

In any contributing part of a catchment, such as a tributary catchment, the potential for input of indirect, non-point land-based sources of contamination will partly be a function of the slope of the land surface. Clearly there is a complex relationship between slope, soil type, vegetation, infiltration and erosion. However, in tropical zones where there are potentials for saturated zone runoff, slope will be a factor in determining if surface water generated on a particular field, for example, will make it to a stream or river along with its suspended or dissolved constituents. Similarly, slope will help determine the volume and timing of sub-surface runoff. Data on hillslope hydrology and runoff and sediment dynamics for Belize is not well developed.

Distance to the Cayes and Depth of Water Offshore

While these are not indicators of contaminant risk they are factors determining the fate of contaminants washed off the land-surface of Belize. Clearly the closer the barrier islands to the shore and the shallower the water between the islands and the mainland, the greater the potential for a given contaminant plume spreading out from a river estuary of reaching the corals surrounding the island. However, since the movement of the plume will not necessarily be perpendicular to the coastline but will be affected by counter-currents and cross-currents caused by tidal and other circulatory flows, it is difficult to develop a meaningful number for each of the catchments. Planned work by the Coastal Zone Management Unit and Geology and Petroleum will shed more light on the patterns of river-derived contamination in the offshore zone.

Pollution Risk Index

As explained in Annex 1, which presents profiles of the sixteen major catchments, work done at the LIC and through Dr. King has established pollution risk indices for Belize. This represents a crude assessment of the potential for a given area to receive agricultural runoff from an area upslope now or in the future. Since it does not factor in contiguity of land units to water bodies or the size of land areas it probably has little direct meaning in establishing an overall risk index of pollution (King, personal communication).

3.5.3 A Tentative River Contamination Risk Index for Belize

In establishing a tentative, preliminary index of the risk of contamination associated with the various catchments of Belize, four categories were selected: total agricultural activity, urban land-use, orchard land-use and industrial activity. Each catchment is assigned a rating from one to five based on the relative magnitude of these categories. The boundaries chosen for the rating are subjective but provide a useful indication of the broad magnitude of relative risk, as shown in Table 3.9. Further, land use activities are ranked comparably, that is citrus area is equal to milpa area and so forth while there actually may be greater and longer lasting impacts from one land use compared to another.

Based on this preliminary rating system, the majority of rivers are, in relative terms, in the low and very-low risk categories. Using the subjective scores based on broad attributes of Belize catchments, there is a considerable range of risk from very low scores of 4-6, which signify hardly modified catchments, to a high of 18, which signifies relatively extensive land-use and environmental pressures that could lead to water quality impacts. As explained below, the index is weakened by the lack of data on potential inputs from the non-Belize portions of catchments but it is based broadly on the concept of the mass of contaminants available rather than the concentration or transport processes within the catchment. The latter could not be considered because of the lack of adequate data on the discharge from all catchments. While it is possible with the information available on average precipitation and total catchment area to calculate the annual volume of water input, this does not necessarily indicate the expected volume of output because it does not account for the function of relief, vegetation, soils and geology in controlling runoff.

Table 3.9 Tentative Relative Risk Index for Belize Catchments

CATCHMENT	TOTAL AGRICULTURAL LAND-USE	TOTAL URBAN LAND-USE	TOTAL 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	4	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

These data indicate that the higher risk catchments are in the north of the country, with the lowest risks occurring in the south. The three most important catchments, all things considered, are the Belize River, New River and North Stann Creek. Given the relatively large size of the Rio Hondo, it should also be considered of key interest. This is an important observation for coastal zone contamination since there is reported to be a general north-south movement of nearshore coastal water which could lead to contamination on the southern cayes.

Table 3.10 Distribution of Catchment Land in High Risk Land-Uses

CATCHMENT	AREA (ha)	AGRICULTURE	% OF CATCHMENT	% OF TOTAL	URBAN	% OF CATCHMENT	% OF TOTAL	ORCHARD	% OF CATCHMENT	% OF TOTAL
Rio Hondo	267454	57076	21.3	27.9	1145	0.4	16.2	41	0.0	0.3
New River	190731	40563	21.3	19.8	791	0.4	11.2	0	0.0	0.0
Belize River	654857	48134	7.4	23.5	3217	0.5	45.5	1048	0.2	6.5
Sibun River	98701	2547	2.6	1.2	504	0.5	7.1	1542	1.6	9.6
Manatee River	48448	1052	2.2	0.5	5	0.0	0.1	1052	2.2	6.5
Mullins River	15707	799	5.1	0.4	28	0.2	0.4	799	5.1	5.0
North Stann Creek	27932	7383	26.4	3.6	251	0.9	3.6	6230	22.3	38.7
Sittee River	44946	1422	3.2	0.7	66	0.1	0.9	1422	3.2	8.8
South Stann Creek	25792	580	2.2	0.3	130	0.5	1.8	547	2.1	3.4
Monkey River	127558	2769	2.2	1.4	76	0.1	1.1	2769	2.2	17.2
Deep River	34709	102	0.3	0.0	20	0.1	0.3	102	0.3	0.6
Golden River	20414	2636	12.9	1.3	20	0.1	0.3	323	1.6	2.0
Rio Grande	71764	15874	22.1	7.8	225	0.3	3.2	215	0.3	1.3
Moho River	81317	17612	21.7	8.6	405	0.5	5.7	11	0.0	0.1
Temash River	35936	5259	14.6	2.6	180	0.5	2.5	0	0.0	0.0
Sarstoon River	19320	767	4.0	0.4	0	0.0	0.0	0	0.0	0.0
TOTAL	1765586	204575			7063			16101		

* Areas are taken from LIC data generated from individual land-use polygons stored in GIS coverage and do not include land area in Mexico or Guatemala.

Table 3.11 Risk Class Values

RISK CLASS	AGRICULTURE	URBAN	ORCHARD
5	>25000 ha	>2500 ha	>2500 ha
4	10000-25000 ha	1000-2500 ha	1000-2500 ha
3	5000-10000 ha	500-1000 ha	500-1000 ha
2	1000-5000 ha	100-500 ha	100-500 ha
1	0-1000 ha	0-100 ha	0-100 ha

Limitations of the Index

One of the clearest limitations of the risk index, apart from its subjectivity, is the lack of data on the total land-use of the shared catchments with Mexico and Guatemala. No data were obtained on the land-uses from Mexico or Guatemala. It can be expected that in the case of the Moho River, Temash River and Sarstoon River, that there are sizeable areas of land devoted to Milpa and non-mechanized annual crop production. In the case of the Rio Hondo, sizeable areas of urban and non-built up urban land-use as well as annual crops and sugar cane exist on the Mexican side, whereas the Guatemalan portions of the catchment seem to be mostly undeveloped. This is not true for the Belize River which is thought to receive considerable waste from Melchor de Mencos and other towns upstream, especially hospital discharge and sewage (Richard Belisle, Personal Communication). It would be wise to give these catchments special consideration for monitoring, particularly downstream of the national border to determine the incoming water quality to Belize. This sentiment was also expressed in the Public Health Bureau's comments on the draft of this document (Arthurs, correspondence).

To establish full environmental profiles and more inclusive risk indices requires that DOE staff increasingly liaise with their Mexican, and if possible, Guatemalan counterparts for the exchange of information on the patterns of land-use, runoff and the location of known sources of contamination.

3.6 Existing Analytical Capacity

Initial assessment of laboratory conditions and analytical/technical capability within the country was conducted during the week of February 1, 1994. The results are summarized below.

Existing Government Laboratories:

Water and Sewerage Authority (WASA)
Public Health Bureau (PHB)
Ministry of Agriculture
- veterinary lab
- agricultural lab (Central Farms Research Station)

Department of Fisheries

Table 3.12 Summary of Major Laboratory Facilities in Belize

Laboratory	Personnel	Analytical	Approximate Throughput
WASA	2	BOD, COD, FC, misc. anions, cations	100 samples/yr
PHB	2	BOD, FC, misc. anions, cations	600 samples/yr
Veterinary	2	AA, GC,	100 samples/yr
Central Farms	2	AA	500 samples/yr
Fisheries	1	FC	500 samples/yr

(Abbreviations: BOD is biochemical oxygen demand, COD is chemical oxygen demand, FC is faecal coliform, AA is atomic adsorption, GC is gas chromatography)

3.6.1 WASA

The WASA Laboratory is located at the Double Run water treatment plant located approximately 17 miles northwest of Belize City. The treatment plant generates drinking water for approximately 13,000 residents of Belize City and the surrounding area. The treatment process includes clarification, filtration and chlorination. Water from the treatment plant is pumped to the Wilson Street Reservoir prior to distribution. The system was designed to deliver 2.4 MGD annually to 60,000 consumers. Additional water treatment plants monitored by WASA laboratory personnel include:

> Burrell Boom - Located on the Belize River downstream of the Double Run Facility, the Burrell Boom treatment plant consists of clarification, filtration and chlorination of water diverted from the Belize River. Annual treatment volumes are estimated to be approximately 72,000 gallons.

Belmopan - The treatment plant for the city of Belmopan uses the Belize River as a source of water and treatment consists of clarification, filtration and chlorination. The system generates approximately 10,547,000 gallons annually.

Dangriga - The treatment plant at Dangriga uses North Stann Creek as its water source and treatment consists of clarification, filtration and chlorination. The system generates approximately 7,361,000 gallons annually.

Corozal - The water distribution system in Corozal consists of a series of central groundwater pumping stations followed by chlorination. Annual volumes generated by the plant are approximately 9,816,500 gallons.

Orange Walk - The water distribution system in Orange Walk consists of a series of four central groundwater extraction wells followed by chlorination. Annual volumes generated by the plant are approximately 11,310,000 gallons.

Benque Viejo - The water treatment system for Benque Viejo uses water from a spring located near the Mopan River. Treatment consists of chlorination and generates approximately 2,389,710 gallons annually.

Punta Gorda - The water distribution system in Punta Gorda consists of a series of three groundwater extraction points followed by chlorination. Annual volumes generated by the plant are approximately 5,184,000 gallons.

San Ignacio / Santa Elena - The water treatment system for San Ignacio uses water from a spring located near the Belize River. Treatment consists of chlorination and generates approximately 13,008,000 gallons annually.

Hattieville - The water distribution system in Hattieville consists of groundwater pumping followed by chlorination. Annual volumes generated by the plant are approximately 25,000 gallons.

San Pedro - Water treatment at San Pedro uses groundwater pumping and seawater as sources. Treatment consists of aeration, filtration and reverse osmosis. The system generates approximately 2,146,343 gallons annually.

The laboratory personnel consist of two technicians: Mark Menzies and Beverly Clare. Menzies indicated that he has been on staff at WASA since 1986 and has received training in Jamaica. Clare indicated that she had been previously employed by PHB (laboratory technician) and has been on the WASA staff since 1990. Clare also indicated that she had received a 3 month training course at Johns

Hopkins University.

The main function of the laboratory is the water quality monitoring of WASA treatment plants and supply systems. Each of the nine water treatment plants listed above are monitored on a monthly basis. The WASA document titled "Sampling Frequency for Urban Communities" indicates a higher frequency of sampling is required (e.g. 4 chemical samples per month from the Double Run treatment plant), but the technicians indicated that each system was, in general, monitored only once per month. Data forms provided by WASA for various locations indicate inconsistent monitoring or incomplete reporting of sampling events.

The technicians are responsible for field sampling as well as laboratory analysis for each of the nine WASA treatment facilities. Transportation to the field locations consists of public transportation and air transport to remote locations (Dangriga, Punta Gorda and San Pedro). Samples are generally taken in 250 ml polyethylene or 1,000 ml glass bottles. Monitoring consists of grab sampling at points within each drinking water system. Integration devices are not used. Transport of samples includes preservation to 4°C (i.e. insulated container and freezer packs). No chemical preservatives are added to samples.

Parameters Analyzed

pH - electrometric (lab only)
temperature - (lab only)
Specific conductance - (lab only)
Residual Chlorine - HACH (all sites)
Turbidity - HACH (all sites)
Alkalinity - HACH (all sites)
Color - HACH DR2100 vis spec. (all sites)
Al^{3+} - HACH (all sites)
Fecal and total coliform bacteria - filtration method (all sites)
Chlorides - HACH (all sites)
Hardness - HACH (all sites)
Nitrate - HACH DR2100 vis spec. (all sites)
Sulfate - HACH DR2100 vis spec. (all sites)
PO_4 - HACH DR2100 vis spec. (all sites)
Fe (total) - HACH DR2100 vis spec. (all sites)
F - HACH DR2100 vis spec. (all sites)
H_2S - HACH (San Pedro only)
BOD - HACH 2173B manometric
COD - HACH currently not in use

Miscellaneous Laboratory Equipment

Deionization column
Incubator / Desiccation oven (Fisher Scientific 630D)
Autoclave
Filtration equipment
Magnetic stirrer
Stereomicroscope
APHA 11th and 16th edition
"Procedure Manual for the Bacteriological Examination of Potable Waters" David Bromley Engineers

Analytical equipment at the lab consists of HACH digital titration and HACH DR2100 visible spectrum photometer. pH, EC and DO meters by HACH. Laboratory manuals for the operation of this equipment are maintained in the laboratory and are used as the laboratory protocol. A full laboratory inventory was requested from WASA but was never received.

Quality Control/Quality Assurance

Minimal quality control/quality assurance practices are followed (e.g. split samples analyzed separately by different technicians are compared) but documentation or written procedures are essentially non-existent. Field blanks, trip blanks or spikes are not used. The technicians indicated that calibration of instruments (conductivity, pH) is completed prior to use but information regarding calibration not recorded. Calibration protocol is included in instrument manuals which are available at the lab.

Chain of custody (COC) procedures are currently not in use by the lab. Since the lab technicians currently complete the sampling and analysis, strict COC is not considered necessary.

Data Management

All laboratory results (including minimal QA/QC information, e.g. incubation times and temperatures) are maintained in the technicians notebooks for later transfer to monthly summaries. Analyses completed by the laboratory are compiled on a monthly basis and stored in hardcopy form in file cabinets in the laboratory and at WASA headquarters in Belize City. There has been some indication that inclusion of the WASA data into the PHB data management system may be undertaken in the future.

The technicians indicated that all exceedances of WHO drinking water standards are reported immediately to WASA engineers through verbal communication. Documentation of standard exceedances are maintained only in the monthly lab reports (i.e. incident reports do not exist).

Miscellaneous

The technicians indicated that a monitoring program for sewage treatment plant effluent (Belize City and Belmopan) had been attempted in the past but data was irregularly collected (based on personnel availability, weather conditions, etc.). Analyses associated with this program included BOD and dissolved oxygen (DO). The technicians indicated that DO was taken as a field measurement using a HACH electrometric method. Technicians indicated that monitoring generally consisted of BOD measurements between aeration lagoons within the treatment plant and did not include effluent monitoring. Data associated with this program was not observed.

Tour of the Double Run Treatment Plant indicated that the water samples taken from the Belize River were taken from the intake well prior to treatment process. Sludge from the water treatment plant is discharged to the Belize River downstream of the treatment plant intake approximately twice daily. Volumes of sludge discharge are not recorded. Sludge chemistry is not included as a monitoring parameter.

Other WASA operated treatment systems were not observed during the preliminary visit.

A limited quantity of data from WASA may be of interest to the Department of Environment as intake water quality is monitored at Double Run and Burrell Boom (Belize River) and Stann Creek at Dangriga but, sampling procedures do not include integration with depth or width. Graphic display of data collected as part of the intake monitoring program has been generated in the past by WASA technicians (e.g. nitrate concentration over time Belize River).

The WASA Laboratory is apparently available for contract lab work. Interviews with PAHO personnel and Department of Health and Department of Environment indicate that WASA is operated as a pseudo-private utility and laboratory services associated with an environmental water quality monitoring plan may be available on a contract basis only. The technicians indicated that the WASA Lab has been contracted to complete the analyses for the Miller and Miller Report regarding industrial effluent within Belize.

3.6.2 Public Health Bureau

The PHB Laboratory (established circa 1987) is located in Belize City at the Department of Health building and was built and equipped largely with funds from USAID. The main function of the laboratory is the monitoring of drinking water supplies in Belize, including monitoring of WASA supplied households as a check of water quality from areas serviced by WASA and random monitoring of hand pumps in areas not serviced by WASA. The lab is partially funded by PAHO who have financed minor improvements.

The facility personnel consist of two technicians: Anthony Flowers and Stephanie Flowers. Lab technicians are responsible for a minor quantity of the monitoring but generally rely on Public Health Inspectors (PHI) located in each of the six districts for monitoring (see below for general discussion of PHI responsibilities). Sampling by PHIs is coordinated through the lab (i.e. phone call) and sampling equipment is delivered to the field by public transportation. The samples are returned to the lab by public transportation and picked up at the bus station or airport by PHB staff. Receipt of the samples is not recorded. In the event that PHB personnel are not available for the receipt of samples, the lab packs remain unattended until lab personnel are available. Lab pack seals or chain of custody documentation were not observed during the visit. The technician indicated that chain of custody procedures are not currently used by the lab.

The main parameter of concern to the PHB is coliform bacteria and the laboratory processes approximately 30 samples per month. The laboratory is probably capable of processing a much higher volume of samples, but lack of field support for the collection of samples precludes additional analyses. Sample scheduling is the responsibility of the lab technicians and is currently coordinated by Anthony Flowers. A vehicle is available for use by the technicians for monitoring purposes and is used typically for monitoring in and around Belize City.

Parameters Analyzed

pH - electrometric HACH (field and lab)
temperature - (field and lab)
Specific conductance - (field and lab)
Residual Chlorine - HACH digital titration
Turbidity - HACH DR2000 variable spectrophotometer or Turbidimeter
Alkalinity - HACH digital titration
Color - HACH DR2000 visible spectrophotometer
Al^{3+} - HACH digital titration
Fecal and total coliform bacteria - filtration method
Chlorides - HACH digital titration
Hardness - HACH digital titration
Nitrate - HACH DR2000 visible spectrophotometer
Sulfate - HACH DR2000 visible spectrophotometer
PO_4 - HACH DR2000 visible spectrophotometer
Fe (total) - HACH DR2000 visible spectrophotometer
F - HACH DR2000 visible spectrophotometer
H_2S - HACH
BOD - HACH Manometric
COD - HACH (currently not in use)
Cholera - binary indicator method "Moore swabs"

Miscellaneous Laboratory Equipment

Stereomicroscope
Autoclave
Vacuum pumps
Desiccation oven
Incubator
Access to deionization column in medical facility
Imhoff cone (indicated in lab inventory, not observed during interview)
APHA 18th Edition

Analytical equipment and procedures are very similar to that of the WASA laboratory. Laboratory protocols consist of HACH operation manuals.

Quality Control/Quality Assurance

Laboratory staff are in the process of drafting a Quality Assurance Manual to ensure effective management of the laboratory operations.

3.6.3 Fisheries

The fisheries lab has been established primarily for the analysis of fish exports from the fisheries industry in Belize. The main concern of the fisheries lab are various aquatic bacteria. The lab is staffed by a single technician (Lloyd Parriot BS. Biochemistry University of Michigan). Specific analyses include:

Standard plate count
Total coliform bacteria
E. Coli
Clostridium
Staphylococcus areus
Salmonella
Fecal coliform
Shigella

Laboratory Equipment

Incubator
Autoclave
pH meter (Fischer) - lab only
Unicam UV spec (non-functional)

Deionization column
Stereomicroscope

The lab technician is responsible for sampling tissue prior to the export of seafood products. According to the lab technician, the fisheries department assumes all costs associated with this monitoring program. Aqueous samples have not been analyzed at the fisheries lab in the past and the lab currently has minimal capacity to analyze water quality samples.

The fisheries lab (in conjunction with Coastal Zone Management) is due to be upgraded within the next two years and general plans for construction of the lab have been developed. The current plans for the lab include administration by Lloyd Parriot (currently of the fisheries lab) and a soon to be appointed marine chemist. The intent of the lab is to provide analytical capabilities to Coastal Zone Management. An equipment inventory was requested but never obtained.

3.6.4 Agricultural Labs

The Ministry of Agriculture operates two laboratories, the veterinary lab and the Central Farms soil laboratory:

<u>Veterinary Lab</u>

The veterinary lab, located in Belize City, has probably the most modern equipment in the country. However, the operational status of the equipment is unknown. The technician (Wilfred Pascascio) at the lab indicated that the lab capacity had been 5,000-6,000 samples per year but was currently operating at fewer than 100 per year. If the Vet lab is to be considered for use in the Environmental Monitoring Program, a detailed study of the equipment and facilities is required including cost analysis for the repair of the equipment. Documentation concerning laboratory inventory and analyses was requested from the Ministry of Agriculture but not received to date. It has been suggested that it would be difficult for the Pesticide Residue Section of the Vet lab to be used for analyzing water quality, although the Bacteriological and Elemental Analysis sections may serve for this purpose (Fernandez, written comments).

<u>Central Farm</u>

The Central Farm lab was established for the analysis of agricultural soil samples but lab personnel indicated that aqueous samples could be accommodated easily.

Facilities consist of:

extraction equipment
Perkin-Elmer 1100B AA - lamps available: Ca, Mg, Cu, Zn, Fe, Al, Mn (note: nitrous oxide

and acetylene sources are apparently not a concern, standard solutions are mixed by Mario Fernandez)
Flame photometer
Ash oven
Selective Electrode method (Chlorides)
Water distillation (Barnstead)
Halstead spectrophotometer (K analysis)

The lab is staffed by 3 technicians and assisted by Mario Fernandez (M.S. Chemistry - N.E. Louisiana University). The lab technicians have been on staff at the lab for several years. Mr. Steve Bejos, Senior Technician, recently completed training in Mexico. Ms. Deliah Cabb is currently training at the University of the West Indies, Jamaica in soil chemistry (B.S.) and should return in 1998. Laboratory protocols, QA/QC procedures and data management systems have not been developed. Laboratory protocols consist of operating manuals for the instruments.

The lab is operated on a contract basis in which private parties submit samples to the lab for nutrient analysis ($4-5 fee per sample).

General Discussion Agricultural Laboratories

In general, the Central Farm Lab and the Veterinary Labs are the best equipped laboratory facilities in the country. Both of these labs are underutilized and may accommodate the requirements of an environmental water quality monitoring program if sufficient resources are made available for laboratory improvements. Inventories of equipment for both labs were requested but not received.

3.6.5 Coastal Zone Management

Coastal Zone Management has initiated a program to monitor marine water quality. The program appears to be in the initial stages as the data collection is irregular in schedule. The technician (Eldridge Castillo) has apparently received training from the HACH Laboratory in Loveland, Colorado.

Equipment consists of a HACH field testing kit. Field analyses are recorded on field data collection forms and maintained in hardcopy form in the fisheries department. Sampling events are coordinated with either the PHB lab or the Fisheries lab (whichever has available time and equipment). Sampling protocols and QA/QC procedures have not been developed.

The CZMU technician typically uses the PHB lab for analysis and conducts all of the analytical work associated with the CZMU program. Laboratory data are entered into a spreadsheet program (LOTUS) and maintained in files at the Fisheries department.

Future Developments

One of the stated goals of a UNDP-funded research project on the management of the physical resources of the Belize coastal zone is to develop a nearshore mathematical circulation model (UNDP, 1994). At the project planning stage, UNDP have already recommended that the research program be amplified to include sampling of water quality variables and processes aimed at expanding the nearshore model to include a water quality component. They have proposed the inclusion of the following chemical, ecological and chemical sediment variables in UNDP/GEF (hence CZMU) activities:

- chemical: dissolved oxygen, nutrients (nitrite, nitrate, phosphate, total-phosphorous and total-nitrogen), heavy metals (zinc, cadmium, lead, copper and chromium)
- chemical sediment: heavy metals (zinc, cadmium, lead, copper and chromium), loss on ignition, total-nitrogen and total-phosphorous
- ecological: chlorophyll-a, phytoplankton, zooplankton

This would require significant expansion of laboratory and human resources.

3.6.6 Other Laboratories

The PAHO Report "Assessment of Water Quality Analysis Capability of Laboratories in Belize" (de Esparza, 1993) indicates the existence of several private laboratories within Belize (e.g. Citrus Company of Belize, Belize Brewing Company, etc.) which may be available for use in a self monitoring program. Promulgation of regulations containing a self monitoring program has apparently been considered but it is unclear if the regulations will contain laboratory certification of any type.

Forensics Lab

Mario Fernandez (Agricultural Lab) indicated the existence of an operational gas chromatograph at the forensics lab in Belize City. This lab is not identified in "Assessment of Water Quality Analysis Capability of Laboratories in Belize".

3.7 Institutional framework

The Belize water sector is clearly going through significant changes. Historically, this sector has been characterized by a disaggregation of responsibilities, formal and informal, based on a series of legal enactments and implementing institutions, replete with several overlaps and omissions. This context was formally described and presented by the Belize Minister of Natural Resources in his august presentation to the PARLACEN meeting, Guatemala (GOB, 1994a).

As stated by Juan (GOB, 1994a), data on water quality are collected by the National Hydrological Service, WASA, and the Meteorology Department of the Ministry of Energy and Communications. The collection of data and information on water quality is the responsibility of the Ministry of Health, the National Hydrological Service, WASA, the Rural Water Supply and Sanitation Department, the Department of Environment, and the Fisheries Department of the Ministry of Agriculture and Fisheries. As indicated in Annex IV of the Draft National Environment Report (GOB, 1992b), there are up to 20 agencies in Belize that carry out some form of water testing. All the equipment necessary to carry out even the most detailed of laboratory analysis such as atomic absorption spectrophotometers and gas chromatographs are available in the country.

Much debate has been presented in various reports concerning water quality monitoring and ongoing initiatives. In the opinion of FAO Consultants contracted to evaluate the Belize water sector (FAO, 1994), a fully-fledged water entity is necessary for the Belize government, one that can consider all matters related to water resources and their management, and they recommended the delegation of certain duties and powers away from the DOE to this new agency. One of the suggested functions of this new water entity would be the protection and monitoring of the quality of water resources, with a water quality protection section responsible for developing and operating systems for their monitoring. The DOE would be left with few, if any, direct responsibilities in the field of water resources, their planning, protection and control, having only an advisory function as one of 12 members of the suggested water new agency. Resources Minister Juan stated at a recent regional meeting in Guatemala (GOB, 1994a), that it had been recommended that major water management functions, including control of water pollution, be entrusted to a strong Belize National Water Commission operating under the supervision of the Ministry of Natural Resources. Since this meeting, the Belize National Hydrological Service was transferred to the Ministry of Science, Technology and Transport.

Clearly, many agencies have interests in the measurement and use of water quality data. A key issue over the coming years will be whether the Belize government can unify these interests and overcome a natural tendency for fragmentation and rivalry between institutional elements historically used to acting relatively independently to meet their individual information needs. Clearly, this project must remain aware of ongoing developments in the water sector, for example the prospect of a unifying water commission and changed or new legislation, as well as bearing in mind the existing situation, particularly the stated aims of NARMAP and the EPA. The project must also consider the recommendations and ideas put forward by other consultants in the question of water quality, notably the PAHO (de Esparza, 1993) and FAO (FAO, 1994) specialists. However, the current study represents the only attempt designed to evaluate the complete contextual issue, including the technical and environmental context and not just the laboratory or institutional. This project is to take a holistic, cross-cutting view of the Belize situation and lead to concrete, scientifically based decisions as to how, why, where and who should carry out the water quality monitoring and for whom and with what result.

Newell (1993), working on a UNIDO financed project for the DOE, recommends that a suitable water quality testing laboratory should be established within the DOE whereas Harrison, working on a FAO project for the nascent Water Commission, recommends the upgrading of the Public Health laboratory in Belize City to handle more rigorous analytical efforts to monitor the water quality of the nations rivers and report to the Water Commission. Clearly a solution will need to be found that takes best advantage of the resources available, physical plant, equipment and trained personnel.

Comprehensive water legislation, in the form of a Water Act, is currently being formulated for presentation to the National Assembly (GOB, 1994a). How this will relate to the current EPA and what components it will include is not clear. Other significant developments include the CEDS project, coordinated through the LIC, designed to establish a comprehensive, systematic database of environment and conservation data into which, theoretically, the majority of Belize's governmental and non-governmental agencies will deposit, manage and exchange data of mutual significance. The question of water quality data management and particularly interpretation and application is discussed in the protocol manual associated with this report. Any component of CEDS designed to accept results from the proposed water quality monitoring program should bear the considerations discussed in this manual in mind.

A potential difficulty exists in relation to the Hydrology Department in that although the technicians have been well trained by Mr. Panton and apparently perform field work well, they have not been similarly trained in hydrological information management and interpretation nor in the planning and implementation of a hydrological network, rather in the narrower day to day collection of data and maintenance of equipment. Mr. Panton is clearly the decision-maker in the hydrological service. There appears to be no clear successor to Mr. Panton and the short-term consolidation of existing monitoring stations, their integration into a water quality framework and the development of new stations could be undermined unless steps can be taken to prepare someone to assume Mr. Panton's role upon his retirement. Apparently (Panton, personal communication), it is planned that one of the Hydrology Service technicians will leave for training in 1995 and undertake a Bachelors degree in the hydrological sciences. It should be suggested that this person concentrate also on water quality and environmental monitoring and sampling ready to take an active and integral part in the long-term implementation of the water quality monitoring program in Belize.

Note that during the review session associated with the draft copy of this report that it was suggested that from a national perspective, that the Hydrology Department become part of whichever organization takes ultimate responsibility for water quality monitoring, DOE or the Water Commission, rather than continue to be part of the Ministry of Science, Technology and Transport into which it was reshuffled at the end of 1994. Its expertise and services could be more easily incorporated and coordinated, therefore, into the efforts to develop a full and efficient monitoring scheme for water quality and quantity. Since it is logical to use selected National Hydrological

Service stream gauging network sites as a starting point for the coordinated Belize environmental water quality monitoring program, and that stream discharge measurements are a key component to a successful program, the National Hydrological Service should be empowered to assume a leadership role in the program through attention to the educational needs and successional logistics of its personnel.

It was concluded from the laboratory review that no single laboratory is adequate to conduct and coordinate the full range of analyses necessary to fulfil an environmental water quality monitoring program, although Belize is relatively well endowed with equipment and trained personnel. Because of the dispersed and duplicate nature of facilities, it is recommended that a single laboratory be formulated in which human and financial resources can be best invested to meet national needs. This independent laboratory would be officially approved and certified as to its quality assurance and quality control procedures and its data management, and would be supported by laboratory users according to their use, through budgetary allocations by individual ministries and departments and sample fees.

This move would require efforts to foster the institutional flexibility that will allow water quality samples to be efficiently analyzed by one laboratory for a range of ministries, non-governmental organizations and other interested parties. Already at a small scale this arrangement exists between CZMU and Public Health and appears to be functioning well, with coordinated use and ordering of laboratory reagents and the out-of-office hours use of facilities by the trained CZMU technician. Other Belize laboratories do not appear to have experienced problems offering contract services to external parties, including Central Farms and WASA. A formalized mechanism for inter-agency billing and collection will help increase the Belize analytical capability but will first require the development of a memorandum of understanding between all Belize ministries to identify individual and collective roles with respect to water quality monitoring. This will require discussions at the level of Permanent Secretary and above.

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4.0 Water Quality Monitoring Station Selection

Knowledge of the system to be monitored is critical to sample site selection. Site and study specific factors that should be included in the sample site determination:

- Accessibility - access to any sampling site is directly related to monitoring program cost. Bridges are frequently chosen for establishment of water quality monitoring stations due to access during most flows and they permit sampling at any point across the stream width.

- Safety - monitoring of turbulent streams or during peak flows can be of safety concern for monitoring personnel. Monitoring locations should be chosen that allow sampling at peak flow with minimal risk to sampling personnel.

- Discharge Measurement - Department of Hydrology gauging stations should be used as sampling locations wherever practical and logical. In locations where gauging stations are unavailable for stream discharge measurements, selection of sampling locations may be dictated by criteria recommended for selection of field discharge measurement. Since stream discharge is a calculated value based on velocity and cross sectional area, site location in an area of minimal channel complexity and uniform flow velocities will yield more accurate discharge determinations. In general, relatively straight stream reaches free of mixing zones or zones of high turbulence are preferred. Particular areas to be avoided include: immediately downstream of bridges or confluences.

- Presence of tributaries - stream reaches immediately downstream of a tributary should be generally avoided. Typically, a distance of 5 stream widths below the influence of a tributary is adequate distance to ensure mixing.

- Degree of mixing - complete vertical and lateral mixing within the cross section is generally desirable. Presence of point or non-point discharges of contaminants to the stream should be considered in the determination of monitoring location.

- Presence of industrial or non-point source contamination to surface or groundwater. Also included are areas of potential future development.

For riverine systems, the quality of water flowing past the sampling location is related to upstream conditions. Under ideal sampling conditions, a sample taken at any point in a stream cross section will be of identical concentration to any other taken in the same cross section. Similarly, a sample taken at a point at a given time will yield an identical concentration of any constituent to a sample taken at any other time. Selection of a sampling location to maximize the reproducibility of the sample is critical. Monitoring personnel must therefore not only be familiar with the system as a whole but also familiar with mixing characteristics, fluvial sediment transport, deposition and chemical sorption phenomena.

The concept of establishing catchments as basic planning and monitoring units appears well established in Belize. Recent planning efforts to develop a national water commission, body or agency has promoted the idea of adopting catchment management for all water resources, based on river basin plans, with its own policies and priorities (GOB, 1993c). Clearly, a major step to establishing those independent policies and priorities is establishing the nature of observed risks and problems within each catchment through the adoption of a monitoring program that incorporates each basin. A major objective of a water quality monitoring program for Belize, therefore, is to establish baseline water quality conditions within each major catchment within Belize. Subsequent water quality data can then compared statistically to the existing data and the conclusions used to assess trends in water quality. This approach provides information that can be used in land use management decisions and provides information regarding the general state of the riverine ecosystem. In cases of currently degraded water quality, it may be necessary to sample the stream at a number of points along the affected portion to identify sources of contamination.

It is important to choose sampling sites that will minimize the "masking" effect of extraneous inflow from tributaries. Avoid sampling streams at points, such as backwaters, that are not representative of the main body of flowing water. If streaks or swirls of sediment or color are apparent in the flowing stream, include a representative portion of each in the sample. Prior planning with maps and a sampling outline will often reduce effort and prove more effective, especially when multiple samples are to be collected at various locations.

4.1 Proposed sampling locations

The proposed sampling locations will establish a monitoring network for Belize. These sampling locations will help assess water quality for:

- the major tributaries and the main channels of the rivers of economic and ecological (particularly related to coastal freshwater discharge) importance. By default, this will provide a well stratified, background assessment of contamination levels in natural water bodies due to natural and anthropogenic contamination.

- locations above and below areas of current and future importance as potential sources of anthropogenic contamination. This is designed to keep track on specific, known contaminants and their critical zones of origin and helps to focus available resources and feed information to specific environmental policy areas.

Due to resource limitations and the need to develop in phases the monitoring capacity of Belize, each of these two objectives will necessarily require a strategic and gradual expansion of capabilities and stations over time. Clearly, in terms of a water quality monitoring framework designed to meet the dual needs of background water quality determination and environmental management decision-making it makes sense to select sites that can function for multi-purpose monitoring. One way to facilitate this is to utilize the existing framework of major and minor roads across Belize and their points of intersection with major rivers and their tributaries as the locations for major sampling points. Note that already, many of these intersections have been chosen as the natural site for river flow gauging sites by the Belize Hydrological Service. They give the advantage of easy and relatively good access, low costs to prepare the site for physical sampling, and certain geographical conditions that can be used to good natural advantage in stratifying the sites. In particular, along the coastal plain from Belmopan down towards Punta Gorda, the major highway system skirts along the hilly limestone fringe, crossing major rivers and creeks at their outflow points and thus represents a transition location between upland contributing areas and coastal floodplain morphology where conditions of flow and quantities of runoff received differ greatly.

In a discussion of sampling site locations, it is pertinent to review the Belize Hydrological Service and the work done already in establishing sampling locations of water as an environmental variable. It is also pertinent to consider initiatives established by the Coastal Zone Management Unit.

4.1.1 National Hydrological Service

The long-term goals and objectives of the Hydrological Service of Belize are to:

1. Establish gauging stations on each of the major river systems of Belize based on the twin limitations of accessibility and continuity (i.e. the availability of willing gauge caretakers and readers)

2. Prioritize the installation of those gauging stations based on their considered importance for economic development in Belize (as sources of water and/or risks of flood damage)

3. Establish sufficient gauges so that hydrologically, each river system would monitor the conditions in each major tributary and/or, hydrologically speaking, the upper, middle and lower portions of the catchment.

The Hydrology Service inherited a series of over 25 gauging stations established by various British Government Hydrologists during the colonial period. For a variety of reasons, many of these sites have been allowed to lapse, especially during the mid 1980's, although several new ones have been added.

On the basis of the incremental goals listed above, Hydrology Service technician Mr. Williams has prepared a preliminary listing of additional gauging stations proposed for each of the major catchments. Currently, this listing stands as the blueprint for continued expansion of the network but has not been assessed as to its suitability nor its logistic requirements. Since the Hydrological Service is in the process of improving its equipment inventory, particularly through the acquisition of 10 data loggers to automate gauging stations, expanded monitoring by the Hydrologic Service is imminent. This is further supported by the pending acquisition (already budgeted) of two new water flow meters (Teledyne-Gurney) and a 4wd vehicle which will allow two Hydrology field teams to function independently, one north of Belize City and one south of Belize City.

The Sarstoon River and Temash River are perhaps the most difficult to monitor due to their inaccessibility. While it is possible to access these rivers by boat, perhaps by CZMU, the feasibility of arranging this as part of a regular monitoring schedule needs to be considered. While both DOE and Hydrology have possession of a small towable boat with outboards, the use of this equipment is time-consuming and subject to:

1. The presence of an adequately skilled boat handler (this would require training of sampling staff).
2. Appropriate weather and water conditions - note that it is not known how these boats fare in stormy sea conditions or on rivers swollen to flood stage.
3. Sufficient time in the national sampling cycle to allow for the transportation of the boat, launching, travel time, sampling, return and delivery of the samples to the selected laboratory.

Hydrology field staff suggest that road access is feasible as far south as Aguacate and Santa Theresa although the network of interconnecting roads marked in red on the 1:250,000 Belize maps do not exist in the Toledo District. Moreover, Hydrology staff have reached as far as San Lucas and Otoxha by car and are confident that, at least at certain times of the year, it is possible to reach Barranco. They have previously reached Sunday Wood. It is also possible to take a light aircraft to Barranco and other key southern towns where local transport, either car or boat, could be arranged. The relative costs associated with the two options in terms of airfares, labor and local transport costs versus vehicle wear and tear, petrol, overnight stays and labor costs would need to be compared closely.

Since the CZMU already take samples along the coastline from a boat, using a trained boat captain (PAHO, review correspondence, 16/2/95), it is possible that they could be coopted to take samples from the Sarstoon and Temash (or other rivers, see following section). This would require inter-ministerial coordination and appropriate budget management.

Preparing new field sites for monitoring is likely to be expensive. The estimated the cost of each new hydrological gauging station is approximately US $13,000, including the construction of a stilling-well gauging apparatus, stage posts, access and equipment installation (Panton, personal communication). This does not include the costs of first-year frequent sampling at different flood stages to establish a stage-discharge relationship for the site. It also does not include the cost of establishing a year-round sampling and flow measuring infrastructure at non-bridge sites (boat and cable system, cable walkway or footbridge gantry). It is important that each water quality monitoring location also involve measurements of flow discharge to correlate with contaminant concentrations. The simplest way to do this is establish a reliable stage discharge relation for the permanent site, after which it is only necessary to measure flow depth through the known profile, with periodic discharge measurements to confirm the relation.

4.1.2 Coastal Zone Management Unit

The CZMU has recently developed proposals for a fully-fledged water quality monitoring plan for the Coastal Zone Management Unit (van de Kerk, 1994a). The plan has two main categories: monitoring the water quality and monitoring the general biological health and status of the coral reef community. The main emphasis of the water quality data is designed to address the cause and effect relationships between pollution and the currently unknown:

- nutrient loadings in rivers from plantation agriculture such as cacao, citrus and bananas in the south of the country
- pollution from human developments in coastal areas
- effects of sugar factory effluent

The current river marine outflow sites for CZMU monitoring include (van de Kerk, 1994b):

- Belize River: site near bar at center of river outlet
- Haulover Creek: at beginning of Burdon Canal
- Sibun River: upstream at the first major confluence
- Sibun River: center of river outlet
- Manatee River: upstream at the first major confluence
- Manatee River: at the river outlet
- Quamina Creek: upstream
- Quamina Creek: at the river outlet
- Mullins River: at the river outlet (bar)
- Sittee River: at the river outlet (bar)
- North Stann Creek: at the river outlet

For some of these sampling sites, up to three years of sample data have been collected, at a frequency of around one per month to one per quarter.

Other riverine sites listed as priority which the CZMU wish to include in a monitoring program of water conditions include:

- Monkey River: concern over agrochemical runoff
- Deep River: largely pristine basin to use as comparative data
- Rio Grande: concern over agriculture (sediments) and domestic waste
- Moho River: concern over agriculture (sediments) and domestic waste

4.1.3 Use of Existing Monitoring Sites

The monitoring network in Belize should ideally utilize to the extent possible and logical the existing hydrological monitoring network stations as water quality monitoring points to established background water quality. Samples at additional, new gauging sites (i.e., suitable for taking measurements and feasible for calculating discharge through profile dimension and velocity measurements) can be selected on the basis of filling gaps in the existing network (to provide the appropriate level of background quality sampling) and focussing attention on certain critical zones identified during this analysis both to check assumptions and confirm whether the site should be made permanent stations. Based on information collected by the consultants and a study of the hydrological networks of Belize and distribution of high contamination risk sites, a list of preferred monitoring sites have been established using the criteria listed (Table 4.3). The ultimate decision on monitoring sites should be made as a collaborative and consultative process between the interested parties in the collection and use of river water quality data, principally the DOE, National Hydrological Service, the Coastal Zone Management Unit and probably, WASA. For example, it might make sense for the monitoring of coastal lagoons to be maintained as a task to be conducted by the CZMU as is the case at present.

Table 4.1 Hydrological Network Operated by Hydrological Services

NAME	LOCATION	OBSERVATIONS
Tower Hill	New River. Northern Highway. Toll Bridge Site.	Tidal influence. Low velocity. Difficulties experienced in establishing useful rating curve and measuring Q. Only station on river.
Rio On, Belize River, Macal Sub-Catchment.	Old logging road off Western Highway and Checkable Rd. Wading Site.	Difficult access. Small river with low discharge (normal 1 m^3/s or less). Possible value as comparative quality indicator. Rating curve established.
Cristo Rey	Belize River, Macal sub-Catchment. Turn-off road SE from San Ignacio. Wading or boat site.	Easy access but enormous flow-range (+15m). Requires boat for profiling or construction of walk or cable-way at high flows. Quantifies Macal sub-catchment. Rating curve established.
Benque Viejo	Belize River, Western Branch (from Guatemala). Western Highway. Bridge site.	Accessible site. No special conditions. Quantifies flow from major Guatemala sub-catchment. Rating curve established.

NAME	LOCATION	OBSERVATIONS
Banana Bank	Belize River, Main Channel. Dirt road north off Western Highway near Belmopan. Ferry (boat) site.	Accessible site. Boat and cable but inadequate for peak flows. Downstream of Roaring creek and Spanish Lookout tributaries and main agricultural belt. Rating curve established.
Big Falls	Belize River, Main Channel. Road north off Western Highway. Ferry site.	Close to Bermudian Landing site. Few expected changes in between. Can eliminate one or other. Perhaps eliminate both in favor of Double Run. Rating curve established.
Bermudian Landing	Belize River, Main Channel. Reached via Burrell Boom (connections from Northern or Western Highways). Ferry site.	See above. No rating curve established as yet. Data sufficient to do so.
Double Run	Belize River, Main Channel. Access via Treatment Plant road from Northern Highway. Bridge/gantry site.	Located at treatment plant intake. Last free-flowing station before sea. Important quality site. Rating curve established.
Freetown Sibun	Sibun River, Main Channel. South from Western Highway at Hattieville. Boat site.	Quantifies most of catchment prior to lagoons. Only station. Rating curve established.
Kendall Bridge	Sittee River, Main Branch. Southern Highway. Bridge site.	Excellent access. Captures agricultural activity inland of highway. No rating curve established as yet.
South Stann Creek Bridge	South Stann Creek, Main Channel. Southern Highway. Bridge site.	Excellent access. Captures agricultural activity inland of highway. Rating curve established.
Swasey Bridge (near Logans Bank)	Monkey River, Swasey Branch. Southern Highway. Bridge site.	Excellent access. Captures agricultural activity inland of highway. No rating curve established as yet.
Bladen Bridge (near Melvins Bank)	Monkey River, Bladen Branch. Southern Highway. Bridge Site.	Excellent access. Captures agricultural activity inland of highway. No rating curve established as yet.
Medina Bank	Deep River, Main Branch. Southern Highway. Bridge Site.	Excellent Access. Captures hill catchment runoff but not conditions after the significant coastal portion. No rating curve established as yet.
Hellgate Village	Golden Stream, Main Branch. Southern Highway. Bridge Site.	Excellent Access. Captures runoff from hilly zone. No rating curve established as yet.
San Pedro	Rio Grande, Columbia River Branch. Road north at Southern Highway turn to Punta Gorda. Bridge Site.	Good access. Captures broad interior catchment runoff from major tributary system. Rating curve established.

NAME	LOCATION	OBSERVATIONS
Big Fall	Rio Grande, Main Branch. Southern Highway. Bridge site.	Good access. Captures hillside runoff but is upstream from sizeable coastal section. Few expected differences to San Pedro. Rating curve established.
Blue Creek	Moho River, Blue Creek. Minor roads connecting to Southern Highway. Bridge site.	Captures interior sub-catchment runoff. Characterizes largely undeveloped conditions. Rating curve established.
Jordan Village	Moho River, Main Branch. Minor road west from Southern Highway. Bridge site.	Measures most of catchment runoff just before main coastal section. Probably no feasible site closer to sea. Rating curve but doubts about suitability.

Table 4.2 Potential Best Sites for Overall Catchment Quality Characterization

RIVER	LOCATION	TYPE/OBSERVATIONS
Rio Hondo	Santa Elena. Bridge on Mexican border. 12 km inland. Downstream of Rio Escondido confluence.	Represents 99%+ of catchment. Tidal influences expected. Is downstream of Rio Escondido confluence. Already hydrological station for Mexico and therefore may not require any investment, just cooperation (note that due to the absolute lack of data on this important catchment, more than one station is advisable - see below).
Rio Hondo	Vaqueros. Access by road from August Pine Ridge. Boat site.	70 km inland. Represents mid-section of Belize portion of Hondo and combined flow from Blue Creek and Booth's River. May require cooperation of Mexico.
Rio Hondo	Dos Bocas. Road access from August Pine Ridge. Bridge site.	Confluence of Blue Creek and Booth's River. Can monitor Booth's River sub-catchment.
New River	Libertad. Road access. Boat site.	Location downstream represents 99% of catchment area and industrial point sources between Tower Hill and Corazal Bay. Tidal influences expected.
Belize River	Haulover Bridge. Northern Highway. Bridge site.	Includes 99%+ of catchment area and industrial point sources. Tidal influences expected. Double Run site probably adequate to represent overall catchment.
Belize River	Benque Viejo, Western Branch (from Guatemala). Western Highway. Bridge site.	Downstream site from Guatemalan border on shared river. Quantifies concerns over upstream contamination by Guatemala.

RIVER	LOCATION	TYPE/OBSERVATIONS
Sibun River	Non proposed.	Freetown Sibun is probably adequate to characterize overall catchment.
Manatee River	Government Landing. Exact site depends on best access.	Road access unknown. Boat or wading site. 3-5km inland from the Southern Lagoon. Includes 95%+ of catchment.
Mullins River	Mullins Bridge. Road from Melinda Forest Station. Bridge site.	5km inland. Includes 90%+ of the catchment.
North Stann Creek	Dangriga Town. Upstream from water plant intake. Wading site.	2-4km inland. Includes 95%+ of the catchment. Could reestablish Melinda Forest Station site instead. Channel geometry changes and sediments are a problem.
Sittee River	Middle Bank. Road off Southern Highway. Boat or wading site.	5km inland. Collects from 95%+ of catchment. Kendall site probably adequate. Only 8km down from Kendall with no major tributaries in between.
South Stann Creek	7km downstream from Southern Highway on minor road crossing. Bridge site?	7km inland. Collects from 99%+ of the catchment area. Includes zone of agriculture. South Stann Creek Bridge site probably adequate.
Deep River, Nr. Flour Camp.	Road from Southern Highway. Boat site?	10-12km downstream from Medina Bank but includes significant sub-drainage and around 70% of catchment compared to the 20% or less of Medina Bank.
Golden Stream	5km downstream from Boden Creek confluence. Depends on tracks from Southern Highway? Boat or wading site.	Increases % of catchment to 80-90% compared to 30-40% at Hellgate.
Rio Grande, Big Hill	Major track from Punta Gorda. Bridge site?	5km inland. 15km downstream from Big Falls but expansion of catchment included from 55% to around 80%
Moho River	Confluence of Roaring Creek. Major track from Southern Highway. Boat or wading site?	Jordan Village is probably adequate since this site is only 5km downstream with little gain in catchment.
Temash River	Crique Sarco, or if access, inflow to Temash lagoon. Boat or wading site?	No current site. Crique is around 15km inland and mid-point in the Belize part of the catchment.

RIVER	LOCATION	TYPE/OBSERVATIONS
Sarstoon River	Confluence with Graham Creek. Depends on access from Crique Sarco. Boat site?	No current site although appear to be two hydrological stations upstream in Guatemala. Potentially difficult to take samples due to political boundary at deepest point. Would require international agreement with Guatemala.

In addition to the sixteen major catchments, there are a series of minor catchments. From a review of the 1:250,000 series topographic maps of Belize, the following rivers and creeks, whose quality and discharge characteristics are not known but which flow to the coast, have not been included in this listing (from north to south).

Freshwater Creek
Northern Creek
Santana Creek
Jenkins Creek
Quamina Creek
Mangrove Creek
Salt Creek
Freshwater Creek
Santa Maria Creek
Silver Creek
Jenkins Creek
Flour Camp Creek
August Creek
Mango Creek
Big Creek
Sennis River
Pine Ridge Creek
Paynes Creek
Upper Freshwater Creek
Middle River
Seven Hills Creek
Joe Taylor Creek

4.2 Sites for "Background" Water Quality Monitoring

In terms of understanding the environmental conditions in Belize, and in particular establishing some background water quality conditions free of specific agricultural or urban related point and non-point contaminant sources, it would be useful to develop a limited number of inland sampling stations measuring flows off more pristine forested and uninhabited hillslopes and some of the lowland, marshy contributing areas. From a review of the 1:250,000 drainage map produced by LIC, it is clear that the opportunities or else the need for an inland sampling point for the Rio Sarstoon, the Temash River, the Golden Stream and the Deep River are minimal. The following represents a list of possible sites that could be selected, that have accessible locations and which would give useful background water quality data:

Rio Hondo	Cedar Crossing - Rio Bravo
New River	Hill Bank (if accessible) or Shipyard
Belize River	Iguana Creek Bank or Labouring Creek
	Rio On (already instrumented)
Sibun River	Sibun Camp or Caves Branch
North Stann Creek	Big Eddy
Sittee River	Guana Church Bank
South Stann Creek	Locust Bank
Monkey River	Chun Bank - Bladen Branch
	Perry Bank - Swasey Branch
Rio Grande	Jimmy Cut or Resumadero
Moho River	San Jose

4.2.1 Inventory of Possible Monitoring Sites for the Current Program

One of the objectives of this report is to establish a functional framework to begin the process of collecting, analyzing and using water quality data in the long-term environmental management and protection of Belize's aquatic natural resources. There is no "correct" combination of sampling sites or form of network, only different levels of investment and density of coverage. Different selections of sites will be appropriate for a surveillance program, a compliance program, surveys for modelling, trend monitoring, early warning surveys, etc.

It must be borne in mind in these discussions that selection of monitoring sites to a large extent depends on the selected intensity of monitoring and the monitoring objectives at different phases of the planned program. The selection of appropriate criteria is important. For example, if the initial prime objective of the monitoring program is to concentrate on quantifying the overall volume of flow and nature and mass of water quality components leaving the land and entering the marine environment, sites can be prioritized on the basis of the following criteria:

- is the river in question likely to have quality conditions sufficiently different from that of adjacent rivers already monitored and which could otherwise be used as proxies?

- is the volume of flow and the expected water quality information (quantity and type of contaminant) sufficiently valuable to warrant the investment in establishing and monitoring a sampling site?

- does the current sampling site(s) meet the requirements of incorporating the major sources or change agents of water quality variables (i.e. is it close enough to the outflow point that downstream changes will not significantly affect quantity or quality, and/or is it close enough upstream to avoid unwanted tidal effects)?

- is it logistically and economically feasible to establish and maintain a sampling site on the river?

The following objectives produce a rational and workable inventory of sampling sites that provide a broad utility, that takes into account the existing framework of hydrological monitoring stations and the needs for water quality data. Particularly where resources for the collection and analysis of that data are limited and may not best be served in the short or medium term. These objectives are:

1. to establish or consolidate stations and identify and quantify volummetric runoff and quality constituents (types present and mass output) at the most feasible and proximal locations inland of the coastal margins.

2. to establish a series of upstream water quality sampling locations for those catchments with extensive developments and land-use conversions that can provide an assessment of the magnitude of water quality changes taking place within the river system as a result of anthropogenic inputs.

3. to consolidate existing or planned additional water quantity monitoring sites operated by the Hydrology Service to add paired water quality samples and to document the nature of major sub-catchment responses throughout Belize's hydrological system.

4. to establish receiving water assimilative capabilities in the immediate locations of the two major point pollution zones, that of Tower Hill to Libertad on the New River, and Alta Vista to Pomona on the North Stann Creek.

Based on these criteria, given the current network of instrumented gauging stations, a number of significant river systems are not represented while, from the broadest water quality monitoring point of view, certain rivers, particularly the Belize River, are over represented.

Table 4.3 Potential Water Quality Monitoring Sites in Belize for the Short and Medium Term

PRIORITY	WHEN	LOCATION	OBSERVATIONS
Recommended	Year 1	-Dos Bocas (Rio Hondo) -Santa Elena (Rio Hondo) -Libertad (New River) -Tower Hill (New River) -Benque Viejo (Belize River) -Double Run/Haulover Bridge (Belize River) -Freetown Sibun (Sibun River) -Government Landing (Manatee River) -Mullins Bridge (Mullins River) -Alta Vista/Middlesex (N. Stann Creek) -Dangriga Town (N. Stann Creek) -Kendall/Middle Bank (Sittee River) -South Stann Creek Bridge (S. Stann Creek) -Monkey River Town (Monkey River) -Nr. Flour Camp (Deep River) -Boden Creek (Golden Stream) -Big Hill (Rio Grande) -Jordan Village (Moho River) -Crique Sarco/Temash Lagoon (Temash R.) -Graham Creek (Sarstoon River)	Number = 20 Sites designed to determine overall catchment discharge quantity and quality and selected shared catchment water quality issues.
Desirable	Year 2-5	-Cedar Crossing (Rio Hondo/Rio Bravo) -Hill Bank/Shipyard (New River) -Rio On (Belize River) -Iguana Creek/Labouring Creek (Belize River) -Sibun Camp/Caves Branch (Sibun River) -Big Eddy (North Stann Creek) -Guana Church Bank (Sittee River) -Locust Bank (South Stann Creek) -Perry Bank (Monkey River) -Chun Bank (Monkey River) -Jimmy Cut/Resumadero (Rio Grande) -San Jose (Moho River)	Number = 13 Sites designed to determine background water quality characteristics for each major catchment where relevant.
Optional	Year 5-	-Vaqueros (Rio Hondo) -Cristo Rey (Belize River) -Swasey Bridge (Monkey River) -Bladen Bridge (Monkey River) -Medina Bank (Deep River) -Hellgate Village (Golden Stream) -San Pedro (Rio Grande) -Big Fall (Rio Grande) -Blue Creek (Moho River)	Number = 9 Sites designed to mesh water quality monitoring with remaining overall hydro-meteorological network.

Through a process of consultation and resource consideration the selection of sites could be modified. Proposed sampling sites could be eliminated or added depending on how these criteria are viewed by DOE and other Belize ministries. For example, it was suggested during the review of this document that, from a national perspective, it is critical to establish a monitoring site at the point of entry of the Mopan River tributary to the Belize River at Benque Viejo due to the importance of this river and the anecdotal evidence of contamination occurring on the Guatemalan side of the border. Thus the Benque Viejo gauging station is included in the recommended category, as is the Dos Bocas station on the Rio Hondo to reflect the incoming water from Mexico and Guatemala..

Other important comments received from the peer review indicate that based on decisions concerning national priorities, tempered with resource limitations, a more broad mix of sampling sites could be selected since most of the recommended sites are close to the ends of river systems, designed to quantify total quality conditions from land-based sources rather than the changes due to differing land-use and water and waste management on water quality (PAHO, review correspondence). Clearly, a balance must be struck between the desire to develop useful data and the cost of doing so. It would appear that adopting a phased approach in which sites at the end of river, key hydrological junctions, and at known point-pollution or other strategically important sites could be expanded over time will meet the suggestion of PAHO although not in the immediate short-term.

With these comments in mind, an emphasis is recommended in the short-term on quantifying the overall characteristics of the Belize river systems by sampling at lower gauging stations closest to the coastline and downstream of river border crossings within shared catchments with Guatemala and Mexico. This will allow the program to meet the needs of at least three agencies concerned with water quality and quantity at the land-sea interface: the Department of Environment, the National Hydrological Service and the Coastal Zone Management Unit, and will provide a basis for regional collaboration to control water quality. This program will allow the Government of Belize to inventory their natural resources and provide guidance in their management and economic development. More detailed analysis of water quality from different geographical elements of the catchments can be added at a later date based on future resources.

4.2.2 Sampling Frequency and Logistics

In natural systems, water quality extremes are most likely to occur during very low or very high flows. For surface water the common ions (calcium, magnesium, sodium, potassium, sulfate, chloride, and bicarbonate) and total dissolved solids are typically near their maximum when flows are very low. Suspended solids, on the other hand, are generally highest during high flows. Design of a monitoring program must include a sampling schedule that accounts for extreme flow events to more accurately identify extremes or variability in water quality concentrations.

In general, the frequency at which a water is sampled is specific to the study objectives. There is no reason why a monitoring program should require uniform sampling frequency for all sites, since this depends on the type of sample site, the reasons for monitoring and the type of variables analyzed. Generally, however, background monitoring designed to determine overall environmental conditions will typically adopt a sampling frequency of one sample per site once or per month or per two months. The attached table indicates typical frequencies associated with various water quality monitoring objectives:

Table 4.4 Monitoring Type and Frequency

Monitoring Type	Frequency	Duration
Compliance	low	long
Assessment	high	short
Inventory	low	long

For purposes of the Environmental Water Quality Monitoring Program, a low intensity, long duration sampling frequency is recommended. Initially, the sampling frequency will be dictated by existing laboratory capacity and cost. As laboratory capacity within Belize is increased, the sampling frequency and scope of parameters can be expanded.

Emphasis is placed on the need to obtain representative samples, properly collected and adequately documented in the field at the time of collection. Field personnel should exercise proper care and custody of samples until they are delivered for appropriate analysis.

The frequency with which streams are sampled for the program will vary according to the quantity and quality of disturbed-area discharge, the rate of streamflow, and the relation of natural daily and seasonal variations to water-quality characteristics. In general, an undegraded system will require a high sample number in order to increase the comparative ability with subsequent samples. In cases where stream water quality is apparently related to precipitation events, sampling should be coordinated with changing streamflow or stage. Suspected instances of deliberate pollution require preparation and often unusual inspection hours and techniques.

As indicated in other discussions within this report, a logical approach in sampling, assuming that water quality samples would be brought to a single, accredited laboratory somewhere along the Western Highway corridor (i.e. Belize City, Belmopan or Central Farm), would be to establish two teams, one with responsibilities for all sites south of Belmopan (Southern Highway Team) and one with responsibility for all sites along the Western Highway and Northern Highway. Two teams would allow flexibility in collecting samples within comparable time-clusters at the various locations around the country. It would also accomplish a neat division by catchments and allow technicians to develop a good feel for the individual rivers they are monitoring in their entirety. This approach was already envisaged early on in Belize. The proposed aim of the Hydrometeorological Service at the turn of the eighties was to help and advise government departments on all aspects of water resources (Panton, No Date). In the original plan for the department, two monitoring teams were envisaged, one for the north and one for the south of the country. They were to be based, with transportation, in Belize City and Melinda Forest Station so as to reduce overnight field expenses and promote efficiency in the number of possible visits. During the briefing of peer reviewers that accompanied the presentation of the draft version of this report, Mr. Panton expressed a view that two teams may not be sufficient and, assuming resources were to be made available, three teams would be more appropriate, one for the north, one for the central zone and one for the south.

Assuming two sampling teams, each able to spend "T" work days in the field, the following estimates can be made of the maximum number of sample sites "S", that can be monitored depending on the frequency of sampling "F" and an average of "N" sample sites per day (including transportation requirements, time for discharge measurements and so forth). The selection of T will reflect whether existing technicians will assume sampling as only part of their responsibilities, or will be dedicated to this task, and F indicates the level of intensity of monitoring. Note that both could be increased or decreased in time depending on the resources available and the results of pilot strategies. Note that N will reflect both the nature of the sampling (number of samples, on-site measurements and types of bank-side preparations necessary to prepare samples for transport) and whether stage-discharge relations are or will be established at the range of sites. N will also be proportional to the average degree of difficulty for the sites including their accessibility relative to the technicians geographic base and the laboratory location and the ease of sampling. The total number of samples delivered to the laboratory during 12 months is listed as "L" and is the product of the number of sites S and the frequency F.

Table 4.5 Sampling Limitations Based on Frequency and Personnel

Sample Freq. **Tech-Team Days**	**F=12**	**F=6**	**F=4**
T=200*2 T=400	N=2,S=66,L=792 N=1,S=33,L=396 N=0.5,S=16,L=192 N=0.25,S=8,L=96	N=2,S=133,L=798 N=1,S=66,L=396 N=0.5,S=33,L=192 N=0.25,S=16,L=96	N=2,S=200,L=800 N=1,S=100,L=400 N=0.5,S=50,L=200 N=0.25,S=25,L=100
T=100*2 T=200	N=2,S=33,L=396 N=1,S=16,L=192 N=0.5,S=8,L=96 N=0.25,S=4,L=48	N=2,S=66,L=396 N=1,S=33,L=192 N=0.5,S=16,L=96 N=0.25,S=8,L=48	N=2,S=100,L=400 N=1,S=50,L=200 N=0.5,S=25,L=100 N=0.25,S=12,L=48
T=50*2 T=100	N=2,S=16,L=192 N=1,S=8,L=96 N=0.5,S=4,L=48 N=0.25,S=2,L=24	N=2,S=33,L=192 N=1,S=16,L=96 N=0.5,S=8,L=48 N=0.25,S=4,L=24	N=2,S=50,L=200 N=1,S=25,L=100 N=0.5,S=12,L=48 N=0.25,S=6,L=24

Note that based on a consideration of distances and access, it is probable that an average of 0.5 or

1 sample site per workday per technical team reflects the likely conditions DOE would encounter during the first year of monitoring. Since there are 16 major river systems in Belize, not counting the smaller catchments and channels draining to the ocean nor the individual, large sub-systems dividing up the large catchments, one overall sample site per river would still require a sizeable investment in human resources (two teams each working 100 days assuming a monthly sampling frequency and an average of one sample per team retrieved per 8 hours of work). Sampling for the 42 recommended, desirable and optional sites listed in Table 4.4 would require two teams to each work 200 sampling days per year, visiting a little less than 1 sample site per workday at a frequency of one sample every two months.

Table 4.5 provides an idea of the sampling logistics associated with given intensities of sampling. However, it is noted (van de Kerk, review comment) that not every sampling site will need the same frequency, and some may be monitored monthly, others annually. However, the table provides an indication that the laboratory facilities will not likely be a limiting factor, given their current under-utilization in Belize, rather it will be the ability to mobilize two or more sampling teams for the number of days required to collect the larger number of samples.

It is proposed that the two teams begin a sampling program to develop systematic water quality and quantity data based on a regular cycle, most probably a conservative one sample every two months, with an attempt to take up to two more samples each year at the extremes of high and low flows as technically feasible for each site. The teams should ideally be made up of a combination of one National Hydrological Service and one Department of Environment technical personnel, with a vehicle provided by each department. However, following training conducted during this project, there are now thirteen technical staff from various Belizean institutions trained in applying the environmental water quality monitoring program protocols associated with this program.

Based on the conservative consideration of two field teams, for a recommended twenty sampling stations during the first year, at around 0.5 sites per day, with 8 samples per year, this would require up to 320 days in the field (160 per team) and generate 160 samples for the laboratory. Increasing the frequency of samples to monthly, 14 samples would be taken per station, boosting total team field days up to 560 (280 per team) and generate 280 water samples for the laboratory. Note that on the basis of the results achieved for critical zone monitoring sites, sites can be dropped, added or modified to better quantify the upstream-downstream limits, and hence the impacts of, key non-point or multiple point pollution sources. The more monitoring sites that have established stage-discharge relationships, the less time-intensive will become the sampling program, since velocity-area discharge measures will not be necessary for the majority of samples.

4.2.3 Background Monitoring and Compliance Monitoring

During the review process of the draft document, the point was raised (PAHO, review correspondence) concerning the relationship between "background" environmental water quality monitoring discussed in this report and manual and the compliance monitoring required by the EPA of 1992 and detailed in the effluent quality standards report by Miller and Miller (1994). Clearly, based on the proposed sampling methodology to be developed over the long-term, several of the environmental water quality sites will be oriented at principal point-pollution zones or at locations where industrial facilities will be required to undertake some form of compliance monitoring, probably using their own facilities, or by sampling and sending samples to an accredited laboratory. Based on comments by PAHO, it could therefore be possible, in order to save government time and resources, to coopt those mandated to undertake compliance monitoring to also undertake the environmental monitoring at pre-agreed locations (for example, Tower Hill Sugar Refinery, Sierra Madre Shrimp Farm, Belize Foods, etc.). Moreover, private institutions such as Rio Bravo MCA could be contracted to take samples possibly at a cheaper cost than the government service (PAHO, review correspondence). While this suggestion merits consideration by DOE, it does raise the issue of quality control and the differences in timing of compliance (random or more infrequent) and background environmental (systematic, regular) monitoring and the types of variables to be analyzed. Also, it might be expected that the more individual agencies involved with DOE in a monitoring program, the greater the opportunity for experimental and administrative errors to occur and the greater the needs for coordinated information management.

4.3 Data Management

In terms of past environmental data collection and management in Belize, one of the principal features has been the diversity of groups involved and methods used (Gray and Belisle, 1993). Much of the past data has proved unreliable and has been characterized by its incompatible formats, varying detail and accuracy and lack of coordination and dissemination. This is clearly true for the water quality sector and will need to be addressed.

The accompanying document to this report (Stednick and Gilbert, 1995), discusses in detail the practical issues associated with the collection and delivery of samples, conducting field and laboratory tests, reporting results and storing data that are each important phases in effective data management. Clearly, greater control and less margin for error will be experienced if a single agency can assume total responsibility for each of these phases. However, the situation in Belize is not yet clear as to who will or should ultimately be responsible for the collection of samples and field testing (DOE, Hydrological Service, both and/or other), the analysis of samples (a wholly new lab, an improved existing lab, various labs including foreign facilities), and the processing and storage of data (DOE or CEDS). Similarly, this is true for the implementation of actions to ensure that water quality standards are being met since existing legislation duplicates responsibilities, although the EPA of 1992 gives considerable, and possibly over-riding power to the DOE in this respect. Through discussions held during the implementation of this project, it seems clear that making recommendations at this stage would be premature and potentially divisive since it is still a subject of much high-level discussion (see documents related to the Pro-Tem Water Commission and National Water Agency). The information provided in this report can be used to help these types of decisions to be taken by consensus at the appropriate inter-institutional level. Experience in Belize has generally shown that at least logistically, single-institution chains work adequately for the collection and measurement of water quality variables (as in the case of WASA) but become difficult in the case where agencies rely on resources beyond their direct control (as in the cases of the Hydrological Service and the Coastal Zone Management Unit, both of which have sought to develop their own analytical capability after periods of sub-contracting to another agency).

The following sections summarize the specific experiences and nature of data management in Belize for four agencies likely to play a major role in terrestrial water quality monitoring. Information management at WASA, who appear to be considered somewhat apart from other institutions in terms of environmental water monitoring (due to their quasi-private nature), has previously been discussed in Section 3.6.

4.3.1 Department of Hydrology

The National Hydrological Service has developed a data management system for the recording of stage-discharge information and the calculation of relationships between these two variables. Data is encoded into a Fortran program run on a microcomputer by Hydrology staff in conjunction with data files prepared from the various types of field stage data (digital data logger records, hard-copy stage recorder graphical charts, or hand-written stage-reader logsheets). The programs read the prepared data files and calculate the daily mean values and compute the following summary stage and discharge variables:

STAGE:
Mean Monthly Daily Mean Stage
Maximum Monthly Daily Mean Stage
Minimum Monthly Daily Mean Stage
Mean Daily Mean Stage
Maximum Daily Mean Stage
Minimum Daily Mean Stage
Highest Recorded Actual Stage (at any time)
Lowest Recorded Actual Stage (at any time)

DISCHARGE:
Total Monthly Flow
Mean Monthly Daily Mean Flow
Maximum Monthly Daily Mean Flow
Minimum Monthly Daily Mean Flow
Mean Daily Mean Flow
Maximum Daily Mean Flow
Minimum Daily Mean Flow

Highest Computed Flow (at any time)
Lowest Computed Flow (at any time)

For the purposes of classifying catchment systems, attempts were made to identify and develop tables of stage and discharge data for those rivers with gauging station information on daily flow conditions. This data is collected and analyzed for Belize by the Hydrological Service of the Ministry of Natural Resources.

The Hydrological Service has, over the last two years, been trying to convert from an in-house system of data management and stage-discharge calculations to an international system promoted by the World Meteorological Organization called HOMS. Due to the relative complexity of the task and the sheer volume of data involved, there have been a number of delays and difficulties in the transfer process to date, and also in reliably working up raw data collected for some locations in Belize since the 1970's. Many data sets have missing readings, some for several months of a given year, in other cases, several years worth of data are missing.

A total of 744 computer files and directories (Hydrology Service, Disks 1994a-1994e) were copied from Hydrology master disks maintained by the technicians for the purpose of extracting information on stage-discharge relations and historical mean, maximum and minimum values. No summary master file has been maintained and annual reports have not been produced since the early 1980s. It is probable that more files exist on one of the two office computers that were not copied onto the consultants disks since the collection of files seemed incomplete. However, this was difficult to ascertain since no index listing was available of original and transfer files created. Data, therefore, could not be categorized as easily available or retrievable and this must be borne in mind in future DOE activities.

Only a few of the 744 files actually provided usable data when examined. Data management and retrieval capabilities will probably improve with time once the transfer of data to HOMS is complete and operator familiarity with the system increases. Useful data retrieved has been summarized in each of the river catchment profiles. Note that the ability to store, calculate and verify stage-discharge curves will be an important component of the successful water monitoring program.

The experience of hydrological data retrieval suggests that considerable attention needs to be placed on the question of discharge measurement. Given the human and financial resources at their disposal, the Hydrological Service collects a considerable amount of valuable and applicable data. Anecdotal information from Mr. Panton, Mr. Williams and Mr. Johnson of the Hydrology department would suggest, however, that there are a number of weak links in the data chain that could undermine the water quality program without the allocation of more resources to the Hydrological Service (assuming they continue to perform these activities as part of the new monitoring program):

1. Reliance on volunteer stage-recorder readers with honorariums (paid on a

data-received basis) is unreliable and has lead to periods in which several months data has been missed. Quality control of actual readings is also difficult to ensure (a solution to this is the installation of reliable, automatic stages at each gauging site, preferably electronic data-loggers).

2. Difficulty of hydrology personnel to establish and maintain a regular and frequent schedule of gauge site visits due to transport and equipment availability and maintenance limitations.

3. Periodic failure of equipment or their removal for servicing without installation of back-up replacement systems to ensure data continuity.

4. Difficulties with data management including the ability to process all incoming data on a timely basis, particularly for the purpose of problem or error identification, and in systematic checking for and management of unavoidable errors, especially those already within data sets.

Water quality data management by the Hydrological Service in the 1980s was not totally effective, in terms of field handling of samples (delays in analysis), documentation of testing procedures, results and significance (not kept), and preparation and storage of result sheets (incomplete hard-copies).

Decisions on how to progress with paired water quality and quantity measurements should involve a process of inter-institutional dialogue between personnel at DOE and the Hydrological Service, particularly between Mr. Panton and Mr. Fabro. Special attention should be geared to the practical questions of upgrading of existing monitoring sites, installation of gauges and stage recorders at new sites, establishment of rating curves, and the use of existing and the purchase of additional field equipment.

4.3.2 Public Health Bureau

Data is recorded on hard copy forms and transferred to a dBase III management system designed for handling water quality information. Operation of the database was observed during the interview but access and output were limited. Database management is the responsibility of the lab technicians but expertise appears limited. Results of statistical analysis of data was not observed or indicated by the lab personnel. The technician indicated that exceedances of the fecal or total coliform standards (WHO) resulted in verbal communication to WASA or the Public Health Inspector in the field such that action can be taken to properly treat the contaminated supply (e.g. supplemental chlorination). Documentation of action taken in the event of an exceedance was not observed. Nor was evidence encountered that incidences of contamination were followed by a follow-up monitoring program to ensure that standards were subsequently being met. Data is summarized and reported on a monthly basis to PHB management. Hard copies of the monthly reports are also forwarded to WASA and

PAHO. Public Health laboratory personnel have participated in a range of regional courses and seminars on different types of public health, water quality and laboratory data management systems over the first half of 1995 (Flowers, personal communication).

4.3.3 Department of the Environment

The first major function listed in the DOE Mission Statement, 3.02a, is to be responsible for the continuous and long-term assessment of natural resources and of pollution. Subsequent mission statement elements clearly adopt a central role in questions of environmental quality and pollution, including establishing and enforcing standards for its prevention, control, investigation, and sampling. This will require that the DOE develop significant data collection, management and processing capabilities in excess of their current capacities. DOE and its technical staff are increasingly computer numerate, using standard and advanced software on a daily basis for routine tasks and for the development of a computerized literature database of reports and documents using Micro-Isis. However, as yet, the major part of the required capabilities have not yet been developed.

4.3.4 Land Information Centre

The aims of the LIC (NARMAP, No Date) are to:

i. act as a central information base to support Government planning and environmental monitoring activities,
ii. act as a clearing house for information, supporting participating member institutions (GOB Departments, Technical Units, NGOs and Projects)

The Geographical Information System (GIS) it currently operates, a powerful mainframe version of the popular software ARC/INFO, is intended to support physical planning activities but has significant implications for DOE as well as other institutions that develop and manage spatial data sets, including CZMU, Public Health and Forestry among others. GISs are being increasingly used in hydrological applications, particularly in the area of pollution risk assessment and pollution control. Water quality data is inherently spatial in character. Particularly for river water quality samples, it comprises point samples at distinct locations along linear features that reflect the point and non-point influences of contaminant sources within the defined surface area of the contributing upstream basin. Each of these elements are eminently suited for inclusion in a vectorial GIS like ARC/INFO which can manage both the spatial locations, and the attributes of water quality and contaminant sources within its relational database management system. It can update and produce maps rapidly, be used to keep track of both raw water and effluent water characteristics and be used for detailed risk assessment work once data sets improve with continued monitoring work.

Project NARMAP and the LIC also plan to establish a Conservation and Environmental Database System or CEDS (NARMAP, No Date). The objective of this database was originally to collate and maintain databases detailing biological diversity and ecologically important habitats. Clearly, data on water quality will provide critical inputs to these databases. However, it is not clear how these databases would or could be constructed to serve the specific needs of DOE to process and store the large amounts of water quality data that will result from future activities, only parts of which will be of relevance to or used by other departments.

4.3.5 Peer Group Suggestions

Comments were received concerning the question of data management, which is generally seen as an important issue on which the success of the water quality monitoring plan depends. Given that water quality is a nation-wide concern and that multiple agencies will be involved in the use and possibly the collection of that data both in the short and the longer term, a central agency charged with management, analysis (summaries, trends, etc.) and dissemination was supported by the peer group in general. The Public Health Bureau made the specific recommendation that the proposed Water Commission, should it go forward, would be the most appropriate agency to deal with all issues related to water quality data, rather than the proposed CEDS, which they suggest would act as merely recipients of data first received and sent on by the Water Commission.

According to comments by PAHO (review correspondence 16/2/95), the issue of storage, retrieval, analysis and dissemination of data is very important and has not been dealt with in detail in this report. As stated by PAHO and discussed already in this report, there is a need for clear decisions at an inter-ministerial level concerning what is best for the country as a whole in terms of information management and use, as well as what level of laboratory facility is needed to meet national needs. At the time of preparation of this report, the discussions as to CEDS and the role of LIC in national information management is still in progress, as are discussions concerning the establishment of a Water Commission. As such, it is difficult to outline a blueprint for information management, rather the consultants have indicated which types of information should be collected, in what format and for what uses. The nuts and bolts of their computerization and best presentation to analysts can be considered during the implementation of the monitoring plan and its harmonization with the related steps being taken at a national level, particularly CEDS.

It is specifically recommended that this project be followed by the preparation of an appropriate personal computer-based, integrated data management component for water quality and quantity information, geared to specific user needs and compatible with the nascent CEDS and existing National Hydrological Service discharge data management program HOMS. Moreover, a program is necessary to provide training to environmental water quality monitoring personnel on data management and statistics and to introduce existing water quality and quantity data into the selected data management system.

4.4 Laboratory Facilities

4.4.1 Institutional and Technical Considerations

As indicated in section 3.6 of this report and emphasized in the Draft National Environment Report (GOB, 1992b), the majority of the analytical equipment needed to carry out even the most detailed of laboratory analysis such as atomic absorption spectrophotometers and gas chromatographs are available in the country. From the national perspective, it seems only a matter of GOB departments reaching agreement on the use of this equipment for environmental monitoring purposes. However, since this cuts across budgets and responsibilities, rationalizing laboratory facilities will not be an overnight process. Moreover, since efficient analysis probably requires that physical and human resources be consolidated to simplify logistics and promote quality assurance and quality control this is likely to involve a degree of reshuffling, the political acceptability of which is not clear to the consultants.

From conversations with interested parties, particularly with DOE staff, it is clear that Belize seeks to avoid duplication of existing capabilities and the situation in which, using their statutory powers, an entirely new level of analytical capabilities are created above the existing laboratories with new, additional equipment and premises just for the purpose of water quality monitoring and implementation of the Environmental Protection Act. While the idea of starting from scratch is appealing in that greater control could be exerted over the design of facilities and selection of equipment necessary to best perform the protocols detailed in the accompanying manual (Stednick and Gilbert, 1995), it would pay lip-service to the experience already developed amongst the other governmental agencies in the country. Having said this however, a major criticism of Belize water laboratories has been that their physical space is inadequate and physical-chemical measurements are made in the same space as bacteriological measurements with possibilities for direct or indirect contamination of samples (de Esparza, 1993). Physical concerns like this will need to be addressed during the implementation of future monitoring protocols.

There has been considerable debate concerning the best path to be taken by Belize in establishing a national capacity to perform an adequate analytical component to a comprehensive environmental monitoring program. A key question relates to the wisdom of adopting a patented kit-based approach to selected analyses, as has largely been the case in Belize over the past ten years. However, experience with the introduction of more complex equipment not requiring off-the-shelf procedures has been mixed. For example, although Belize has equipment to perform chromatography, it has never been installed to working order for want of certain parts and skilled staff to take responsibility in the host institutions.

Investment in kit-based approaches has many advocates in Belize. WASA and PHB use HACH kits in many analyses, specialist work undertaken on industrial effluent used kits with some success, CZMU have requested kits as part of their future analytical work as has the Hydrological Service who previously used HACH DREL field kits for their water quality sampling in the 1980's. Based on work undertaken using HACH kits during sampling for the UNIDO study of sugar-cane effluent (Newell, 1993) and in setting effluent standards (Miller and Miller, 1994), the DOE submitted a funding request to USAID for the purchase of kits to be used in the implementation of a pollution control monitoring program (NARMAP, 1994). The list was prepared based on good-faith recommendations made by the UNIDO consultant. However, this request was turned down by USAID on the basis that any purchases for this purpose should be based on recommendations made on variables to be measured and methods of analysis recommended during this current consultancy (USAID, 1994). These are listed fully in the accompanying water quality monitoring protocol document (Stednick and Gilbert, 1995). It should be noted that a PAHO consultant from CEPIS who evaluated water quality monitoring laboratory capabilities in Belize in 1993 was critical of the reliance of water quality laboratories on patented kits and recommended more rigorous and sensitive technologies be employed (de Esparza, 1993). She concluded that Belize needs to reinforce its analytical capacities, recognize that the patented kits used by Belize labs do not necessarily yield reliable results and requires a program for training laboratory staff to improve and widen the analytical capacity of adequate indicators appropriate for Belize conditions and to give increased reliability to their results. Moreover, this training must permit staff to begin to adopt standard methodologies for the analysis of water and simultaneously bring in a program to guarantee and control analytical quality. There is a need for computers and computer training for the purposes of statistical analysis (de Esparza, 1993).

Another important observation by the PAHO consultant which was supported during this report was the difficulties experienced by the various laboratories in terms of their ability to count on institutional support or necessary resources to operate efficiently. WASA, due to its semi-autonomous nature and more secure finances, was perhaps the best situated laboratory in terms of its ability to order and count on regular supplies, maintenance, and so forth. This was not generally true for the other laboratories in Belize.

It is clear that the establishment of an appropriate laboratory for the purpose of processing water quality samples collected in this new program requires decisions that must be taken at the national level, rather than unilaterally by DOE. Sufficient information is available to indicate which of the existing labs are best equipped to carry out testing work and where current duplications could be eliminated if a single laboratory were to be created. However, insufficient information is available with which to judge the institutional willingness to adopt different strategies from present. If anything, current evidence indicates that Belize is expanding the number of individual facilities and independent, duplicated capabilities with the emergence of a newly expanded Coastal Zone laboratory, purchase of field sampling equipment by the National Hydrological Service and this current DOE/NARMAP initiative.

Recommending a single course of action and dictating a given institutional arrangement for implementing water quality monitoring, as indicated in the original request for proposals associated with this project is premature at this stage in the proceedings. Based on the laboratory reviews conducted in this project and previously by PAHO and USAID staff, several relatively straightforward alternatives for selecting or establishing a laboratory could be made including:

- establishing a wholly new accredited national laboratory,
- expanding and/or reconditioning an existing laboratory/ies,
- maximizing in-field analysis, and/or
- sending samples abroad for selected laboratory tests.

However, institutional responsibilities are still not clearly defined in Belize and are, in fact, in a state of flux (see GOB, 1994a and other documents related to the water sector). Since ultimately, decisions on investments in laboratory facilities, sampling personnel and training require institutional agreement as to who will be responsible, a period of prior negotiation is required based on the considerations and data presented in this report which has concentrated more on the what, why, how and where of water quality sampling.

4.4.2 Specific Recommendations

Comments received by the peer review group concerning this document raised a number of questions and suggestions concerning laboratory facilities. The Public Health Bureau strongly recommends the setting up of a wholly new, accredited national laboratory and moreover, that it should be both privatized and seek accreditation at a regional level (for example from PAHO, the USEPA or other relevant body). They do not recommend that this laboratory be formed by the government through the redistribution and rationalization of existing laboratories, personnel and equipment within the national ministerial framework and budget. The main concern is the impacts on individual institutions and the possible loss of decentralized facilities during any reshuffling, possibly preventing them carrying out day to day work pertinent to the roles of their departments. They strongly believe a new laboratory should be created with new equipment and trained staff, leaving the existing laboratories, such as the Public Health laboratory, intact. The drawback with this approach is that it would duplicate efforts and facilities, increasing the levels of redundancy and sub-utilization within the national system, which at a national budget level, implies much greater costs per sample. However, it points to a clear requirement that if a single national laboratory is to be created, then it must be accompanied by a system in which the daily needs of individual government departments who would become subscribers to the testing facilities on offer (assuming that in the process, they may lose part or all of their own water analysis capabilities) can be met efficiently and with high degrees of quality control and assurance. This would require efficiency and adequate control and coordination at both the subscriber (sampling) and the tester (analysis) ends of the custody chain.

Discussions during the briefing that accompanied the presentation of the draft version of this document in January, 1995 focussed on the current level of duplication and under-use in existing laboratories. According to Mr. van de Kerk, a maximum of about 1,800 samples are taken in the whole country currently, about 5 per day. Even with the increased number of samples from a monitoring program with 40 or 50 sampling sites, the number per day would not increase by more than 50% (see Table 4.5). The numerous advantages of an accredited central laboratory for Belize, not withstanding the individual losses of facilities at a ministry or departmental level, was stressed by most meeting participants and the DOE was urged to consider pay-per-sample schemes for both government and private clients. The disadvantages of the current system of multiple laboratories in terms of the lack of focus for overseas material assistance, the loss of investment in reagents and equipment that have already occurred, for example associated with the purchase of a gas chromatograph on the part of USAID, were mentioned also.

The issue was raised during the draft review process that a concrete recommendation should be made concerning this question. The consultants feel that a decision must be made at the cabinet level if a central laboratory is to be established, particularly if it involves the redistribution of existing equipment and the closing of existing facilities. The views of most peer reviewers, as well as the consultants is that a central laboratory makes logistic and budgetary sense, although it may not be politically acceptable. It was suggested by DOE (review correspondence, 11/4/95) that the central laboratory could in fact be designated a Pollution Control Laboratory, either a government financed and controlled Statutory Board or a privately owned and operated laboratory offering both monitoring, compliance and private testing of soil, water and air. This takes even further the question of centralization and reorganization of facilities and responsibilities, and clearly reflects the mandates and needs of the EPA of 1992 for coordinated monitoring and control of these three environmental elements.

In the light of these issues, it is recommended to develop a memorandum of understanding between all Belize ministries to identify individual and collective roles with respect to water quality monitoring. This will require discussions at the level of Permanent Secretary and above.

4.5 Training

An Environmental Water Quality Monitoring Program protocol document has been developed for this project (Stednick and Gilbert, 1995) and will serve as a textbook for all future training sessions associated with this environmental water quality monitoring program and as a manual for its implementation. It can be noted that in 1993, a PAHO review of water quality laboratory facilities recommended significant amounts of training for the two major laboratories at PHB and WASA (de Esparza, 1993).

While it has proven possible to put together an appropriate protocol document (Stednick and Gilbert, 1995), deciding who should receive and apply this training and when requires institutional decisions to be made, the nature of which are discussed in this report. As part of this project, training in the protocols of environmental water quality monitoring was provided over a three-day period (June 6-8, 1995) to a core group of 13 young technicians from a range of pertinent institutions in Belize, selected by the consultants and the Department of Environment based on the assumption that they would be the field operatives in any future expansion and consolidation of systematic, national water quality monitoring. Represented institutions included the Public Health Bureau (2), the Central Farms laboratory, the Department of Environment (2), University College Belize (2), WASA, CZMU, the Belize Centre for Environmental Studies the National Hydrological Service (2) and a recent graduate from a US university Masters program in watershed science. However, each of the participants expressed uncertainty as to where the ultimate responsibility would fall for the implementation of a comprehensive water quality program and laboratory arrangements for the analysis of samples.

A commitment must be made to a certain level of monitoring, the number of sample teams and field and laboratory personnel must be selected and identified, and the time and laboratory resources/field equipment must be made available. It was recommended in the peer review (PAHO, review correspondence, 16/2/95) that a well trained professional will be needed to direct the total water quality monitoring program, given the numerous quality assurance and quality control requirements associated with sampling and sample management. Clearly, there are a number of well qualified individuals in Belize who could be candidates for this role, including Anthony Flowers of the Public Health Bureau and Mario Fernandez of the Pesticides Control Board as well as DOE Environmental Officers who could receive specialized training to a management level. It is expected that these training and resource allocation issues, as well as other questions raised in this report, will be resolved in discussions at an inter-ministerial level that follow the reading of this final report. At the least, discussions should follow at a Permanent Secretary level if not higher.

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